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GIS based approach for suitability analysis of residential land use

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Abstract

Developing countries in particular are experiencing a tremendous rise in urbanization. Population growth and internal migration generated rapid urbanization and uncontrolled infrastructure construction in urban and semi urban area in Nepal. In general, local needs for infrastructure development, and construction of housing and apartments are typically used to select the most suitable site for residential use. Identification of the criterion is crucial to a suitability analysis based on local needs. Site suitability analysis is used for identification of the best location or site for residential area using geographic information system (GIS) based on multi-criteria evaluation (MCE). Majority of research work, spatial analytical hierarchy process (AHP) is a suitable tool and used in suitability analysis purpose. The criteria were determined through prior work and customized in the local situation interaction with land use planner as expert perspective and focus group discussions, and utilized in land suitability analysis. In this study, GIS-MCE-AHP models is applied as an effective approach of spatial decision making process and play efficient vital role for identifying the potential areas for residential use. In the suitability residential index map, suitable level of residential area is covered only 5% and 38% land covered with the moderate suitable for residential area in Sambhunath municipality. The suitable for residential area is mainly occurred along the major road network and surrounding to the existing settlement area. GIS conjunction with MCE and AHP is useful for conducting land suitability analysis and serving as planning tool for suitable residential site.

Keywords: Land suitability analysis, Geographic information system, Multi-criteria evaluation, Analytical hierarchy process

Introduction

There are numerous types of land use including agricultural, residential, commercial, industrial, environmentally eco-friendly and risk sensitive areas. Residential area is one of the major land use class and significant land use patterns among them (Rossiter 1996). In particular, urbanization is rising quickly mainly in developing countries (Navodya & Hemakumara 2020) like Nepal. At present, Nepal is recorded within the top ten nation in the world with the fastest urbanization growing rate (UNDESA 2015). High population growth rates in urban and semi-urban areas lead to rapid unplanned urbanization and haphazard infrastructure development (Karna *et al.* 2021). After eradication of malaria and construction of east-west highway, migration primarily occurred in rural areas in Tarai region for urbanization (Khanal 2000). The census, 2001 indicated that the internal migration rate was 8.6 percent (CBS 2003). It is further corroborated by very high rural to urban migration rate of 37.7 percent (MoUD 2017) from for searching job (employment) and educational opportunities that connect rural and urban areas. The internal migration occurred mostly as a result of poverty, unequal economic distribution, and unemployment (KC 2003). Land use land cover (LULC) changes for urbanization has continually exceeded and led to increasingly serious conflicts between different land use types (He *et al.* 2017), and raised serious eco-environmental issues, such as air pollution, and shortage of land resources (Huang *et al.* 2019). Also, LULC changes occurred mainly by human settlement with relationship in interdisciplinary approach to land fragmentation and land development for residential use. Part of these issues is due to the plan or policies of land-use adopted by public officials have not undergone adequate scrutiny (Karna *et al.* 2022). So, it is desirable to determine whether a site is suitable for city development due to population expansion and urban sprawl (Santosh *et al.* 2018). So, with the social and economic development of the towns, there was a rapid expansion of residential activity. The rapid population growth in a small area has led to a number of deficiencies that generated significant problems for land use planner. These significant problems concerns lead to issues with planning process. The right choices should be taken during the planning process to address these issues that are meeting the growth of population and internal migration. As a result, planners need to exercise caution while considering social, economic, and environmental concerns. Additionally, people have been compelled to relocate from their birthplace to other suitable places in order to support themselves (Khadaka 2019); due to sporadic natural calamities like floods and landslides. Therefore, there is required urgent rescue and help of vulnerable situations people in disaster prone area to live in safe area through resettlement plan in safe area (KC 2003).

Land suitability analysis (LSA) is an assessment of land performance process for proper allocation of land use to alleviate land use conflicts in terms of sustainable development

