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Optimal Urban Waste Dumping Site Selection in Kalutara DS Division of Sri Lanka using GIS-based Multi-Criteria Decision Analysis

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Abstract: Improper waste dumping is an emerging issue in Sri Lanka because of the unsystematic urbanisation process. The main problem of the study is determining sites that are ideal for waste dumping. The use of improper waste disposal methods adversely affects the environment and human lifestyle. This study focuses on integrating a structured approach under multi-criteria decision analysis for waste dumping. The present study has been carried out in Kalutara DS Division, integrating Analytical Hierarchy Process (AHP)-based Multi-Criteria Decision Analysis (MCDA) and geospatial techniques to find suitable waste dumping sites. Ten different types of criteria were selected for the study in vector and raster format, namely, land use, population density, schools, religious places, government offices, coastal areas, hospitals, roads, railways, and environmentally sensitive areas. After finalising the criteria, the GIS-based AHP-MCDA methodology was used for weighting, standardisation, and normalisation by obtaining the opinions of experts and conducting literature surveys. The results of the study are sorted into not-suitable, less-suitable, and suitable dumping sites. Classified suitability maps revealed that 36.94% are not suitable, 53.06% are less suitable, and completely 9.9% are suitable for urban waste dumping sites. The spatial variance of suitable and not suitable waste disposal sites was found in the north, north-eastern, and western and central parts of the study area. Hence, based on the results indicated using such methods, it will be an effective manual for engineers, regional planners, and decision-makers to implement sustainable waste management in the study area in the future.

Keywords: AHP-MCDA, GIS, Suitability, Urban, Waste Dumping.

1.0 Introduction

The disposal of solid waste is a critical consequence in the present world due to rapid urbanization, growth of population, industrialization, and rural migration. In the present world, the identification of proper solid waste dumping sites is an essential mechanism to reduce adverse impacts in urbanized areas. Solid Waste Management (SWM) is a dominant challenge for municipal council areas in the developing world due to inadequate technology and resource, unsystematic urban expansion, low contribution towards the SWM from the community, and unsuitable planning (Saketa et.al. 2022). Waste is one of the materials discharged from daily consumption of human lifestyle which sources lead to negative consequences for the human health sector and environmental pollution (Bringi, 2007). Solid waste represents different forms like solid, liquid, semi-solid, and gaseous material as well as those sources are emitted in the agricultural sector, industrial, municipal use, mining, and commercial. Presently, each year 2.01 billion waste materials are produced by the countries, and out of them, 33% of waste was not dumped using an eco-friendly manner (Kaza et.al.2018). Globally, highly discharged solid waste including the urban cities, especially in developing countries have been contributed to the high amount of waste. According to estimations of future garbage output, 3.40 billion tons of rubbish would be produced annually by 2050, with low-income nations predicted to contribute the most (Vij, 2012; Sharma and Jain, 2020). However, almost half of the total generated waste remains uncollected in the developing world (Sasikumar & Krishna, 2009). It has been estimated that 30% of total urban dwellers are un-served in terms of waste Collection (Shafiullah, 1996). There was an estimated Municipal Solid Waste (MSW) that will be increased by 1.42kg/capita (2.2 billion tons per year) per day in 2025. As well as they have predicted this waste is generated by 4.3 billion urban residents at the global level.

Landfill, incineration, open dumping, and controlled dumps are the widely used methods of waste disposal in the world. Developed and developing countries are following different kinds of methods to manage solid waste. Although developed countries account for just 16% of the world's population, they make up nearly 34% of total waste (683 million tons) produced globally, 2% of which is mismanaged (Ellis, 2018). Analytic hierarchy Processes (AHP) and MCDM methods are highly used to identify appropriate sites for waste dumping in urban areas.GIS and MCDM are widely used to select Municipal Solid waste dumping sites in any region of the world including India (Ali et.al, 2021); (Paul and Gosh. 2022); (Hazarika and Saikia, 2020), Thailand (Kamdar et.al.2019), Iran (Pasalari et al. 2019) and as an effective method. Paul and Gosh identified a suitable site to waste landfilling in India's Kolkata Metropolitan region using the Fuzzy-AHP model. Terefe, wagari, and Habtamu, 2022 have examined suitable sites for waste dumping in Shambu town in Ethiopia. (Jayaweera et.al 2019); Fernando, (2022) also conducted studies in Sri Lanka, Using the MCDM approach in order to identify a suitable location for solid waste dumping. However, above mentioned studies are focused on different perspectives on the selection of appropriate sites for dumping. In the Sri Lankan context, solid waste disposing of is a serious problem in urbanized areas. Per day Sri Lanka is generating 7000 Metric Tons of Solid waste including the Colombo district is contributed 60% of waste daily. Each person 1-0.4% Kg of waste per day (statues of Waste Management in Sri Lanka, 2017). However, this rate can be varied based on the income level and households of individuals. As well as low-income communities produce half of a kilogram of garbage but this rate is exceeding high-income families (Gunaruwan & Gunasekara, 2016). Especially Colombo metropolitan region and other urbanized areas are facing this problem due to the unavailability of a suitable location for dumping solid waste. Such kind of problem can be identified in other urban areas in Sri Lanka.

According to the relevant legal enactments, the Local Authorities (LA) such as Urban Councils, Municipal councils, and Pradeshiya Sabah in Sri Lanka are fully accountable for Solid Waste Management (SWM). Under the Pradeshiya Sabah Act No. 15 of 1987, urban council Ordinance No. 61 of 1939, and Municipal Council Ordinance No. 16 of 1947 are related to Solid waste management in Sri Lanka. Presently, municipal councils collect 50% of solid waste while urban councils collect 17% and Pradeshiya Sabah collects 33% of solid waste covering Sri Lanka. Presently, there are various issues with the dumping of solid wastes in the urban and Divisional Secretariat Division (DSD) areas due to limited spaces, population density, urbanization, and environmentally sensitive areas. Some areas are not suitable for waste dumping due to the location of the settlement and environmentally sensitive areas. Therefore, the selection of suitable areas for waste dumping is a critical decision. Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) are effective modern tools for analyzing and estimating the suitability of the location compared with traditional methods (Bilgilioglu et al, 2021).

Kalutara District is the main district in the western province of Sri Lanka. Kalutara DSD is a significant DSD in the Kalutara district because this is the capital city of the Kalutara district. It is important ecologically and economically. This area has not a high variation of topography but there

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is socioeconomic diversity. Urban and peri-urban characteristics are highly distributed along the study area. Government institutions, commercial areas, and other service areas are widely integrated in the area. Therefore, a particular area has some waste disposal issues due to a lack of facilities, urbanization, lack of space, technology, and knowledge. Therefore, the research problem is which areas are suitable for solid waste dumping in the Kalutara DSD. The study aims to select suitable areas for solid waste dumping in Kalutara DSD and delineate the maps. Therefore, this study mainly focused on analyzing the suitability of solid waste dumping sites in the Kalutara DSD using the Geographic Information System (GIS). It will be beneficial to fix suitable selection conditions for the identification of new.

2.0 Materials and Methodology

2.1 Study Area

Kalutara Divisional Secretariat Division (DSD) is located in the Western Province of Sri Lanka and consists of 87 Grama Niladhari Domains (Figure 1). Its geographical coordinates are 6°34' 34" North, 79° 57' 58" East. Kalutara DSD covers an area of 78 square Kilometers and mainly faces the coastal region. Considering the topography of the region, in terms of the overall landscape, very high zones cannot be identified in the area, which is spread as a lowland zone, and the coastal zone is at a height of 30 meters above sea level. There is a temperate climate and uniform temperature and rainfall can be found in the region. The rainfall pattern is primarily determined by the southwest monsoon and convection. There is an annual rainfall of about 2900 mm from September to November. In the land use pattern in the area, the land has been used as water bodies, paddy fields, gardens, and buildings, and the mangrove ecosystems around the lagoon estuary and a beach are unique.

