Locational Suitability for Residential Development in Kandy District: GIS-Based Multi-Criteria Evaluation

Ms. Gayani Lakmali Pathirage & T.W.M.T.W. Bandara
Department of Geography, University of Peradeniya
gayanipathirage@gmail.com

Abstract

The research was carried out with the main objective of evaluating the locational suitability of the residential development in Kandy District using Geographic Information Systems (GIS) integrated Multi-Criteria Evaluation (MCE). Therefore, eight criteria, namely slope, landslide vulnerability, land use, population density, proximity to town centres, proximity to roads, proximity to schools and proximity to hospitals were used to achieve the said objective. Mainly secondary data that were used for the study were acquired from the Kandy District Secretariat, the National Building Research Organization (NBRO), the Provincial Department of Education Central Province, the Office of Regional Director of Health Services of Kandy and the Survey Department of Sri Lanka. The suitability maps were generated for individual criterion using ArcGIS 10.5 software. The weights for each map were assigned based on the Analytic Hierarchy Process (AHP) method considering the recommendation of the experts of relevant fields. Finally, all the map layers integrated using weighted overlay analysis method, and the suitability map was generated. According to the results of the analysis, 512 km^2 of land extent is highly suitable while 666 km^2 of area is suitable for residential development. In addition, another 390 km^2 area could be identified as moderately suitable. On the other hand, 78 km^2 and 260 km^2 of areas are identified as unsuitable and extremely unsuitable for residential development respectively. Hence, the 82.2% of the total land area in the Kandy District is suitable (26.8% highly, 34.9% generally and 20.5% moderately suitable) for residential development, which 17.8% area is not suitable (13.7% unsuitable and 4.1% extremely unsuitable).

Keywords: *Locational suitability, Residential development, Geographic Information Systems, Multi-Criteria Evaluation*

Introduction

Locational suitability of residential development plays a vital role in procuring better living standards for all human beings who live in every corner of the globe. Particularly, environmental and socio-economic factors of the residential area strongly influence to decide the quality of lives of the people.

However, at present, the situation has revolutionarily changed with a high demand of land, occurring as a result of increasing of the population, induces people to settle down where they can find plots to build houses without considering its consequences. These unplanned residential developments reversibly influence to make environmental and socio-economic problems such as increasing deep-seated poverty, increasing level of under-education, health problems and inability to existing resources in the area in the long term. As a result, identifying suitable land areas for residential developments is becoming an essential practice in the context of regional planning and development. Therefore, this study was carried out on locational suitability for residential development in Kandy District, where records the second highest population in Sri Lanka, using Geographic Information Systems (GIS) based on Multi-Criteria Evaluation (MCE) method.

Locational suitability analysis involves a large set of feasible alternatives and multiple and conflicting evaluation criteria. "The residential developments required to focus on the affordability of the residents to live and work with accessibility, infrastructural facilities, environmental quality, financial ability etc." (Ekanayake and Weerakoon, 2009). As a result, the need for MCE emerges as an essential requirement in locational suitability analysis. Selected criteria for evaluating the locational suitability are weighted with the relative importance accordingly.

Many spatial decision problems give rise to the GIS-based MCE. On the one hand, GIS techniques play an important role in spatial decision making contexts. On the other, MCE provides an invaluable set of techniques to structuration the problem and design, analyse, evaluate and prioritize the criteria.

This study is theoretically and philosophically integrated with the central concepts of Spatial Science and inclines in the direction of how phenomena are organized in the space. Any phenomenon takes places and unfolds at a particular space and at a particular time. Interactions with these physical and human phenomena at individual places and their interaction tend to emerge patterns over the space, which is known as the organisation of space. The organisation of space depends on location, distribution, the arrangement of the phenomenon, the association of the phenomenon, structures, interaction and interrelations. This study focused on the Kandy District as the location. The locational suitability for residential development in the Kandy District was analysed using the generated maps in terms of land cover, slope, landslide vulnerability and population density which were shown the spatial distribution patterns of the area.

"Everything is related to everything else, but near things are more related than distance things" (Tobler, 1974). According to Nystuen (1963), abstract spatial analysis has three elements as direction, distance and connectivity. Even though it may happen unconsciously, humans excessively behave rationally, according to their ontological and epistemological experiences. People always expect to fulfil their needs from a short distance rather than a long distance. Therefore, when they establish residences, they obviously consider the distance for accessibility such as to roads, town centres and other public places to fulfil their needs in an easy and comfortable manner. As Morril (1970) argued in his book of Spatial Organization of Society, five qualities are relevant in understanding human spatial behaviour, namely distance, accessibility, agglomeration, size and relative location. According to the spatial theory, societies try to achieve two spatial efficiencies. The first is to use every piece of land to the greatest profit and the second is to achieve the highest possible interaction with the least possible cost. Therefore, it is very important to use the criteria of proximity to town centres, roads, hospitals and schools when analyzing the locational suitability for residential development.

In addition, Haggett (1965) argues that there are six elements in the schema for studying spatial systems as movements, channels, nodes, hierarchies, surfaces and diffusion. The process of creating spatial patterns starts with movements, and in a causal relationship, it leads to others. In this study, the road network, which was one criterion, can be considered as channels, and intersection of these roads, as nodes. Hierarchies are clearly identified with the distance from the main towns to these nodes and the areas which are at the top of the hierarchy are the most suitable places to live in terms of proximity to the roads. These hierarchies are created surfaces, and helps to identify the pattern of suitable areas for residential development through the diffusion.

The purpose of this study was to identify suitable areas for residential development in the Kandy District. Eight different criteria in terms of slope, landslide vulnerability, land use, population density, proximity to town centres, proximity to roads, proximity to schools and proximity to hospitals were selected to identify the suitability area. Secondary data sources were mainly used to acquire the data and a field survey was carried out to do the verifications. While weights were assigned for each criterion following the Analytic Hierarchy Process (AHP) method which is on the pairwise comparison, the weighted overlay method was used to integrate all the weighted layers and generate the final suitability map.

Statement of Problem

The demand for the lands has increased with the increase in population by an alarming rate during the last few decades. In addition, due to the unawareness of residents regarding the suitability of the land for residential developments, they unconsciously build houses and settle the places where they can find a plot of land. As a result, several socio-economic and environmental problems such as disasters, poverty, inability to access the infrastructure and other facilities have emerged.

In most cases, the areas are suitable in one aspect but unsuitable in others. Therefore, various criteria which represent several aspects should be used to identify suitability and unsuitability of areas for residential development.

Research Objectives

Primary Objective

- To evaluate the suitable areas for residential development in the Kandy District using GIS integrated Multi-Criteria Evaluation (MCE).

Specific Objectives

- To map suitable areas for individual criteria
- To develop a GIS integrated MCE model to identify suitable areas for residential development
- To identify the suitable and unsuitable areas for residential development in the Kandy District

Research Methodology

This study was carried out with the main objective of evaluating the locational suitability of residential developments in the Kandy District in terms of slope, proximity to roads, proximity to town centres, proximity to schools, proximity to hospitals, landslide vulnerability and population density.

Data Collecting Methods

The secondary data sources were obtained from the Kandy District Secretariat, the National Building Research Organization (NBRO), the Provincial Department of Education Central Province, the Regional Director of Health Services of Kandy and the Survey Department of Sri Lanka. Population data in 2016 was taken from the Kandy District Secretariat. A base map on landslide-prone areas of the Kandy District was received from NBRO while land use, contours, town centres and roads of the district were extracted using the 1:50,000 topographic maps published by the Survey Department of Sri Lanka and updated using the Google images. The locational data related to the schools and the hospitals were taken from the Provincial Department of Education Central Province and the Regional Director of Health Services of Kandy respectively. Expert knowledge was used in order to assign the weights for generated maps using above base maps.