and meeting the demand of land use from multiple aspects and different interest groups. LSA is applicable in site suitability analysis for spatial planning and land use planning (LUP) in the management of land resource (Collins *et al.* 2001, Malczewski 2004). Generally, LSA is essential to fulfill the growing demand for residential land to make better living environment as people work to maximize the available land resource (Rossiter 1996). Identification of potential sites for residential areas is one of the vital issues for planning perspective. To allocate the needs of appropriate site for residential areas, site suitability analysis has become inevitable. LSA is one of the most useful applications to select specific site of residential area using geographic information system (GIS) for spatial planning and management based on the existing site qualities and factors, that will used for required activity. Also, GIS is used for visualization tool that ability to mix many sorts of data to aid in better decision-making. LSA is also used the multi-criteria evaluation (MCE) technique that is based on the decision maker's personal preferences, weighted criteria, and assessments of attaining the goals (Malczewki 1999, Karna *et al.* 2021). Research in GIS-based MCE falls into two categories: first, the field of application is expanding; and second, more MCE techniques have been incorporated into GIS-based land-use suitability analysis. MCE has been used to choose the appropriate location for facilities in the public and private sectors (Liaghat *et al.* 2013), evaluating suitable particular land use (agriculture, residential and quantitatively monitoring urban development (Luo *et al.* 2015). GIS-based MCE method used for finding a more effective way for applying weights to each evaluation component according to scientific principles (Huang *et al.* 2019) and comparison of each factor's importance and calculate each factor's weights. The concept of fuzzy (linguistic) quantifiers has been applied in GIS-MCE based LSA through ordered weighted averaging (OWA) to identify the most suitable lands for housing development (Malczewki 2006), analytic hierarchy process (AHP) for urban residential (Shukla *et al.* 2017), and genetic algorithms for monitoring environment of urban settlement (Huang *et al.* 2019). Also, fused many MCE methods (such as hierarchy analysis, fuzzy evaluation, genetic algorithms, etc.) and factors of natural condition indicators derived from multisource data into LSA model to evaluate urban human settlement environment (Luo *et al.* 2015). AHP is applied in LSA with MCE in the various fields for decision making process of suitability site selection. In AHP, the weight of factors/parameters were compared on the basis of relative significance in pairwise comparisons (Miller *et al.* 1998). In this study, GIS-MCE decision-making tool is applied for site selection of residential area from handling large amount of spatial information. So, MCE-AHP has been used extensively in addressing difficult issues with a variety of parameters at multiple levels by interacting these parameters in common traits (Tiwari *et al.* 1999, Karna *et al.* 2021). In this study, GIS-MCE-AHP models is applied as a cost-effective and time-efficient approach for spatial decision making and play vital role for identifying the potential areas for residential use (Rossiter 1996).

The study area

The location map of the study area is shown in Figure 1.

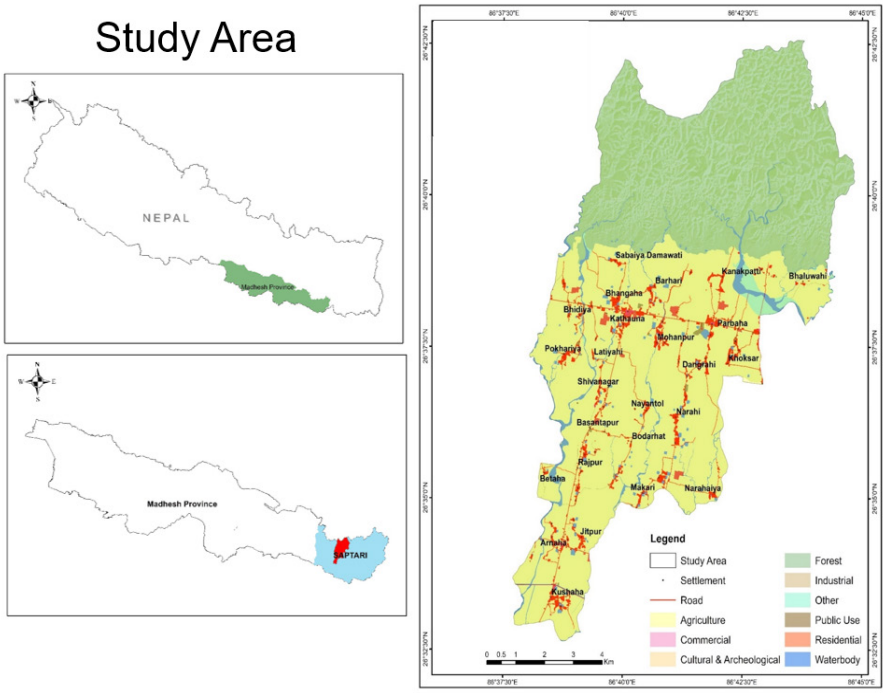


Figure 1: The study area

The study area, Sambhunath municipality is located at the latitude between 26^0 23' 35" to 26^0 42' 36" and longitude between 86^0 37' 39" to 86^0 44' 54" in Sapatari District of Madhesh Province (Karna *et al.* 2022). The extent of the municipality is 108.46 sq. km. and divided into 12 wards as its sub-administrative unit. The municipality headquarter is located at Kathauna Bazar. There are 8824 household occurred in the municipality. The average household size in the municipality is 4.66 people, with a total population of 39423 (CBS 2021), including 18943 male and 20480 female. Hindus make up the majority population (91 percent), followed by Muslims (6 percent), Buddhists (1 percent), and other religions (2 percent) in 2011 (CBS 2012).