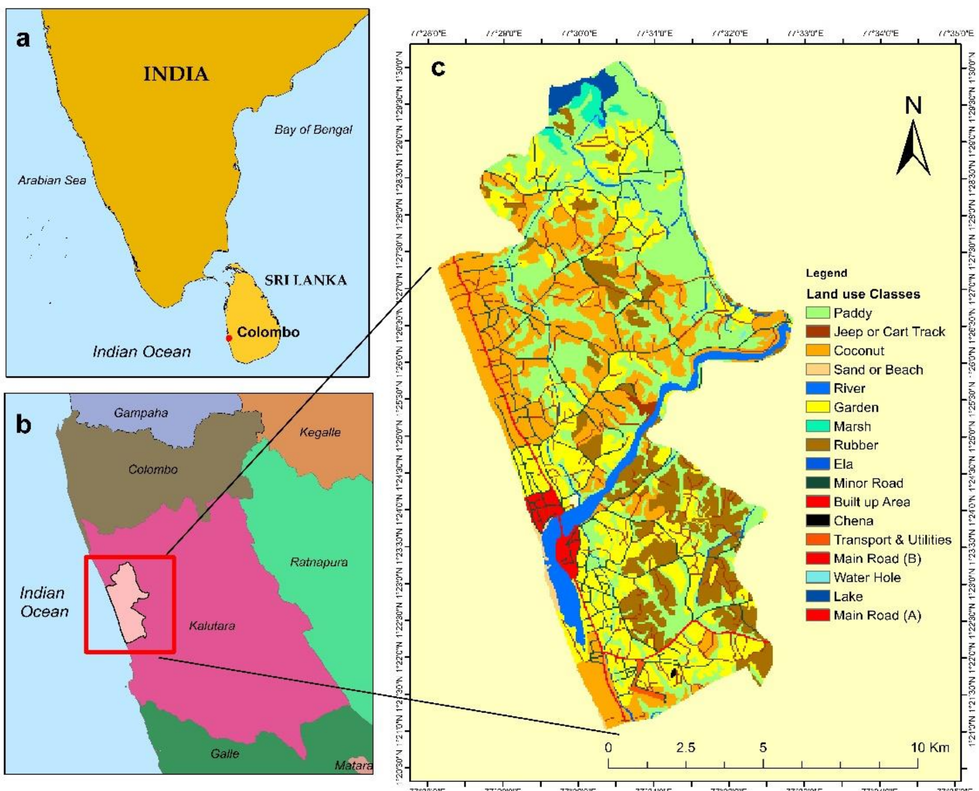

Figure 1: Study Area

2.2 Data Sources

An attempt has been made to select suitable areas for waste disposal using spatial analysis techniques available in GIS using 10 criteria covering the study area. Several criteria were identified based on previous literature investigations in identifying suitable areas for urban waste management and disposal. Different types of spatial data were used in the study. 10 criteria were used in identifying suitable areas under multi-criteria decision analysis (Table 1). Based on local and international literature from experts in creating classification maps related to the 10 criteria through GIS and AHP techniques. Each map related to all the criteria consists of a database prepared in GIS (Alkaradaghi et al, 2019). Inputting all the data through the AHP model is done through several steps which are as follows.

1. Development of Digital Database (GIS) integrated with selected criteria.
2. Creating an appropriate buffer zone for each criterion using the Rasterization process.
3. Determining the weights applied to each criterion using the MCDA model based on the opinions of experts for the selected criteria.

Buffer zones were created using spatial analysis tools concerning each criterion based on specific geographic features. By creating buffer zones, areas belonging to any criteria can be separated according to different limits (based on distance). In determining the minimum and maximum distances of the criteria based on various requirements and processes, appropriate recommended zones should be characterized by different distances, taking into account the aspects of environmental risks and human health. In the criterion maps, suitability scores from 0 to 5 were used to assign ranks to the classification classes, and areas with 0 were considered not suitable areas and areas with 5 were

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considered highly suitable areas (Table 2). Using Arc GIS software, multiple-ring buffering, clipping, weighting, and overlay analysis methods have been adopted for the criteria. All criteria maps created were converted into raster format and weighted for each determinant based on the values calculated using Analytical Hierarchy Process (AHP). The methodology used in the study area to select suitable waste disposal sites is shown in Figure 2.

Table 1: Summary of the Data Sources

Major Criteria	Scale	File type	Data Source
Land use	1:10,000	Shape file	Survey Department Digital Data layers
Population Density	1:10,000	Census Data	Resource Profile, Kalutara DSD
Roads	1:10,000	Shape file	Survey Department Digital Data layers
Railway	1:10,000	Shape file	Survey Department Digital Data layers
Coastal Line	1:10,000	Shape file	Survey Department Digital Data layers
Schools	1:10,000	Kml file	Google earth pro/field survey
Religious Places	1:10,000	Kml file	Google earth pro/field survey
Hospitals	1:10,000	Kml file	Google earth pro/field survey
Government Office	1:10,000	Shape file	Survey Department Digital Data layers
Environmental Sensitive areas	1:10,000	Shape file	Survey Department Digital Data layers

Source: Compiled by Authors, 2022

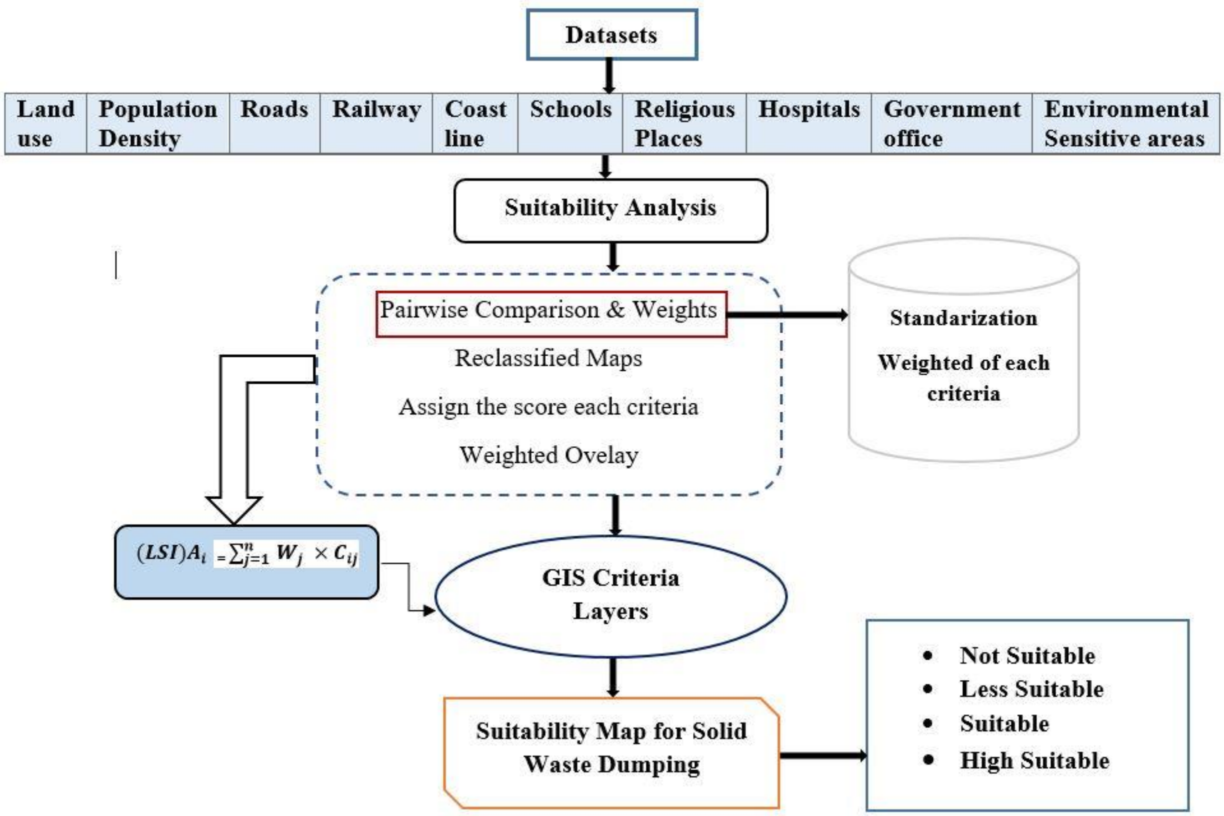

Figure 2: Workflow for solid waste dumping site selection

Table 2: Criteria, variables, and the ranking (Scores) used in the site selection process