Data Quality and Reliability

Data quality refers to the "fitness for use" of data for the intended application. Therefore, data must be accurate in order to consider them as usable to do a reliable analysis. In this study, 1:50,000 scale topographic maps were initially generated using several technical methods such as photogrammetry. According to the accuracy standard, the 1:50,000 scale maps have ± 25 m effective resolutions (Lo and Yeung, 2005). In fact, all the base maps and data used for the study have been published by government institutes and organizations namely, the Kandy District Secretariat, the National Building Research Organization (NBRO), the Provincial Department of Education Central Province, the Regional Director of Health Services of Kandy and the Survey Department of Sri Lanka.

Furthermore, the weights for each map were assigned based on the AHP method considering the recommendation of the experts of relevant fields.

Software Selection

To calculate the weights for the individual classes of the maps and the map layers, and to conduct the quantitative analysis, Statistical Package for Social Sciences (SPSS) 20 software version was used. The ArcGIS 10.5 version was used to conduct slope analysis, calculate density of population, Euclidean distance from town centres, roads, schools and hospitals, and finally to integrate all the map layers using the weighted overlay method assigning weights.

Data Processing and Analysing

After collecting the data using the above methods and sources, data processing and analysing were conducted using GIS and AHP method. Slope analysis was done using the contour layers, whereas Euclidean distances were calculated for the road network, town centres, schools and hospitals. Based on the map from the NBRO, the landslide-prone area map was created. Population density was calculated based on the tabular population data, which was taken from the Kandy District Secretariat. A land use map was created using topographic maps and Google Images.

In addition, class maps related to slopes, landslide vulnerability, road network, town centres, schools, hospitals, population and land use types were obtained using created map layers. In order to assign the weights for the individual classes and map layers according to their relative importance. Accordingly, weights for eight main criteria and each sub-criterion of the main criterion were calculated based on the AHP method, which is a pairwise comparison matrix. This method was specifically used for this study due to its theoretical basis than rating or ranking methods. It is also widely used to identify locational suitability in previous studies. Table 1 shows a pairwise comparison matrix for eight main criteria and Table 2 to **Table 9** show the pair-wise matrixes for individual main criteria and its sub criterions.

Criteria	**Landslide vulnerability**	**slope**	**Land use**	**Proximity to the roads**	**Proximity to the hospitals**	**Proximity to town centres**	**Proximity to the schools**	**Population density**	**Weight**
Landslide vulnerability	1	1	3	5	5	7	7	7	0.2893
Slope	1	1	3	5	5	7	7	7	0.2893
Land use	1/3	1/3	1	3	3	3	5	5	0.1407

Proximity to the roads	1/5	/5	/3	1	3	3	3	5	0.0953
Proximity to the hospitals	1/5	1/5	1/3	1/3	1	3	3	5	0.0758
Proximity to town centers	1/7	1/7	1/3	1/3	1/3	1	3	3	0.0496
Proximity to the schools	1/7	1/7	1/5	1/3	1/3	1/3	1	3	0.0357
Population density	1/7	1/7	/5	1/5	1 /5	1/3	1/3	1	0.0239

Table 1: Pair-wise comparison matrix for the main suitability criteria

Slope	**0-10**	**10-20**	**20-30**	**30-40**	**>40**	**Weight**
0-10	1	1	1	5	7	0.2994
10-20	1	1	1	5	7	0.2994
20-30	1	1	1	3	7	0.2712
30-40	1/5	1/5	1/3	1	5	0.0942
>40	1/7	1/7	1/7	1/5	1	0.0355

Table 2: Pair-wise comparison matrix for slope

	1	**2**	**3**	**4**	**Weight**
1	1	3	7	9	0.5490
2	1/3	1	5	9	0.2914
3	1/7	1/5	1	7	0.1202
4	1/9	1/9	1/7	1	0.0361

Table 3: Pair-wise comparison matrix for landslide vulnerability

	0-1	**1-2**	**2-3**	**3-4**	**>4**	**Weight**
0-1	1	3	5	7	9	0.4785
1-2	1/3	1	3	5	9	0.2538
2-3	1/5	1/3	1	5	7	0.1555
3-4	1/7	1/5	1/5	1	7	0.0822
>4	1/9	1/9	1/7	1/7	1	0.0278

Table 4: Pair-wise comparison matrix for proximity to roads

	0-2	**2-4**	**4-6**	**6-8**	**>8**	**Weight**
0-2	1	3	5	7	9	0.4483
2-4	1/3	1	5	7	9	0.2842
4-6	1/5	1/5	1	7	9	0.1623
6-8	1/7	1/7	1/7	1	9	0.0839
>8	1/9	1/9	1/9	1/9	1	0.0259

Table 5: Pair-wise comparison matrix for proximity to hospitals

	0-2	**2-4**	**4-6**	**6-8**	**>8**	**Weight**
0-2	1	3	5	7	9	0.4785
2-4	1/3	1	3	5	9	0.2538
4-6	1/5	1/3	1	5	7	0.1555
6-8	1/7	1/5	1/5	1	7	0.0822
>8	1/9	1/9	1/7	1/7	1	0.0278

Table 6: Pair-wise comparison matrix for proximity to town centres

	0-1	**1-2**	**2-3**	**3-4**	**>4**	**Weight**
0-1	1	3	5	7	9	0.4785
1-2	1/3	1	3	5	9	0.2538
2-3	1/5	1/3	1	5	7	0.1555
3-4	1/7	1/5	1/5	1	7	0.0822
>4	1/9	1/9	1/7	1/7	1	0.0278

Table 7: Pair-wise comparison matrix for proximity to schools

	< 300	**300-1000**	**1000-2000**	**2000-3000**	**>3000**	**Weight**
< 300	1	5	7	9	9	0.4888
300-1000	1/5	1	7	9	9	0.2615
1000-2000	1/7	1/7	1	9	9	0.1485
2000-3000	1/9	1/9	1/9	1	9	0.0749
>3000	1/9	1/9	1/9	1/9	1	0.0253

Table 8: Pair-wise comparison matrix for population density

Consistency Ratio (CR) related to the suitability criteria and sub-criteria was calculated using the following equation:

CR = Consistency Index (CI) / Random Consistency Index (RI)

Saaty (1980) proved that for consistent reciprocal matrix, the largest Eigenvalue is equal to the number of comparisons, or $\lambda_{max} = n$ Then he gave a measure of consistency, called Consistency Index as deviation or degree of consistency using the following formula.

$CI = (\lambda_{max} - n) / n - 1$

λ_{max} is the Principal Eigen Value; n is the number of factors

$\lambda_{max} = \Sigma$ of the products between each element of the priority vector and column totals

Source: Saaty (1980)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49
n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49
n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49
n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49
n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Random Consistency Index (RI)

Source: Saaty (1980)

As shown in **Table 10** below, the CR values are calculated in relation to the overall context, and sub-criteria are less than 0.1. Fulfilling the condition of CR<0.1 proves that the assigned weights are within the acceptable range.

Finally, the weighted overlay method was used to integrate all layers into one and generate the suitability map for residential development in Kandy District. In this case, the calculated weights using AHP method were multiplied by 100 to convert the decimal values to integers. That is because the weighted overlay method only accepts integer values. The weights used for the study are shown in **Table 11** below.