Method and materials

Data used

The data collected from secondary sources that utilized to create the influencing factors as criterion map and determine the suitability site for residential use are described in Table 1.

Table 1: Data and data sources

Data Type	Compilation From	Year
World view satellite image, 2016	National land use project	2016
Land use map, scale 1:10000	National land use project	2017
Topographical map, scale 1:25000 & its digital layer	Survey department	1996
Land system, scale 1:10000	National land use project	2016
Land capability map, scale 1:10000	National land use project	2016
Strategic road network map, scale 1:25000 (its seamless digital layer)	Department of Road	2019
Geology map, scale 1:125000	Survey department	1986
Population	Central bureau of statistics	2021

Likewise, primary data/information were gathered through expert interview and two focus group discussions with 9 persons and 98 persons respectively. Nine key expert were mainly involved as land use professionals from government officials ((2 persons from Federal Ministry of Land Management, Co-operatives and Poverty Alleviation, 3 persons from National mapping Agency, Survey Department, 2 persons from provincial Ministry of Land Management, Agriculture and Co-operative, Madhesh Province, and 2 persons from Shambhunath Municipality) through in depth- expert interview with semi-structure questionnaires. Similarly, focus group discussion meeting held at Rupani Bazar and Arnaha Chowk involving 47 persons and 51 persons respectively as respondent using shortlisted criteria and its ranking priority from previous study work.

Selection of criteria

The focus group discussion is aimed to finalize the criteria based on the views of planning perspective for decision makers and stakeholders. At first, the standard criteria were determined for residential use from literature review of different article, scholarly journals and reports. These determined criteria were modified by collaborating with planners, acceptability of stakeholders and adjusted with local situation. Physical, climatic, soil, accessibility and availability of services and amenities, as well as human activity characteristics, were considered as contributing factors for expansion of residential area (Table 2).

Table 2: Criteria used

Criteria	Description	Mapping technique
Physical factors		
Slope	Acts as construction stability and useful for managing sewerage and sanitation work	DEM derived from topographical data in scale 1:25000. Slope from DEM using surface analysis.
Geomorphology (Land form &landscape)	Represent formation of landscape and managing terrain stability	Rasterization of vector layer from scan land system map
Land capability	Preserve high arable fertile land	Rasterization of vector layer from scan land capability map
Proximity to Fault Line	Consider precaution from seismicity possibility	Convert analog map into digital from geology map, scale 1:125000 and apply Euclidian distance function
Human activities factors		
Land use	Describe existing situation of land use pattern	Supervised image classification from World View 2016 and field verification
Surrounding to settlement/ business area	Minimize development cost, maintaining socio-economic condition and densification of built-up area	Euclidian distance of settlement and business area derived from land use/land cover map
Socio-economic factors		
Population density	Generate pressure on land for housing public service and facilities area	Ward wise proportional quantification classification
Access to basic infrastructure (road, electricity, water supply, sanitation, solid waste and telecommunication)	Availability of public facility infrastructures mainly,	Euclidian distance of infrastructure facilities derived from land use/land cover map
Access to service centre (school, campus, health post, police office, old age building, open space and recreational area	Easy access of commodity service, social service infrastructure and business facilities	Euclidian distance of service area derived from land use/land cover map
Strategic road network	Connectivity to major business & service area through public transportation	Euclidian distance of road derived from digital road layer
Environment factors		
Pollution (air &noise) quality	Consider living environment situation and availability of fresh air	Euclidian distance from the brick chimney, industrial site and strategic road with traffic volume
Greenery &recreation	Enhance the life quality managing park, open space, green belt	Euclidian distance from park, open space and recreational feature

Ranking criteria

Each criterion is then broken into rankings according to their weights inside the criterion's variable. To establish a link between current residential area conditions and other influencing elements or criteria, the multi-collinearity method is utilized to analyze the one independent variable highly correlated with one or more of the other independent variables, and the sub-categories are then categorized (Karna *et al.* 2021). Based on correlation values as a measure of priority, these subcategories were ranked. Using the fuzzy membership function based on spatial autocorrelation that helps understand the degree to which one object is similar to other nearby objects, the rank of subcategories is established by standardizing the priority values inside each criteria. Along with unsuitable as a restricted category due to restrictions, the rank of the subcategories ranged continuously from 1 to 9 in each category.