Criteria	Variables (Buffer zones)	Scores	Description of the ranking scale
Population Density (person/ha)	470 – 1700	5	High Suitable
	1800 – 3600	3	Suitable
	3700 – 6700	3	Suitable
	6800 – 14000	1	Less Suitable
	15000 - 46000	0	Not Suitable
Roads (m)	0 -270	0	Not Suitable
	270 – 545	0	Not Suitable
	545 – 818	0	Not Suitable
	819 – 1090	1	Less Suitable
	1100 - 1360	3	Suitable
Railway (m)	0 – 750	0	Not Suitable
	751 – 1500	1	Less Suitable
	1501 – 2250	3	Suitable
	2260 – 3000	3	Suitable
	3010 - 3750	5	High Suitable
Coastal Line (m)	0 – 700	0	Not Suitable
	700 – 1400	0	Not Suitable
	1400 – 2100	1	Less Suitable
	2100 – 2800	3	Suitable
	2800 - 3500	5	High Suitable
Schools (m)	0 – 614	0	Not Suitable
	615 – 1230	0	Not Suitable
	1240 – 1840	1	Less Suitable
	1850 – 2460	3	Suitable
	2470 - 3070	5	High Suitable
Religious Places (m)	0 – 455	0	Not Suitable
	456 – 911	0	Not Suitable
	911 – 1370	1	Less Suitable
	1380 – 1820	3	Suitable
	1830 - 2280	5	High Suitable
Hospitals (m)	0 – 805	0	Not Suitable
	805 – 1800	0	Not Suitable
	1805 – 2800	1	Less Suitable
	2805 – 3800	3	Suitable
	3805 - 4800	5	High Suitable
Government Office (m)	0 – 650	0	Not Suitable
	650 – 1300	0	Not Suitable
	1310 – 1960	1	Less Suitable
	1970 – 2610	1	Less Suitable
	2620 - 3260	3	Suitable
Environmental Sensitive Areas (m)	0 – 505	0	Not Suitable
	506 – 1010	0	Not Suitable
	1020 – 1520	1	Less Suitable
	1530 – 2020	1	Less Suitable
	2030 - 2530	3	Suitable
Land use (Types)	Paddy	3	Suitable
	Road Network (Main)	0	Not Suitable
	Coconut	3	Suitable
	Sand or Beach	0	Not Suitable
	Water Bodies	0	Not Suitable
	Garden (Homestead)	0	Not Suitable
	Marsh	0	Not Suitable
	Rubber	3	Suitable
	Chena	3	Suitable
	Built-up area	0	Not Suitable
	Jeep & Cart Track	1	Less Suitable

2.3 Multi-Criteria Decision Analysis Methods

2.3.1 Analytical Hierarchy Process (AHP)

The AHP was chosen to break down the decision rules difficulties into manageable chunks; each of these chunks is examined separately and then logically combined in accordance with Saaty and Malczewski's recommendations (Saaty, 1980 & Malczewski, 1997). Through this model developed by T.L Saaty in 1980, a pairwise comparison of criteria can be done and can be used as a more effective tool in multi-criteria decision analysis. This is used to calculate the weights related to each criterion and for that, for evaluating the pairwise comparison, a basic AHP scale with values from 1 to 9 is used (Table 3). Also, Multi-Criteria Decision Analysis (MCDA) has been used in evaluating various land suitability and solving problems. MCDA method is used in many GIS-related studies because it provides significant analysis for the final result of the study. The AHP offers a tried-and-true method for handling complex decision-making. It can help with the selection criteria's identification and weighting, the analysis of the gathered data, and the speeding up of the decision-making process. The participants are asked to assess the off-diagonal relationship in one-half of each pair of comparison matrices that represent the hierarchy's structural breakdown. AHP was utilized to calculate the relative relevance weights for the assessment criteria to evaluate the site selection criterion. MCDA separates the decision problems into smaller, more manageable criteria, analyses each criterion separately, and then logically combines the criteria.

Table 3: Paired comparison in the AHP scales

Numerical Value	Definitions
1	Equal Importance
2	Equal to moderate Importance
3	Moderate Importance
4	Moderate to strong Importance
5	Strong Importance
6	Strong to very Strong Importance
7	Very Strong Importance
8	Very to extremely strong
9	Extreme importance

Source: Saaty, 1980

2.3.2 Criteria Weights

The weighing of factors can be done in several ways. The pair-wise comparison method, which was initially put forth as an analytical hierarchy process in the decision-making process concept, is the one that is applied in this work. A hierarchical structure with constraint and factor criteria makes up the problem of choosing a solid waste disposal site. Various levels of criteria utilization and combinations of various techniques are used in the study. In assigning weights to the criteria, the pairwise relationship between them is important in quantifying the extent to which it applies to this study (Wijesinghe et al, 2023). A specific value can be introduced as a weight to indicate the relative importance of each criterion considered in the study. The comparison matrix shows how much weight each criterion in the columns and rows has concerning each other. A comparison between criteria determines which of the two criteria is more important, and specific values are given to show how much it is greater. After inputting data through ArcGIS software, spatial analysis tools were run to calculate land suitability index scores. In evaluating the suitability index map, the weighted linear combination (WLC) method was applied to all the criteria using the available GIS "map algebra" spatial analysis tool (Al-Anbari et al, 2018). This is achieved by summing the products of the sub-criteria ranking values for each criterion multiplied by the corresponding relative importance weight. In using the WLC method, the Land suitability index (LSI) value is obtained based on the following formula.

$$(LSI)A_i = \sum_{j=1}^{n} W_j \times C_{ij} \quad (1)$$

where, A_i : is the suitability index, W_j : is the relative importance weight of the criterion, C_{ij}: is the grading value (*i*) under criterion (*j*), and *n*: is the total number of criteria (Alkaradaghi et al, 2019).

And also, the calculated weights for each column are summed and each element of the matrix is divided by the sum of the corresponding column. An average was calculated for the phenomena in each row of the normalized matrix. In this study, using Arc GIS 10.8 software, the criteria Normalization, Standardization, and Weighting were done based on the basic process, and finally, the overlay tool was used in assessing the suitable area. Then, after transforming the criteria into raster format, their percentage values were calculated as they were classified as not suitable, less suitable, and Suitable. A land area with a land suitability index score ie 7.72 km^2 was indicated to be suitable for waste disposal. Also, we must decide how qualitatively all the factors used in the analysis should be presented. Quantitative weights are assessed for all criteria under the pairwise comparison method (Wijesinghe & Withanage in press, 2022). In the study, a judgment matrix was established based on evaluations using AHP, focusing on factors such as field observations, expert opinions, and literature reviews in determining suitability factors (Table 4). The comparison matrix is then organized using these weights to update the proper weight for each parameter. Pair-wise comparison is used to assess each level's criteria against each other, and a Saaty standardized table is used to determine the numerical precedence. However, efforts were made to implement methods like the AHP in order to refine the weight-assigning process as objectively as feasible.