Land use	Coconut	Chena	Forest	Home garden	Paddy	Tea	Rubber	Reservoir	Scrub	Stream	Tank	Rock	Other	Weight
Coconut	1	1/3	9	1/5	1	1	1	9	1/7	9	9	9	9	0.0875
Chena	3	1	9	1	3	5	5	9	1/3	9	9	9	9	0.1472
Forest	1/9	1/9	1	1/9	1/7	1/5	1/5	1	1/5	1	1	1	1	0.0166
Home garden	5	1	9	1	5	7	7	9	1/3	9	9	9	9	0.1753
Paddy	1	1/3	7	1/5	1	3	3	9	1/7	9	9	9	9	0.0966
Tea	1	1/5	5	1/7	1/3	1	1	9	1/7	9	9	9	9	0.0770
Rubber	1	1/5	5	1/7	1/3	1	1	9	1/7	9	9	9	9	0.0770
Reservoir	1/9	1/9	1	1/9	1/9	1/9	1/9	1	1/7	1	1	1	1	0.0145
Scrub	7	3	5	5	7	7	7	7	1	7	7	7	7	0.2505
Stream	1/9	1/9	1	1/9	1/9	1/9	1/9	1	1/7	1	1	1	1	0.0145
Tank	1/9	1/9	1	1/9	1/9	1/9	1/9	1	1/7	1	1	1	1	0.0145
Rock	1/9	1/9	1	1/9	1/9	1/9	1/9	1	1/7	1	1	1	1	0.0145
Other	1/9	1/9	1	1/9	1/9	1/9	1/9	1	1/7	1	1	1	1	0.0145

Table 9: Pair-wise comparison matrix for land use

Criteria	CR Value
Overall suitability criteria	0.095
Slope	0.053
Landslide Prone Areas	0.023
Proximity to Roads	0.019
Proximity to Hospitals	0.038
Proximity to Town Centres	0.019
Proximity to Schools	0.019
Population Density	0.060
Land Use	0.017

Table 10 Consistency ratio related to criteria and sub-criteria

During the weighted overlay analysis, the following steps were followed.

i. Select an evaluation scale: The evaluation scale was from 0 to 100 in increments of 1 as 0 for extremely unsuitable areas and 100 for the most suitable areas.

ii. Set scale values: The cell values for each input raster in the analysis were assigned values from the evaluation scale. This made it possible to perform arithmetic operations on rasters that originally held dissimilar types of values. Values from 0 to 100 were assigned to each range according to suitability.

iii. Assign weights to input rasters: Each input raster was weighted a percentage influence based on its importance. The total influence for all rasters was equal to 100% as required.

iv. Run the weighted overlay tool: The cell values of each input raster were multiplied by the raster's weight or per cent influence. The resulting cell values were added to produce the final output raster.

No.	Criteria	Weight on each criteria	%	Sub Criteria	Weight	%
i	Landslide vulnerability	0.29	29%	1	0.55	55%
				2	0.29	29%
				3	0.12	12%
				4	0.04	4%

ii	Slope	0.29	29%	0-10	0.30	30%
				10-20	0.30	30%
				20-30	0.27	27%
				30-40	0.09	9%
				>40	0.04	4%
iii	Proximity to roads	0.10	10%	0-1	0.48	48%
				1-2	0.25	25%
				2-3	0.16	16%
				3-4	0.08	8%
				>4	0.03	3%
iv	Proximity to hospital	0.08	8%	0-2	0.45	45%
				2-4	0.28	28%
				4-6	0.16	16%
				6-8	0.08	8%
				>8	0.03	3%
v	Proximity to town centers	0.05	5%	0-2	0.48	48%
				2-4	0.25	25%
				4-6	0.16	16%
				6-8	0.08	8%
				>8	0.03	3%
vi	Proximity to schools	0.04	4%	0-1	0.48	48%
				1-2	0.25	25%
				2-3	0.16	16%
				3-4	0.08	8%
				>4	0.03	3%
vii	Population density	0.02	2%	< 300	0.49	49%
				300-1,000	0.26	26%
				1,000-2,000	0.15	15%
				2,000-3,000	0.07	7%
				< 300	0.49	49%
viii	Land use	0.13	13%	Coconut	0.09	9%
				Chena	0.15	15%
				Forest	0.02	2%
				Home garden	0.18	18%
				Coconut	0.09	9%
				Paddy	0.10	10%
				Tea	0.08	8%
				Rubber	0.08	8%
				Reservoir	0.01	0%
				Scrub	0.25	25%
				Stream	0.01	0%
				Tank	0.01	0%
				Rock	0.01	0%

Table 11: Weights for each criterion

Finally, a model was created to identify suitability areas for residential development in the Kandy District. The map indicates the highly suitable areas, suitable areas, moderately suitable areas, unsuitable areas and extremely unsuitable areas. Furthermore, a comparison was conducted in terms of the DSDs **(Figure 1).**

Results and Discussions

Suitability for Residential Development based on Slope

According to the Digital Elevation Model (DEM) generated using contours, the elevation varies from 61 m to 1,859 m. The highest elevation records from the knuckles mountain region lie in the northern part of the eastern half of the district. Despite this, the Southwestern part of the district shows a comparatively higher elevation **(Figure 2).**

The slope calculated through the DEM varies from 4.78^0 to 64.93^0. Similar to the elevation, the highest degree of the slope can be seen in the direction of Knuckles Mountain region. Slope less than 10^0 has distributed 728 km^2 (38.20%) and slope within 10^0-20^0 distributed in 684 km^2 (35.89%) while 19.41% of the district (370 km^2) covered from the slope within 20^0-30^0. Only 101 km^2 (5.30%) is covered with the slopes within 30^0-$40^{0,}$ and 1.20% (23 km^2) of the land area shows more than 40^0 of slope distribution **(Figure 3).**

According to DSDs, high slope areas belong to Ududumbara DSD, and most of the low slope areas belong to Harispaththuwa, Kundasale, Yatinuwara, Poojapitiya and Udunuwara DSDs. In this context, the lowest slope areas are considered as the most suitable areas for residential development, whereas the high slope areas are considered unsuitable for residential development.

Suitability for Residential Development based on Landslide-prone Areas

As shown in **Figure 4,** the edge line of the Eastern Kandy District and middle part of the district delineated the areas which have no vulnerability while most of the areas in the eastern part of the district and southwestern region fell into the category of high and very high vulnerability.

In addition, the most vulnerable areas belong to Udadumbara, Medadumbara, Panwila and Ganga Ihala Korale DSDs. On the other hand, the less vulnerable areas belong to Pathadumbara, Kundasale, Yatinuwara, Udunuwara and Pathahewaheta DSDs. The eastern part of the Minipe DSD shows no vulnerability while the western part of the Minipe DSD shows high potential for landslide occurrences.