Table 4: Normalized Pairwise comparison matrix for the AHP process

	LU	PD	R	RW	CL	S	RP	H	GO	ES
Land use (LU)	1.00	0.2	0.33	0.33	0.2	0.2	0.2	0.2	0.2	0.14
Population Density (PD)	5.00	1.00	3.00	3.00	1.00	1.00	1.00	1.00	1.00	3.00
Roads (R)	3.00	0.33	1.00	1.00	0.2	0.33	0.33	0.33	0.33	0.2
Railway (RW)	3.00	0.33	1.00	1.00	0.2	0.33	0.33	0.33	0.33	0.14
Coastal Line (CL)	5.00	1.00	5.00	5.00	1.00	1.00	3.00	1.00	1.00	1.00
Schools (S)	5.00	1.00	3.00	3.00	1.00	1.00	1.00	1.00	1.00	3.00
Religious Places (RP)	5.00	1.00	3.00	3.00	0.33	1.00	1.00	0.33	1.00	0.33
Hospitals (H)	5.00	1.00	3.00	3.00	1.00	1.00	3.00	1.00	1.00	1.00
Government Office (GO)	5.00	1.00	3.00	3.00	1.00	1.00	1.00	1.00	1.00	0.33
Environmental Sensitive areas (ES)	7.00	0.33	5.00	7.00	1.00	0.33	3.00	1.00	3.00	1.00

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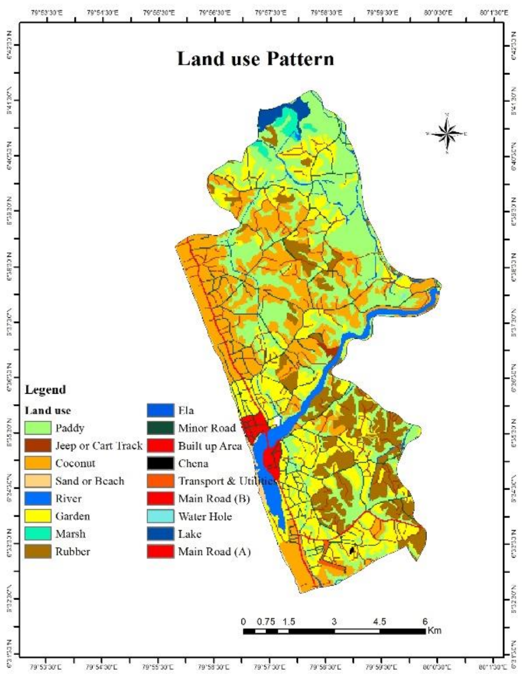

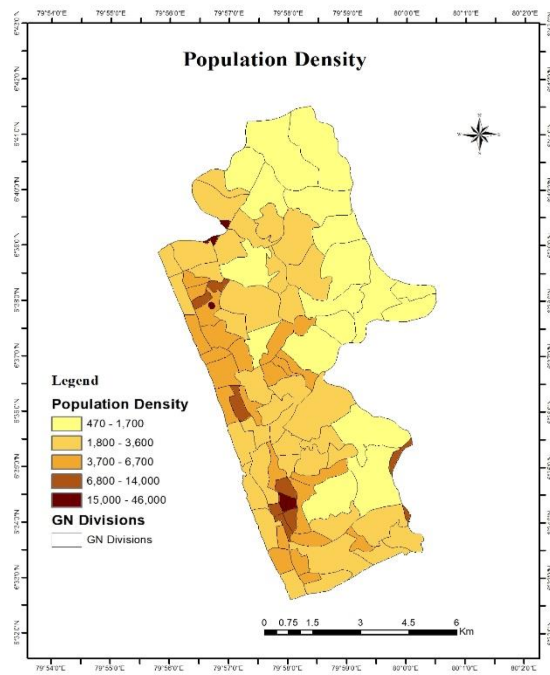

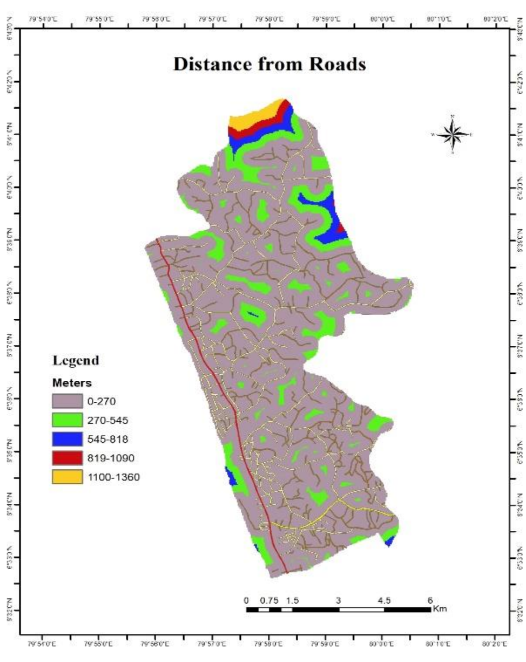

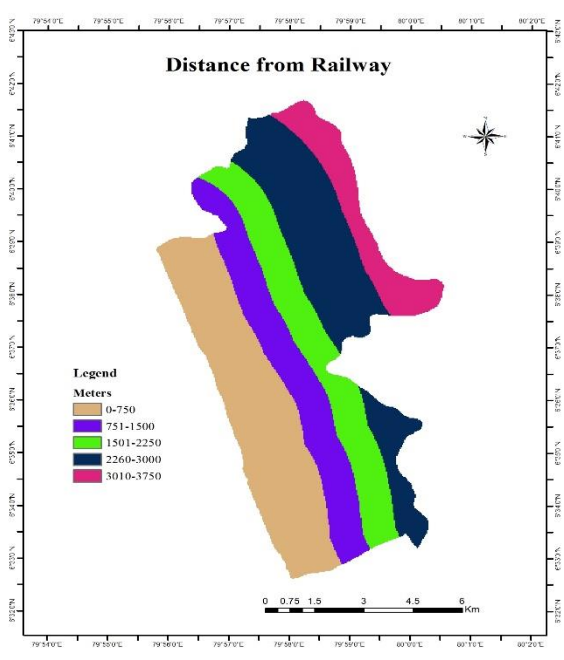

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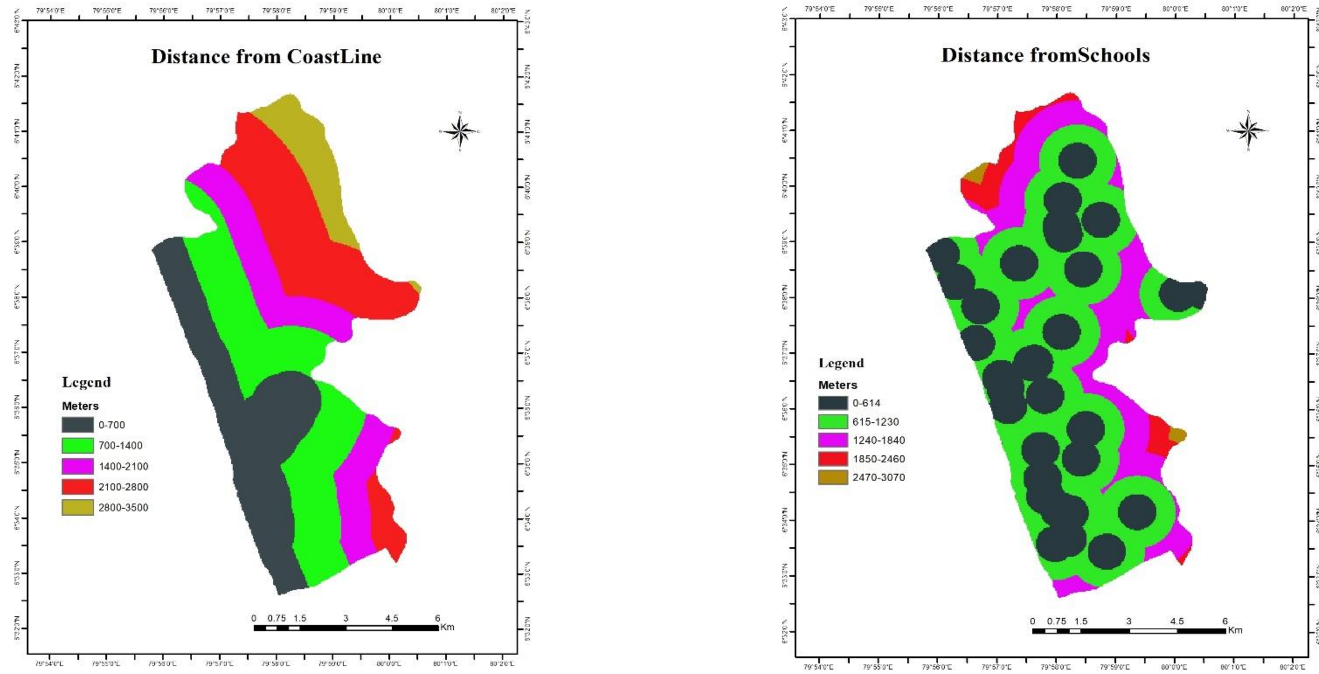

Figure 3: Thematic layer for spatial analyst

3.0 Results

The datasets generated have varying degrees of influence on the decision of where to dump solid waste. Consequently, the primary eigenvector computation was used to estimate the relative significance of each parameter. Based on the literature, these criteria were chosen, assessed, and ranked in order of priority. The research also offered the use of additional criteria that were distinct from those identified in the literature due to variances in the fields of this study. Different information on the geographical features of the Kalutara DS division was needed in order to choose suitable areas. The parameters needed for the process of selecting suitable disposal locations are described with the help of the following illustration. The method utilized here is simple to comprehend and can show which locations are more or less suited for choosing a place for dumping waste or any other facility's site selection process.

3.1 Suitability Analysis for Urban Waste Dumping site selection

3.1.1 Land use pattern

Kalutara DS division is the prominent Ds division consisting of 87 Grama Niladari (GN) divisions which are including both the Municipal Council area (MC area) and peri-urban areas. The unwelcome facility is being addressed by land use to satisfy people. Therefore, land use pattern is integrated with urban characteristics. The land use map was derived from the Survey Department of Sri Lanka. In This area, the main land use pattern consists of the water body of Kalu River (Ganga) and the sandy beach of the coastline. The distribution of an area of land for agriculture, residence, or industry is referred to as land utilization. However, land cover implies the elements that are present on the earth's surface, such as vegetation and water bodies. Hence, scores were assigned for each land use type in determining suitability levels. Also, the land use patterns likes, chena, rubber, paddy, and jeep & cart road were given the scores 3 and 1 respectively. The low score (0) is consigned to water bodies, sand areas, marshlands, urban areas, and main road networks (see Figures 3 & 5).

3.1.2 Population Density

The population is a vital parameter for planning the waste dumping site. According to the figure highest population density distribution among the Tekkawattha and Mahawathhata GN divisions in Kalutara DSD. Currently, this area has a problem due to the establishment of the organic waste recycling plant in the Nagoda area. The reason is it was established as the center of the residential area. When interviewing the community 98% of people in that area are suffering from bad odor and insect problems at the recycling plant. Therefore, the land value of the area has decreased. It is not uncommon for such a large population density to live within a hectare in an urban area. Under those conditions, there is an increase in the use of garbage and problems arise in depositing it in the proper areas. In the study, we have determined that the region with low population density i.e. between 470-1700 is highly suitable for urban waste disposal. Also, Areas with population densities of 6800-14000 and 15000-46000 are identified as less suitable and not suitable respectively (see figures 03 & 05). Peoples are willing to sell their land and properties who are living in a particular area, but anyone hasn’t purchased due to this scenario. The reason is establishing such kind of project in unsuitable site.

3.1.3 Roads and Railway Network (Distance)

Road networks are playing an important role in the urban area. When establishing a waste disposal site should consider the distribution of this factor because when dumping the waste from the urban council or Pradeshiya sabha from Kalutara region it’s a potential element. Main Roads, railways, and other roads are consisting within the study area. There is very high road network distribution. The Multiple ring buffer/Euclidean distance commands were used to estimate the distance on or off the road network by integrating the road map under buffer analysis. A buffer was created for the entire road network based on a distance of 1400m from the main roads. The buffer distance was classified under 5 zones and the zone between 0-800m was found to be not suitable and 1100-1400m zone was found to be suitable for waste disposal. The results revealed that the suitable area for waste disposal is 0.96% of the land area and the not suitable area is 95.97% of

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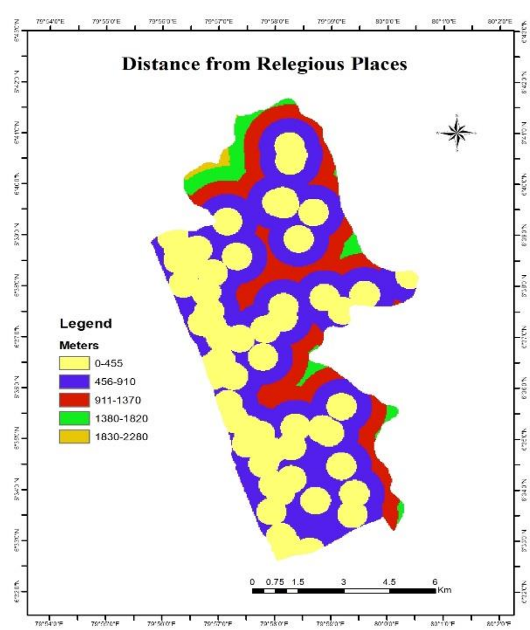
the land area. Sri Lanka's South Coast Railway passes through the Kalutara area and specific distances were considered under the buffer analysis mentioned above. The area 3km from the railway line is identified as highly suitable and the zone between 0 - 1400m is not suitable. Figure 3 & 5 shows how to distribute the road network and classified railways in the area.

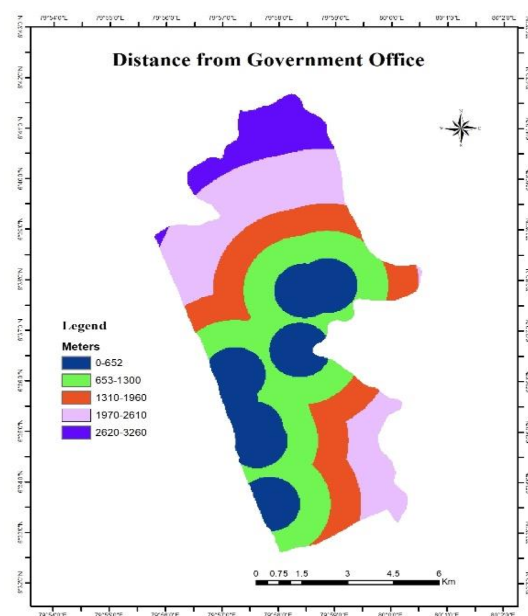
3.1.4 Coastal line

The coastal line is one of the dominant criteria to be considered when siting an optimal urban waste dumping site. Urban waste dumping sites cannot be constructed adjacent to the coastal area, because some kind of ecosystems are located in this area. Based on the various study cases, this criterion is considered to be the most significant one compared to others. If waste dumping sites are built near such ecologically important areas, there is a possibility of pollution of the coastal area along with adverse environmental effects. It has been found that the optimal distance between waste disposal sites and the coastline should be in the region of 2800-3500m and above. Also, it has been decided that the distance between 0-1400m is not suitable for waste disposal. The other two distance categories, 1400-2100m and 2100-2800m were also developed to denote, respectively, less suitable and suitable areas for the selection of waste dumping sites (see Figures 3 & 5).