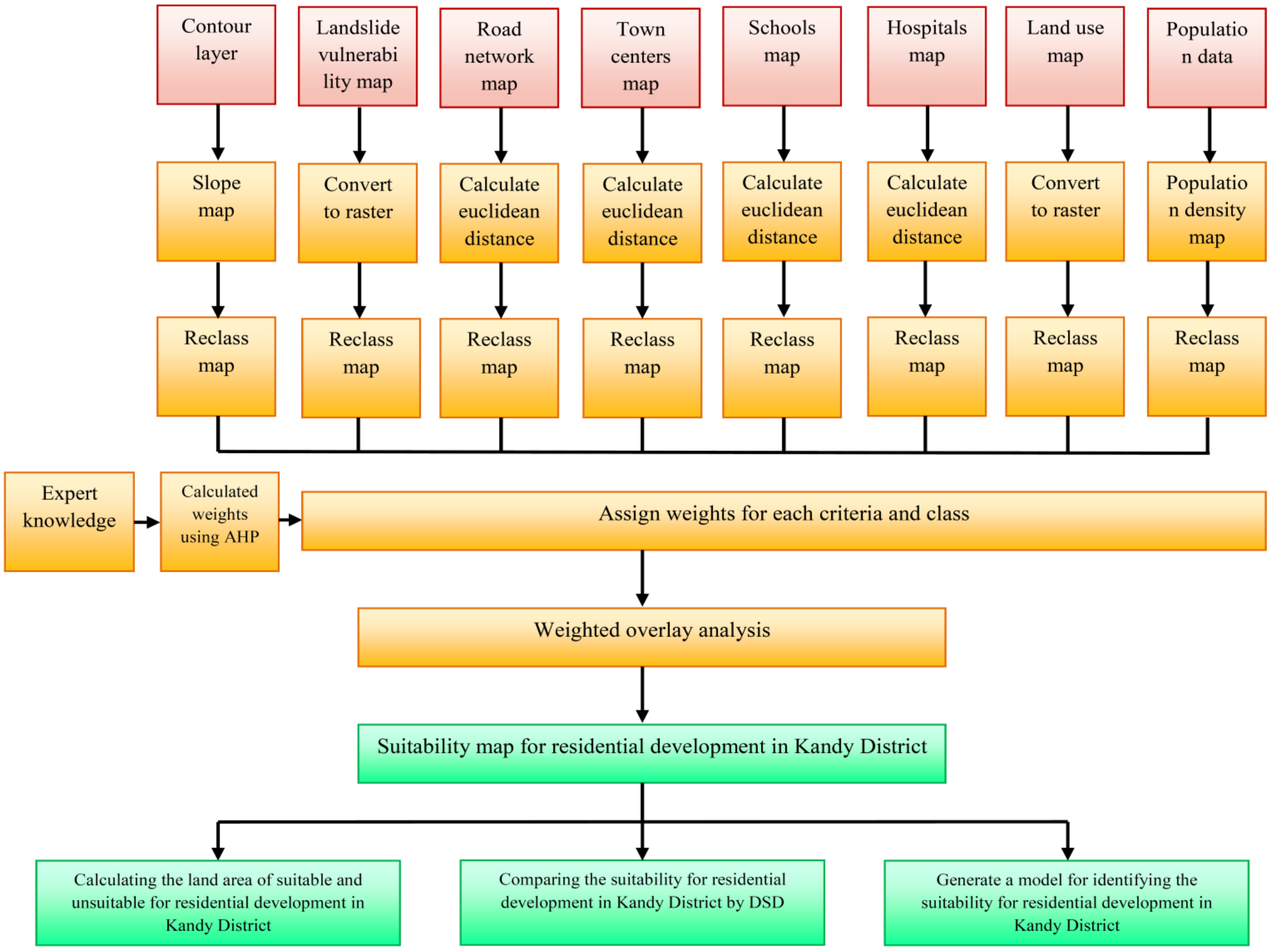

Figure 1: Data processing and analysing the method of the study

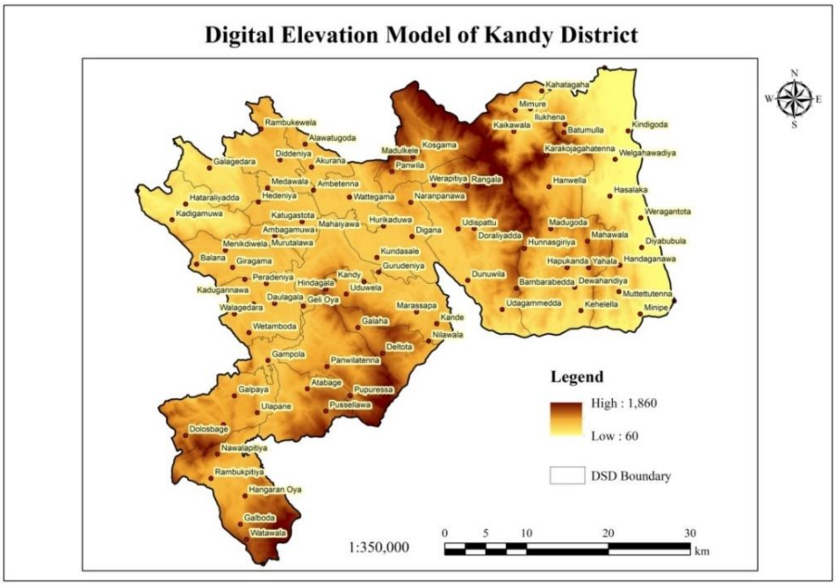

Figure 2: **Digital elevation model of the Kandy District**

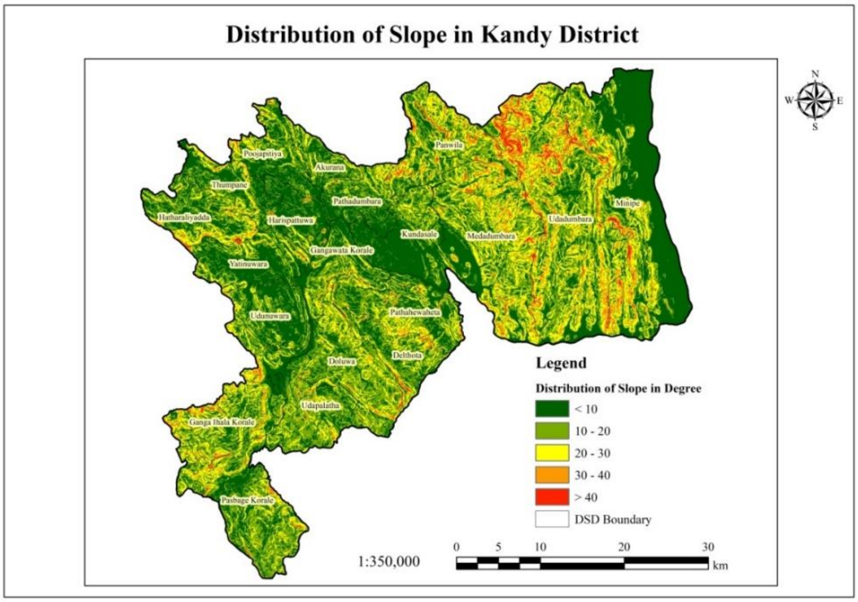

Figure 3: **Distribution of slope in the Kandy District**

Furthermore, there is no vulnerability of occurring landslides for 561 km^2 (29.43%) of the land extent of the district. However, only 185 km^2 (9.71%) of the area has very high vulnerability for landslides while 320 km^2 (16.79%) of land area has a high potential for landslides to occur. In addition, 840 km^2 (44.07%) of the area has moderate vulnerability for landslide occurrences. Therefore, the no vulnerable areas are the most suitable for residential development. The high and extremely high vulnerable areas are unsuitable for residential development.