3.1.5 Schools / Religious Places and Government office

Under these 03 criteria discussed in the study, it has been determined to what extent it will contribute to solving this problem. Several major schools have been established under the Kalutara Regional Division and the school system should remain a very safe and pleasant place around. By considering the school system as a criterion and classifying it based on buffer distance, it has been shown through the results that the region from 0-600m is not suitable for waste disposal and 2470-3070m is highly suitable for waste disposal (Figure 3). Secondly, the other criterion of religious places is also a more significant factor. There are several religious places such as temples and churches in the area. According to the buffer analysis, the classification of suitability has been identified as not suitable, less suitable, suitable, and highly suitable respectively. Areas from 0-900m are identified as not suitable and areas with an area of 1.5km and above are identified as highly suitable (Figure 4 & 5). Thirdly, large public institutions associated with public administration can be identified in the urban environment. The public interacts with these institutions daily and the surrounding environment should be safe and well managed. The results have confirmed that a distance between 2600-3200m is the most suitable to establish a specific site for landfilling. Government institutions are spread towards the center and western part of the study area (see Figures 4 & 5).





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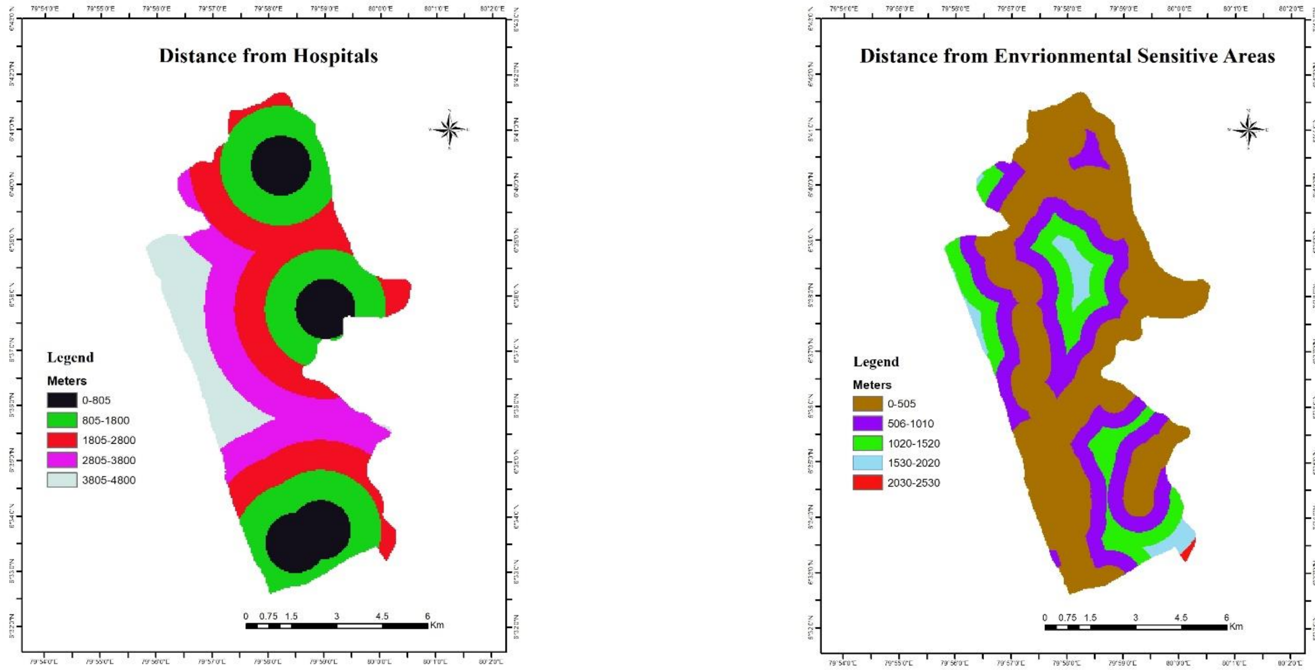

Figure 4: Distance and Reclassfication for selected citeria

3.1.6 Environmentally sensitive areas

According to Figure 4 & 5, Kalutara DSD has rich environmentally sensitive areas. It consists of several large environmentally sensitive zones such as rivers, lakes, marshes, and canals (*Ela*), which also contribute to maintaining the ecological balance of the area. It can be seen how urban waste has accumulated in significant amounts on the banks of the river and in the coastal areas. Sensitive ecological zones are being destroyed due to such deliberate actions by humans. Since the ecological zones have spread to cover the area itself, it is not possible to identify highly suitable areas for landfilling. Based on buffer analysis, specific distances were determined. This study created three distance categories from the environmentally sensitive areas. The area with a distance of 1000m from the ecosystems is not at all suitable. Those areas and the nearest waterways are not suitable for waste dumping. Also, zones with buffer distances between 1020-1520m and 1530-2020m are identified as less suitable. The southeastern border of the area has been identified as a suitable area for landfilling, which comprises 0.17% of the total area. This has spread over a distance of 2030-2530m from environmentally sensitive zones. In the context, based on these facts, we present such problematic natures and it will be fruitful to investigate specific remedies for them.

3.1.7 Hospitals

Hospitals are places where a lot of people congregate and work together. Aspects like people's well-being and health depend on the connections made with such places. Therefore, waste disposal should be done based on an appropriate distance from existing hospitals, minimizing the impact on people's health due to steam and dust. While both government and private hospitals provide services in the Kalutara area, the more the distance from these places, the more landfill areas can be developed. Under buffer analysis, construction of landfill sites within 1800m of hospitals is restricted. Other buffer zones between 1800-2800m and 2800-3800m were used for analysis and those zones were found to be less suitable and suitable (Figures 4 & 5). The hospital system and its surrounding environment should be well-managed and safe in terms of hygiene practices. In the study, it can be pointed out that the area between 3800-4800m is a suitable area for urban waste dumping. It was confirmed that an area of 11.3% of the total area has been allocated for it.

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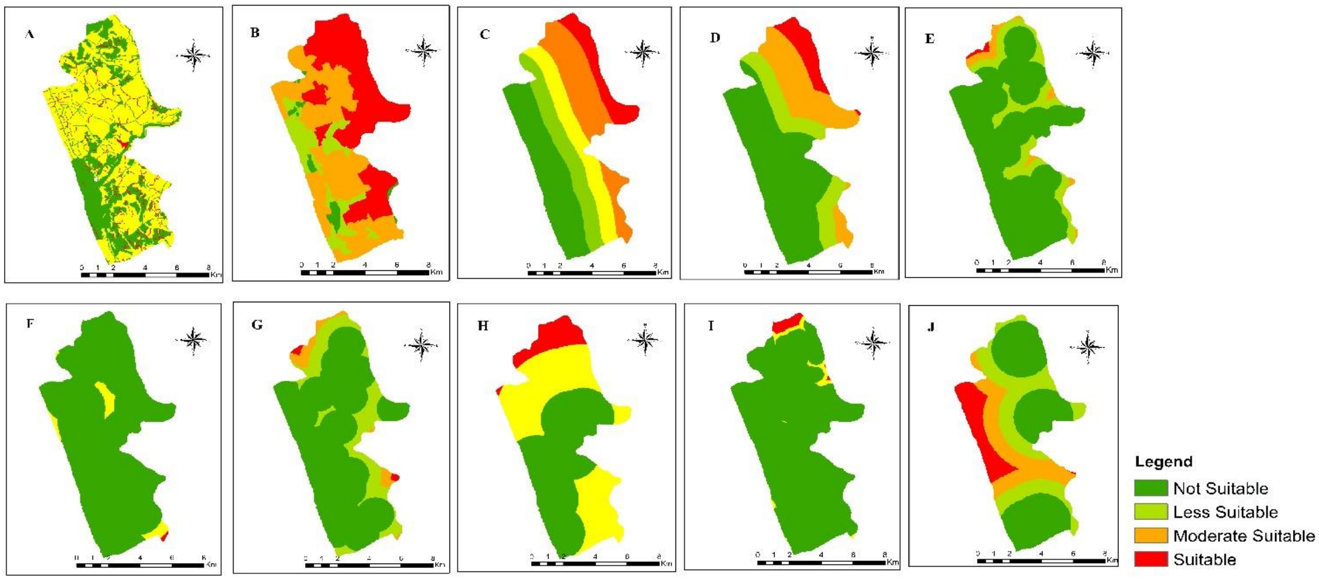