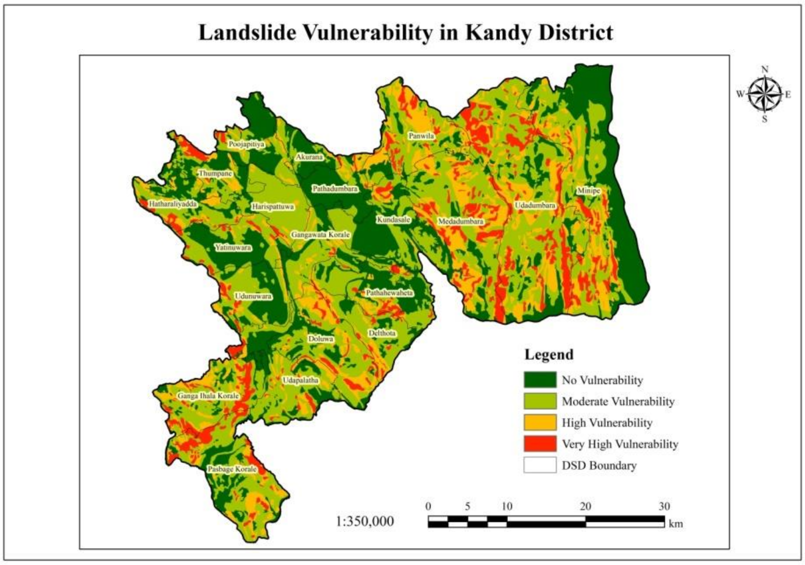

Figure 4: Landslide vulnerability in Kandy District

Suitability for Residential Development based on Proximity to Roads

For this study, roads are considered as main roads, minor roads and jeep tracks. The middle part, western and north-western part of the district consists of a highly dense road network although the density of the road network gradually decline when the area is farther away from the Kandy city area. Mainly, the road network is comparatively poor in the eastern part of the district. However, most of the parts of the district consists of road accessibility, and only a very few parts in the northern and south-eastern part of the district lack the accessibility facilities **(Figure 5).**

The areas which have road accessibility within one kilometre are considered as highly suitable areas for residential development and the areas which do not have the accessibility of more than 4 km are considered as unsuitable for residential development.

Suitability for Residential Development based on Proximity to Hospitals

There are 85 government hospitals in the Kandy District, including teaching hospitals, district hospitals, base hospitals and central dispensaries. When distribution patterns of hospitals are considered, more hospitals are located in the central and northwestern parts of the district in comparison with others. As a result, almost all the people who live in the western side of the district are able to find a hospital within 2 km diameter area. The people who live in 1,548 km^2 (81%) land extent of the district can access a hospital within a 2 km area. At the same time, 67 km^2 (3.52%) of the area, it is difficult to find a hospital unless one travels up to 6 to 8 km. In addition, 23 km^2 (1.2%) of the area cannot access a hospital even after going 8 km of distance **(Figure 6).**

According to the DSDs, Ududumbara, north and eastern parts of Panwila, the Northeastern part of Medadumbara, northern and southern parts of Minipe DSDs have a problem to access a hospital, and the people who live in these regions have to travel more than 4 km in search of hospital. Therefore, these areas can be considered as less suitable for residential development.

Suitability for Residential Development based on Proximity to Schools

For this study, only the government schools were considered as schools when analysing proximity to schools. There are 666 government schools situated in Kandy District. Except in the eastern areas of the district, schools are distributed in all other areas. Schools can be found within 1 km in 1,126 km^2 (58.93%) of the area in the district. The schools lie within 1 to 2 km distance range in 538 km^2 (28.15%) of land extent.

Similar to hospitals, schools cannot be found within a 4 km distance in the Southwestern area, and some parts of the Ududumbara, Minipe and Pasbage Korale DSDs face this problem **(Figure 7).**

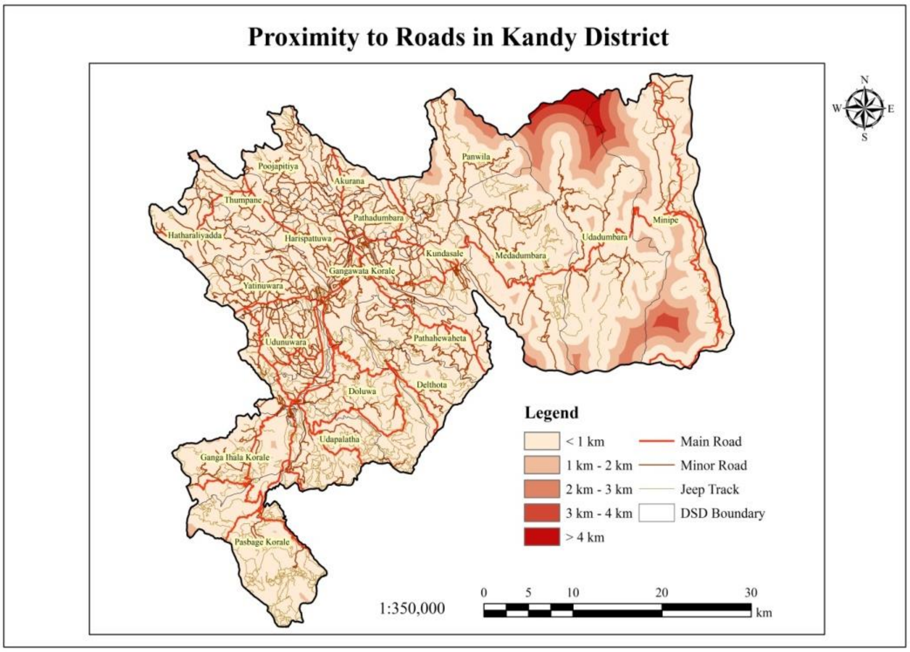

Figure 5: Proximity to roads in the Kandy District

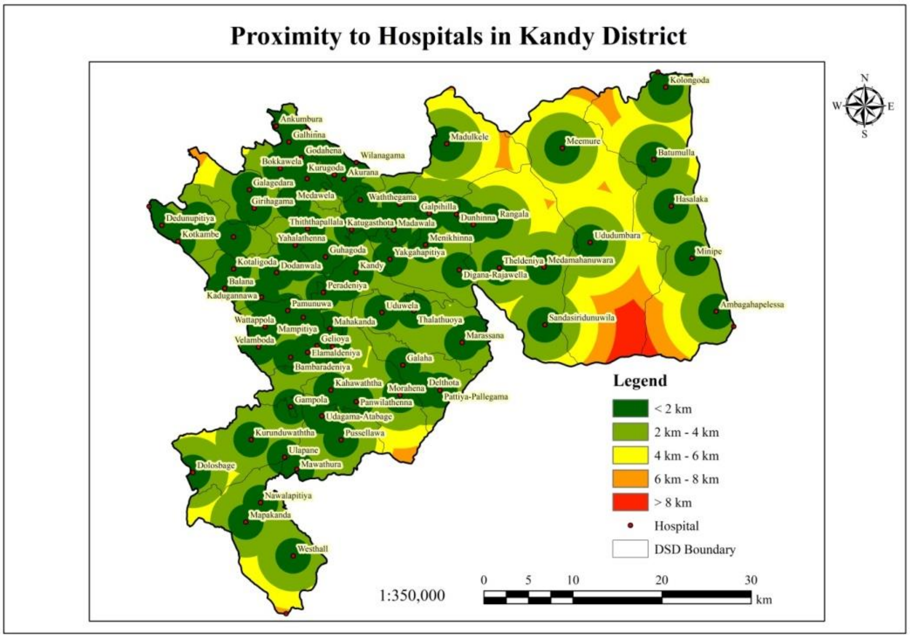

Figure 6: Proximity to hospitals in the Kandy District

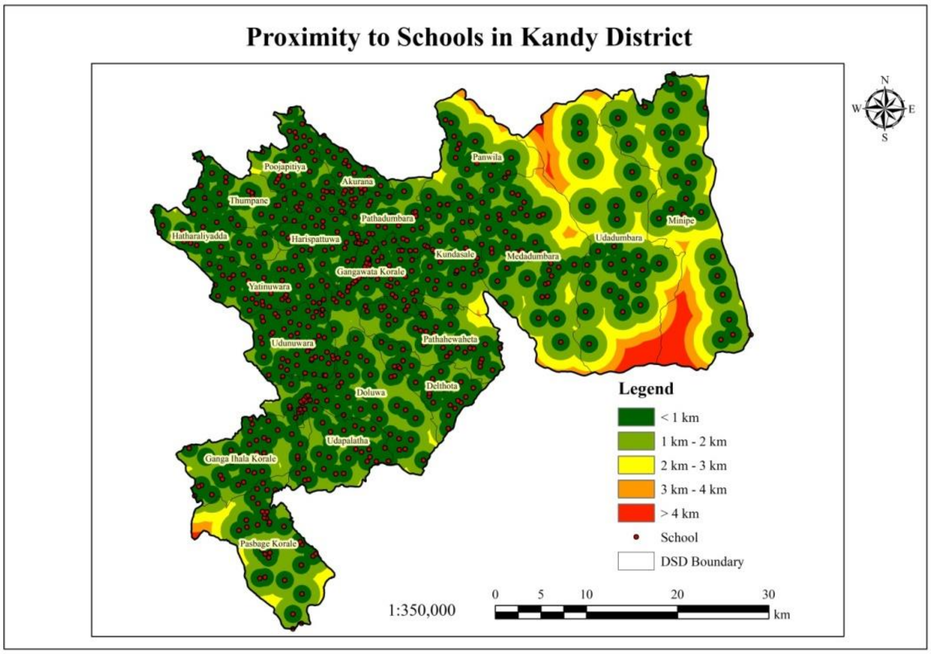

Figure 7: Proximity to schools in the Kandy District

Suitability for Residential Development based on Proximity to Town Centres

91 town centres have been considered in this study for calculated proximity. 906 km^2 (47.42%) of the area situated in less than 2 km diameter from the town centres while 861 km^2 (45.04%) of the area situated within 2 km to 4 km distance. However, only the people who live in 20 km^2 (1.06%) of the area have to travel more than 6 km to find a town mostly in Panwila, Medadumbara, Ududumbara and Minipe DSDs **(Figure 8).** Therefore, the areas located in a distance less than 2 km from town centres were considered as the most suitable for residential development and the areas that deviated from town centres by more than 8 km, as the least suitable areas.

Suitability for Residential Development based on Land Use

In the Kandy District, several land-use patterns were found such as forest, scrubs, chena, coconut, tea, rubber, home garden, paddy, reservoir and tanks. As the major land usage type, home gardens cover 34.2% (655 km^2) of the area from the total land extent, tea is cultivated in 22.6% (433 km^2) while paddy covers 9.9% (189 km^2) of land extent. In addition, forest and scrubs cover 14.3% (273 km^2) and 13.6% (261 km^2) of area respectively.

Scrubs and home gardens were considered as the most suitable areas for residential development because scrublands are mostly situated in lowlands and kind of potential areas to use for development while the residential development can be already seen associated with home gardens. Chena and paddy areas were considered as moderately suitable since these areas are gradually being converted to landfills, and coconut, rubber and tea were considered as low

suitable areas for residential development. Streams, tanks, reservoirs and other areas were considered as unsuitable areas for residential development due to legal and practical barriers of converting as residential areas **(Figure 9).**

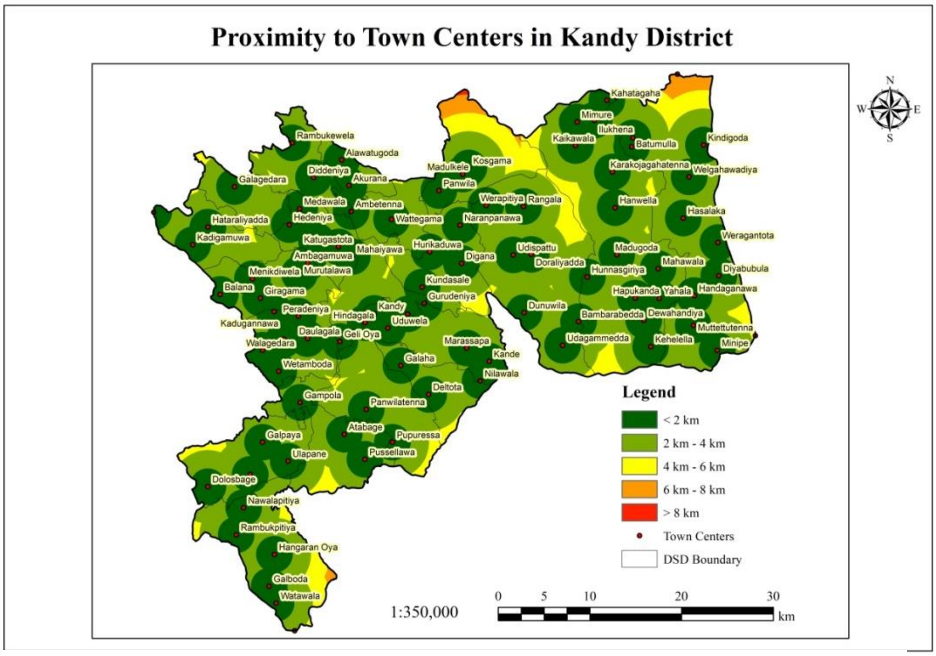

Figure 8: Proximity to town centres in the Kandy District

Suitability for Residential Development based on Population Density

There are 20 DSDs and 1,188 GNDs in Kandy District. According to the statistics in 2016, the total population of the Kandy District was 1,347,612. Gangawata Korale is the most populated DSD in the Kandy District. It records a population of 148,343, and 11.01% from the population living in this DSD. As same as Kundasale, Udunuwara and Yatinuwara DSDs record 127,070 (9.43%), 110,905 (8.23%) and 99,088 (7.35%) of population respectively. On the other hand, Ududumbara, Panwila and Hatharaliyadda record the least number of population as 22,505 (1.67%), 26,294 (1.95%) and 29,520 (2.19%) respectively

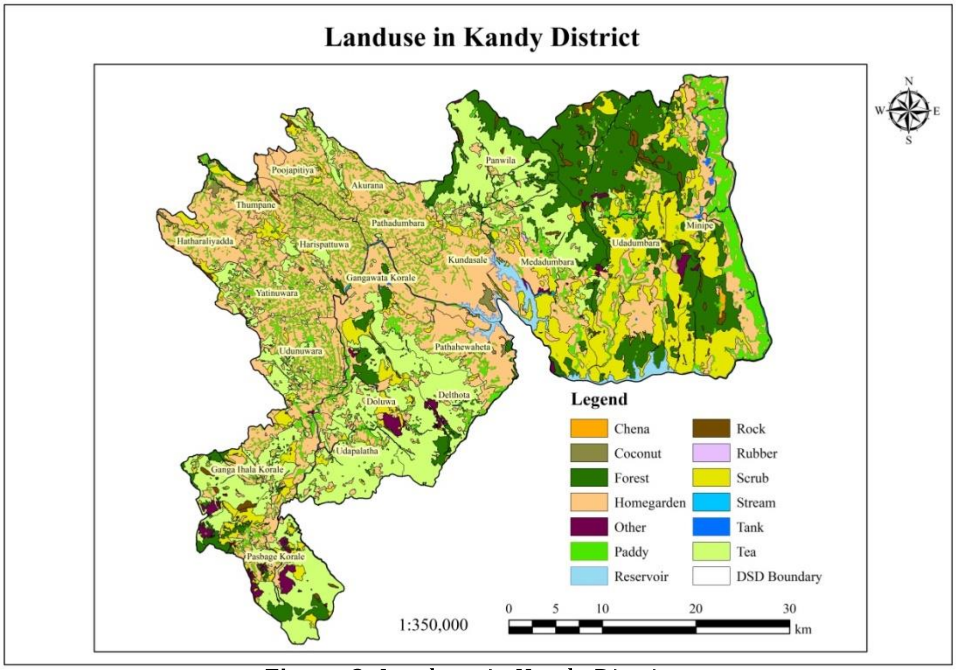

Figure 9: Land use in Kandy District

.