Figure 5: Suitability scores assigned for all criteria **/ A** – Land use, **B** – Population, **C** – Railway, **D** – Coastal Line, **E** – Religious Places, **F** – Eneviornmetal Sensitive areas, **G** – Schools, **H** – Government office, **I** - Roads, **J** - Hospitals

4.0 Optimal Urban Waste Dumping Site

The method utilized here is simple to comprehend and can show which locations are more or less suited for choosing a site for waste dumping or any other facility's site selection process. Table 5 lists the factor weights after normalizing each factor. Regular garbage management is a crucial process because of the daily growth in garbage creation in the studied urban area and the unavailability of space for waste disposal in Kalutara DSD. The weighted overlay analysis technique with GIS-based AHP-MCDA is one of the best techniques to find appropriate dumping sites for urban waste, according to the study's findings, which are summarized. The study identified suitable land based on analysis such as buffer zones using ten more significant criteria. Therefore, attention should be paid to the surrounding environment in order to dispose of the waste in a proper place. Weights are derived in relation to each other's criteria following the opinions of experts and previous literature. High weightage has been given to coastal areas and environmentally sensitive areas. These areas, with their highly transitory appeal and values, are by no means suitable for Urban waste disposal. As it is an urban area, there is a region with a large population density and a weight of 0.1290 has been given to those criteria. If such places are established near areas with high population density, it is difficult for people to maintain a good quality of life. Hospitals and school Networks can be seen as major service providers in urban areas. Taking those criteria into account, a high weightage of 0.1237 and 0.1390 has been given respectively. The area of the solid waste disposal site should be established at a sufficient distance from the main road to make transportation easier and, consequently, lower the expenditure of transportation generally. Those areas are distributed road network well. According to Sam and Steven (2017), a buffer of at minimum 700 m should be maintained to ensure that the dumpsite is easily accessible by road. Multiple buffer zone extents and road grading values were used by Bezawith & Engdawork (2013). However, this study also used multiple ring buffers to identify accessible roads toward the waste dumping site. Environmentally sensitive areas are not suitable for waste dumping because those areas provide ecological services and balance to the ecosystem. Government institutes, schools, and religious places are playing significant services to the community to ease their day-to-day lives. A large number of students study in the school and the region including the hospital should have proper management and a healthy environment. As a large amount of Urban waste is added to the environment daily, the relevant institutions should ensure that they are directed to a suitable place with proper recycling. Different land use types are included in the land use pattern and after comparing with other criteria, a low weight has been given to this. However, it has been discovered that not all areas are suitable for landfilling in land use.

Table 5: Weights obtained for all criteria using AHP Process

Thematic Layers	**Weights**
Land use (LU)	0.0192
Population Density (PD)	0.1290
Roads (R)	0.0360
Railway (RW)	0.0354
Coastal Line (CL)	0.1686
Schools (S)	0.1390
Religious Places (RP)	0.0837
Hospitals (H)	0.1237
Government Office (GO)	0.1027
Environmental Sensitive areas (ES)	0.1578

According to the final suitability map for waste disposal in Kalutara DSD, it is classified under three zones Not suitable, Less suitable, and Suitable (Figure 6). In particular, the inability to detect highly suitable areas for this within the area is not so significant. Because, after analytical comparison with other criteria, the study area is identified as a semi-urban and high population density region. According to the final

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analysis, the suitable areas are indicated in the North and North-East Parts. But since there is an environmentally sensitive area in the northern region, the surrounding areas are not suitable for this and the findings of the study have confirmed that there are opportunities to establish paddy lands, isolated areas, and the less populated north-eastern region as a suitable land for waste disposal. Finally, it can be pointed out in the study that the urban center, areas with high population density, coastal areas, and environmentally sensitive areas are not suitable areas for landfilling.