According to GNDs, Kundasale South is the most populated GND in Kundasale DSD in Kandy District recording 7,040 of population. The second and third populated record Thennekumbura GND in Gangawata Korale DSD and Pussellawa GND belongs to Udapalatha DSD. They record 6,195 and 5,878 of the population, respectively. Imbulpitiya GND belongs to Pasbage Korale has the least number of population recording as only 54 people. As same as the Imbulpitiya, Eriyagasthenna GND in Pathadumbara DSD has 60 population, and Karambaketiya belongs to Udadumbara DSD and has 76 of population.

In terms of the population density, Gangawata Korale DSD shows the highest population density as 4,541 people per 1 km^2. On the other hand, it is the biggest DSD in the district. However, when we look at it on a more micro-scale, according to GND, there is a huge variation in population density. While Bowala GND records 92.49 people per 1 km^2 as the minimum population density in Gangawata Korale DSD, Poorna Watta West GND records 21,270 people per 1 km^2 as the maximum population density in Gangawata Korale DSD, as well as the entire district. The second and third highest population density are recorded from Akurana and

Udapalatha DSDs. They record 3,481 people per 1 km^2 and 2,660 people per 1 km^2 respectively.

The lowest population density is recorded in Udadumbara DSD as 183 people per 1 km^2. The maximum population density within the DSD is recorded from Bambarabedda East GND as 691 people per 1 km^2 and the minimum population density within the DSD and within the entire district is recorded from Karambaketiya GND as 6 people per 1 km^2. Minipe and Panwila DSDs also records the second and third-lowest density **(Figure 10).**

For the purpose of identifying suitable areas for residential development, the densest GNDs considered as least suitable and the low dense GNDs considered as suitable areas.

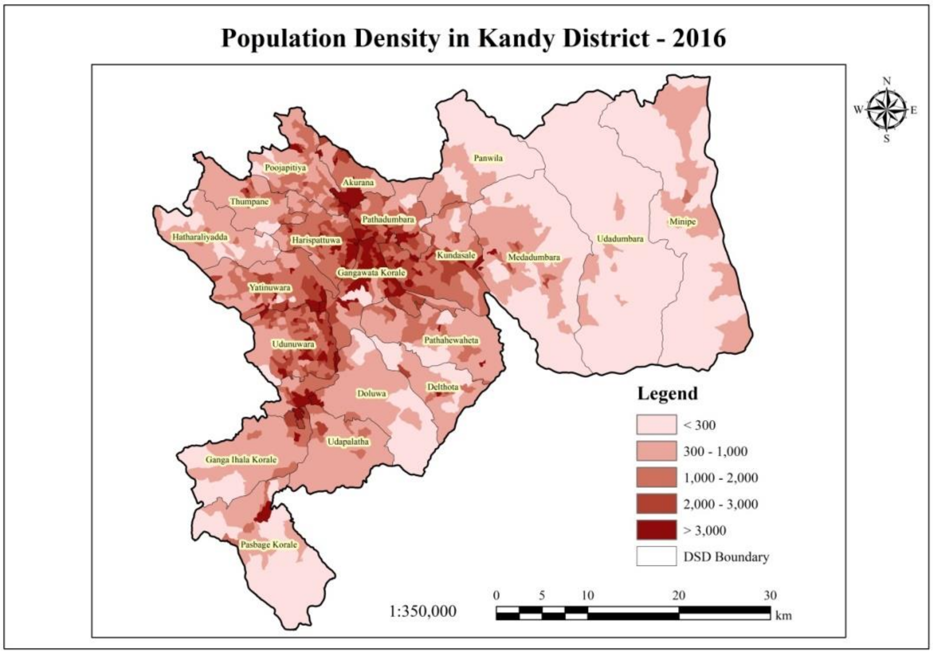

Figure 10: Population density in Kandy District - 2016

Suitability Areas for Residential Development

Based on the above eight criteria, the final suitability map was created for identifying the areas which are suitable for residential development in Kandy District. Results of the analysis indicate that 512 km^2 of land extent is highly suitable while 666 km^2 of area is suitable for residential development. As well as, another 390 km^2 area could be identified as moderately suitable. On the other hand, 260 km^2 and 78 km^2

of areas are unsuitable and extremely unsuitable for residential development respectively **(Figure 11).**

According to the percentage of the total land area of the Kandy District, 26.8% of highly suitable areas and 34.9% of suitable areas for residential development are available in Kandy District. 20.5% of the land area is moderately suitable for residential development. In contrast, 13.7% of the land area is unsuitable, and 4.1% of the area is extremely unsuitable for residential development. Therefore, 82.2% is suitable while 17.8% is unsuitable.

In addition, as the findings indicate, the western part of the district is more suitable for residential development than the eastern part, and most of the unsuitable areas lie in the north eastern part of the district. Figure 11 illustrates the highly suitable, suitable, moderately suitable, unsuitable and extremely unsuitable areas for residential development. As the map indicates, most of the highly suitable areas belong to Minipe, Kundasale, Yatinuwara and Pathadumbara DSDs. In contrast, the highest amount of extremely unsuitable areas for residential development belongs to Udadumbara DSD. Although Minipe DSD records the highest amount of land extent of highly suitable, it records a high amount of extremely unsuitable land extent as well.

According to the DSDs, Minipe DSD has the largest number of highly suitable areas as 95 km^2 while Kundasale, Yatinuwara and Pathadumbara have 40 km^2, 36 km^2 and 35 km^2 of highly suitable land areas respectively. Harispaththuwa and Panwila DSDs show a very limited number of highly suitable land extent for residential development as 3 km^2 and 9 km^2 respectively. For the total of highly suitable areas, Minipe DSD contributes 18.5% and Kundasale, Yatinuwara and Pathadumbara DSDs contribute 7.8%, 7.1% and 6.8% respectively. In addition, Harispaththuwa DSD records 0.6% while Panwila and Delthota DSDs record 1.7% by each.

According to the second category - the suitable areas for residential development-, Ududumbara and Medadumbara record the greatest extent of land area as 75 km^2 and 61 km^2 respectively. Minipe DSD has 52 km^2 of suitable area while Pasbage Korale DSD has 43 km^2 of suitable areas. Pathadumbara DSD has very few land areas (8 km^2) suitable for residential development. Akurana DSD also has 9 km^2 of suitable land area. When we consider the total, Ududumbara DSD contributed 11.3% while Medadumbara DSD contributes 9.1%. In contrast, Pathadumbara DSD contributes only 1.1% of the total suitable areas.

From 390 km^2 of moderately suitable areas, 83 km^2 (21.2%) belongs to Udadumbara DSD and 62 km^2 (15.9%) of land area is recorded from Medadumbara DSD. Minipe has 42 km^2 (10.7%) of moderately suitable land area for residential development while Doluwa has 28 km^2 (7.3%). However, Akurana, Pathadumbara and Harispaththuwa DSDs have the lowest land extent, and belong to a moderately suitable category. Statistically, they record 2 km^2 (0.5%), 4 km^2 (1.0%) and 4 km^2 (1.1%) land extents respectively.

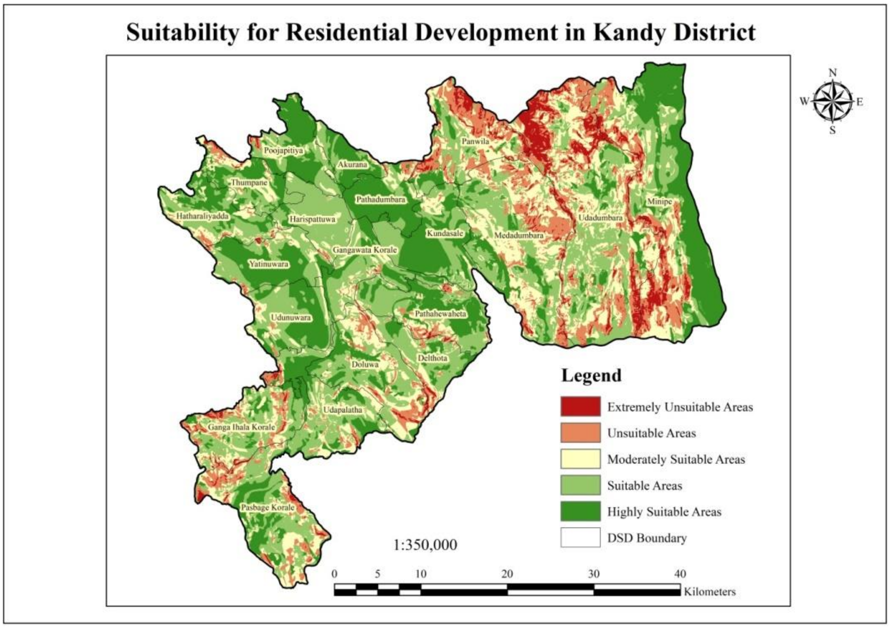

Figure 11: Suitability area extents for residential development in Kandy District

In addition, the highest amount of unsuitable land areas is recorded from Udadumbara DSD as 66 km^2. It is one fourth from the total unsuitable areas. Minipe, Medadumbara, Panwila and Pasbage Korale DSDs also records a high amount of unsuitable conditions for residential development and the land extents are 42 km^2, 39 km^2, 30 km^2 and 22 km^2 respectively. From the total unsuitable areas, they record 16.1%, 14.8%, 11.3% and 8.3% respectively. Akurana, Kundasale and Harispaththuwa DSDs have less than one square kilometre of unsuitable land areas.

Furthermore, when considering extremely unsuitable land areas for residential development, Ududmbara records the highest extremely unsuitable land areas as 36 km^2. It is 45.7% of the total extremely unsuitable lands. Also, Minipe DSD has 16 $km^{2,}$ and Panwila DSD has 9 km^2 of extremely unsuitable land areas for residential development. Kundasale

DSD does not have any land area that belongs to the extremely unsuitable catergory while all other DSDs have less than 5 km^2 area which can be considered as extremely unsuitable for residential development.

Pathadumbara DSD records the highest percentage (71.6%) of its total land area is highly suitable for residential development while Akurana, Poojapitiya and Yatinuwara DSDs record more than 50% of land as highly suitable. The statistics show 59.8%, 55.1% and 52.2% respectively from the total land area of the DSD. On the other hand, Harispaththuwa and Udadumbara have less than 10% of land areas from the total..Harispaththuwa has very few highly suitable land areas and has 83.8% of suitable land areas. When considering highly suitable and suitable lands, more than 90% of areas suitable for living are available in Harispaththuwa DSD. Delthota DSD also has 53.3% of suitable areas from its total land extent. Although Pathadumbara DSD shows the highest percentage of highly suitable land areas, it has only 15.4% of suitable land areas. Except for Pathadumbara DSD, more than 20% of suitable land areas are available in all other DSDs in the Kandy District.

The percentage of moderately suitable land areas from the total land area of each DSD varies from 6.6% to 32.7%. While 6.6% is recorded from Akurana DSD, 32.7% is recorded from Medadumbara DSD. Only 6 DSDs record less than 10% of moderately suitable land areas from the entire land and 7 DSDs record more than 20% of moderately suitable land areas from the total land of each DSD.

Moreover, when considering the unsuitable land areas as a percentage of the total land of each DSD, it varies from 0.8% to 32.3%. A percentage of 0.8% is recorded from Kundasale DSD and 32.3% is recorded from Panwila DSD. In 13 DSDs, less than 10% of unsuitable land areas exist while only 3 DSDs namely Panwila, Udadumbara and Medadumbara show 20% unsuitable areas.

Finally, only Panwila and Udadumbara DSDs record more than 10% of extremely unsuitable land for residential development from its total land area and all other DSDs indicate less than 7% as extremely unsuitable land areas. Harispaththuwa, Kundasale, Udunuwara, Gangawata Korale, Akurana, Hatharaliyadda, Pathadumbara, Poojapitiya and Yatinuwara DSDs have less than 1% .of extreme land areas from their total land.

Conclusions

Most of the highly suitable areas for residential development in the Kandy District belongs to Minipe, Kundasale, Yatinuwara and

Pathadumbara DSDs. In contrast, the highest amount of extremely unsuitable areas for residential development belongs to Udadumbara DSD.

Recommendations

Firstly, it is important to consider the areas where highly suitable, suitable, moderately suitable, unsuitable and extremely unsuitable identified through this study when planning and developing the residential places for Kandy District to avoid and minimize the problems occur through unplanned settlements,

Secondly, the DSDs, especially the DSDs identified as which have more unsuitable and extremely unsuitable areas for residential development in Kandy District, should be avoided to plan or develop any residential places in the unsuitable or extremely unsuitable areas without proper planning.

Thirdly, when conducting residential planning and development programmes in Sri Lanka, it will be more effective to minimize long term problems if a suitability study can be conducted based on relevant criteria and the residences can be placed based on the results of the study.

Finally, to convert unsuitable areas to suitable areas for residential development, infrastructure facilities, accessibility to schools and hospitals have been increased while following landslide prevention and mitigation measures, especially focusing most vulnerable areas.

REFERENCES

Ekanayake, E.W.M.L.R.K. and Weerakoon, K.G.P.K. (2009): Analysis of locational suitability for residential development in Colombo suburban area: Application of Analytic Hierarchy Process, *Sri Lankan Journal of Real Estate*, 1-17.

Haggett, P. (1965): *Locational Analysis of Human Geography*, Edward Arnold, London.

Lo, C.P. and Yeung, A.K.W. (2005): *Concepts and Techniques of Geographic Information Systems*, Pearson Prentice Hall, New Jersey.

Malczewski, J. (2006): GIS-based multi-criteria decision analysis: A survey of the literature, *International Journal of Geographic Information Science* **7**, Vol.20, 703-726.

Morrill, R.L. (1970) *Spatial Organization of Society,* Wadsworth Publishing Company, USA.

Nystuen, J.D. (1963): Identification of some fundamental spatial concepts' in Brian J.L. and Duane F. Marble, *Spatial Analysis: A Reader in Statistical Geography*, 8-37.

Tobler, W. (1970): A computer movie simulating urban growth in the Detroit region, *Economic Geography* 46, 234-240.