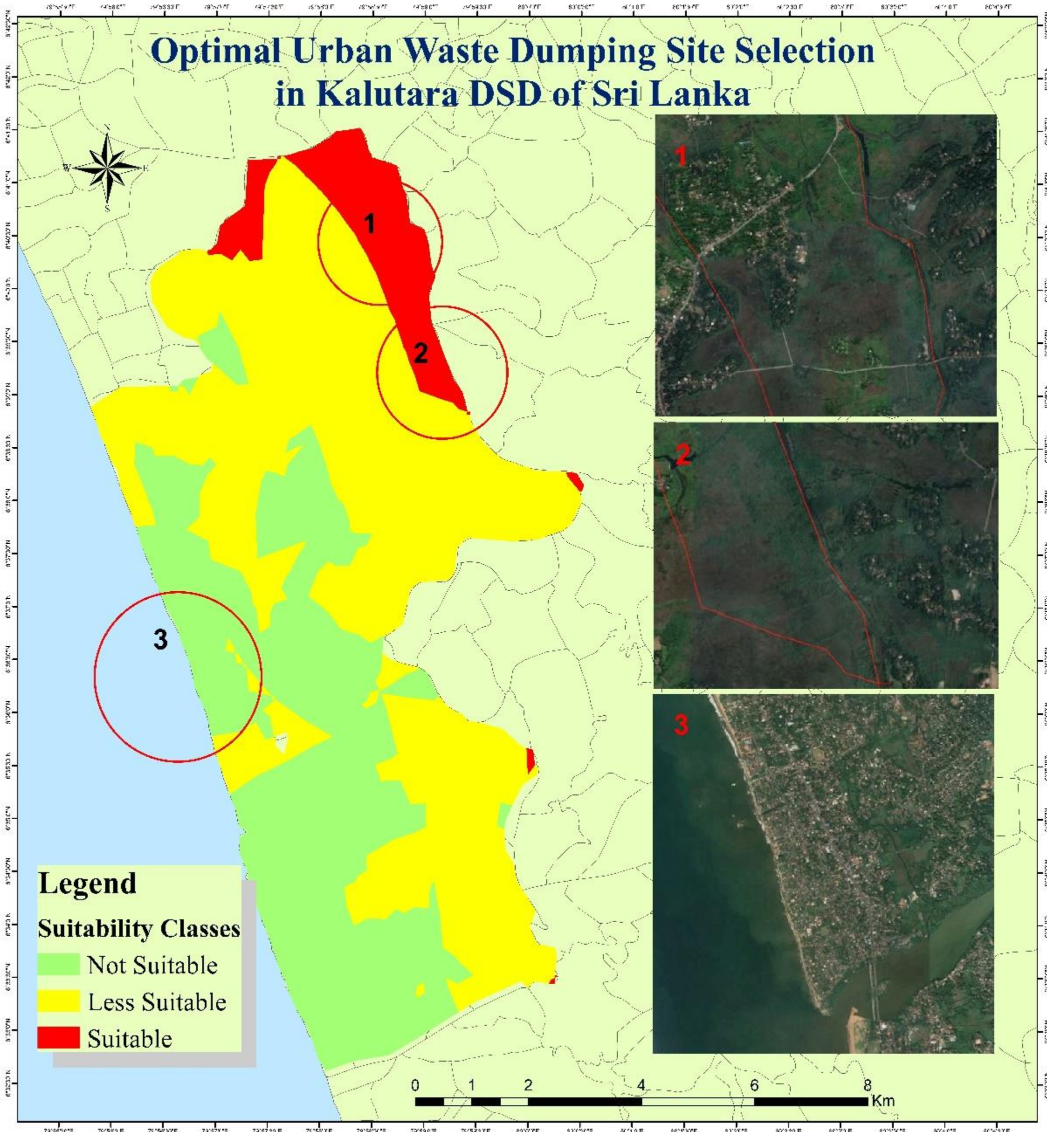

Figure 6: Suitability map for urban waste dumping using MCDA

5.0 Discussion

The study is a significant step in filling a gap in urban waste disposal site detection and enhancing the effectiveness and sustainability of waste disposal initiatives. GIS is an appropriate tool for location selection studies because it can manage huge quantities of spatial data from multiple resources (Kao et al., 1997), and they have recently been used extensively for site selection. Every urban area in Sri Lanka needs to choose a site for the disposal of urban waste, but doing so is complicated and expensive. As a result, GIS and remote sensing techniques have developed into advanced tools for such exploratory studies because of their ability to cope with the considerable amount of geographic data generated from different sources. The AHP approach is also utilized to address the challenges that decision-makers have while handling a lot of complexity. GIS and AHP integration is a potent tool for resolving the waste dumping site selection issue. Through the results of the study, the three suitability zones have been identified as not suitable, less suitable, and suitable. Of the total study area, 9.9% (7.72 Km^2) of land area has been allocated for suitable areas, while 53.06% (41.47 Km^2) and 36.94% (28.87 Km^2) areas have been identified as least suitable and not suitable through the findings of the study, respectively (Table 6). In identifying suitable areas, attention has been paid to population density, distance from criteria, and ecological environment. In identifying suitable areas, attention has been paid to population density, distance from criteria, and ecological environment. Although various projects have been implemented regarding the problem of waste disposal and their proper management, it can be revealed that there is no significant contribution from them. Due to the rapidly growing urban population, these areas have faced many crises due to the lack of properly managed waste disposal and recycling. Adequate technical knowledge, community participation, and attitude promotion are important factors in waste management. Rural people have different responses to the environment compared to urban people. Rural people are used to properly maintain the environment. Issues such as limited space in urban areas have also become a challenge for them. Most of the urban waste management programs that have been implemented so far have not been seen to successfully reach the desired goals in the study area. It is also common to see how some people in the areas dump waste in public places without permission (Figure 7). In the study, we have mainly tried to find suitable land for proper waste disposal. Kalutara Municipal Council areas also lied between the DS area, therefore, have a low potentiality to establish a waste dumping site in the core areas but there is the possibility to establish it in peripheral areas of the Kalutara DSD.

Table 6: Suitability of Land Extent for waste dumping areas in Kalutara DSD

Suitability Index	Area (Sq.km)	Percentage (%)
Suitable Area	7.72	9.9
Less Suitable	41.47	53.06
Not Suitable	28.87	36.94

Source: GIS-based Area Calculation, 2022

At present, people are deliberately adding waste to the environment. Waste has been collected in large quantities mostly in the coastal area. This is a problem that can be identified in every coastal area of Sri Lanka. The western border of the study area is also connected to the coastal zone and it can be seen that waste has accumulated in the areas around the Kalido beach. Some cleanliness is found only near tourist hotels. But, now even the coastal water quality has reduced due to non-biodegradable waste like polythene and plastic. There is no waste collection system within the main city areas either. It is doubtful whether 10% of Sri Lanka's land is covered by formal waste disposal systems. A significant amount of the waste collected daily in the urban areas of Sri Lanka is collected by the Municipal Council and Pradshiya Sabha. At present, the waste collected under the Kalutara Pradeshiya Sabha is not related to the appropriate area found in the study and is being dumped in another area. A project called "*Mihisaru Waste Management*" is being implemented in the Kalutara Nagoda area to successfully solve the garbage issue that has become a problem. The waste that is removed daily from Kalutara Municipal Councils and Pradeshiya sabha areas is turned into compost at the Mihisaru arcade. This project provides a temporary solution to the existing organic waste management problems in the area. Through this, both favorable and unfavorable results can be identified and the people living in the surrounding area mentioned that they are suffering from adverse results such as the bad odor, decline value of land demand and prize, increase of insects and mosquitoes. In such an urban environment, selecting an area for the disposal of solid waste is a complex task, and geospatial technologies have been very helpful in making the process successful. The area's sustainability must be assessed in relation to the dumping of such a large volume of waste and the availability of appropriate sites. AHP has been used in a unilateral way to give the weights of the parameters based on expert knowledge while allowing a certain amount of subjectivity in the pairwise comparison matrix. Each choice in the AHP process has a unique layout connected to a two-dimensional priority matrix. The method employed supports site appropriateness through the use of a weighted linear combination and overlay analysis, which was thought to be desirable since it helps to reduce human bias to give the criteria weight utilizing spatial analyst techniques and a matrix (Gbanie, et al, 2013: Ali, et al. 2020). Through such studies, it can be emphasized that the process of decomposition of natural waste is more efficient through the ecological recycling system fed by advanced technology, and good results can be achieved through the implementation of such a system in different areas of Sri Lanka.

Figure 7: Improper waste management in Kalutara / **A** – Near the Public Market, **B** – Heel Street in Kalutara Urban area, **C** – Near the Heenatiyangala to Wettumakada Road , **D** – Near the Wettumakada *Ela*

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6.0 Conclusion

Waste generation is a continuous process, and each country has a proper mechanism to manage it without any disturbances. As a developing country, Sri Lanka is facing huge problems regarding waste management without proper technical support, knowledge, and funds. The problem of waste has become a crisis today due to factors such as urbanisation, increasing population, the growing needs of human society, and the rapid depletion of space. In the last few decades, along with the growth of the population in Sri Lanka, the irregular disposal of waste has become common. According to a review of previous kinds of literature, no substantial research has been done on the best places to dispose of urban waste in the Kalutara area. The ten criterion layers in the GIS environment were used to create a suitability map during the analysis of the study. The analysis has taken land use, road network, population density, environmentally sensitive areas, coastal areas, government institutes, hospitals, schools, religious sites, and railways as determining factors in order to find an appropriate area for waste dumping. The results of the study have shown that coastal zones, ecologically sensitive places, hospitals, and schools are the most important criteria, and land use is a slightly more important criterion. The findings have shown that 7.72 km2 areas were selected as suitable areas. The sites are easy to access and manage for the disposal of solid waste. Due to the low population density and distance from the service areas, this area has been indicated as suitable for waste disposal. This study used multi-criteria-based appropriateness analysis to provide a considerable scientific foundation for the study area. The government, as well as non-government organisations, can work for the success of waste management. It is important to make the community aware of waste management and to build a sense of responsibility for collecting and sorting waste. Urban waste can be transformed into a resource by disposing of it properly. The cost of recycling or converting unsorted waste into a resource can be avoided by sorting waste. Waste released into the environment from residences, factories, hotels, and other buildings has become a major environmental problem in cities. Even water bodies are polluted near the areas where garbage is dumped. Because of this, the risk of spreading infectious diseases like dengue and diarrhoea has also increased. Considering this situation, waste should be managed and sustainable cities should be recreated. There are cases in urban areas where various ideological actions have been used to create interest in this among the people. That is, recyclable and waste-buying centres have been established in the country. People should be made aware of the need for a public policy on waste disposal. Areas that are suitable for waste dumping often meet key requirements. Especially to safeguard the environment, a thorough evaluation of the area's viability should be conducted, and any adverse effects on the environment should be minimized. Hence, the capacity to use geospatial technology for the effective identification of suitable urban waste dumping sites will minimise environmental risk and human health problems. This study included broad geographical and spatial information input data and retrieved output assessments to determine the degree of appropriateness for waste dumping locations. This study shows that it is possible to apply the GIS-based AHP-MCDA suitability analysis approach to a variety of real-world problems and settings, including a wide range of additional circumstances in urban waste management.

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