Computing weight of the criteria

In accordance with the advice of experts and local stakeholders, AHP a method is used to determine the weight of each criterion based on pairwise comparison with the scale of importance. Reciprocal pair-wise comparison were conducted based on the performance matrix. Each set of criteria in a pairwise comparison characterizes various attributes in accordance with the specific qualities (Saaty 1977, Shahabi & Hashim 2015). These qualities provide the explanation of the significant impact on residential land use for minimizing development cost for infrastructure development activities, maintaining socio-economic condition and densification of built-up area. The entries on the performance matrix use a 9-point rating system to rank each combination of criteria and relationship (Saaty 1980). The rating scale's reciprocals represent the values in direct contrast to one another for each of the different criteria (Table 3).After comparing each interrelated combination of criteria pair-by-pair using the AHP approach, the criterion's weight is determined using numerical numbers. Consistency ratio is used to evaluate weight estimation. The performance matrix is thought to have a limited acceptance level if the consistency ratio is less than 0.1; otherwise, the pairwise relationship of the criterion is rejected (Karna *et al.* 2021).

Table 3: Comparison rating scale

Intensity of importance	Description	Suitability class
1	Equal importance	Lowest suitability
2	Weak importance	Very low suitability
3	Moderate importance	Low suitability
4	Moderate to plus importance	Moderate low suitability
5	Strong importance	Moderate suitability
6	Strong to very strong importance	Moderate high suitability
7	Very strong importance	High suitability
8	Very strong to extreme importance	Very high suitability
9	Extreme importance	Highest suitability

(Source: Saaty, 1980)

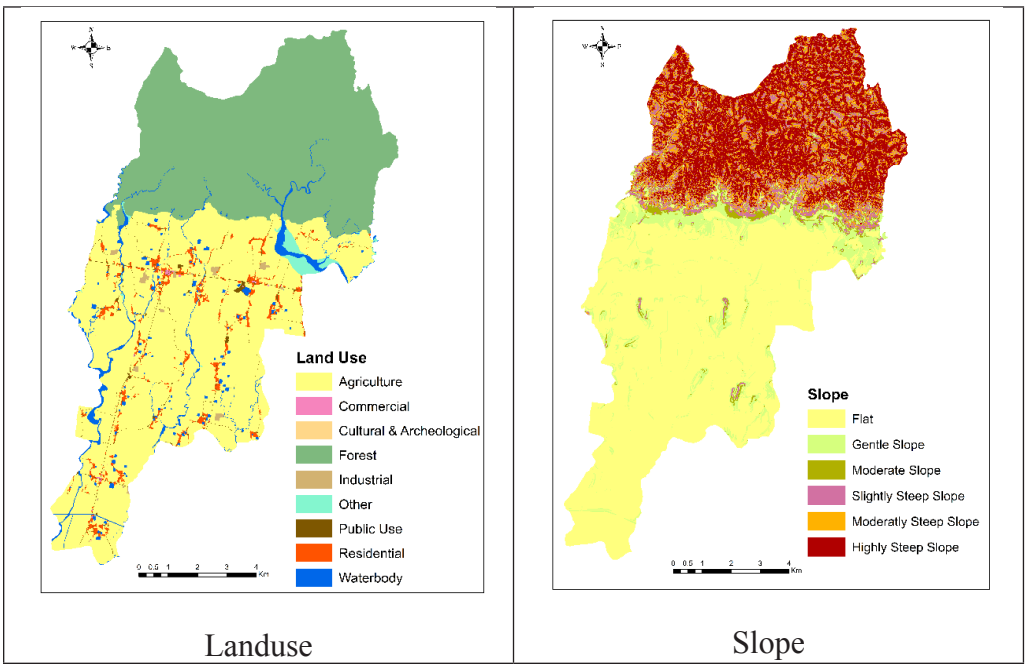
Computation of land suitability level

Based on the relationship between the acceptable performance matrix and the weight of the criteria, the sum of the factor weights is maintained to be 1 in weighted linear combination (WLC) technique (Eastman 2006). By dividing the weights supplied to each attribute factor by the scaled values given to the alternatives on those attribute classes of factor, then adding the results to get the total score for all attributes. Then, the weight and rank of influencing factors are converted into suitability index level in GIS using the weighted overlay function. According to the WLC result, the computed score categorizes the suitability index level. The greatest score signified a class that was very suitable, and the lowest score indicated an unsuitable piece of land. According to FAO, 1993, suitability index level is divided into two orders (suitable and unsuitable) into a total of five suitability classes scores range from 0 to 10 as: 10 being extremely suitable (S1), 8 to 9 being suitable (S2), 6 to 8 being moderately suitable (S3), 4 to 6 being marginally acceptable (S4), and less than 4 denoting unsuitable (N).

Results and discussion

Influencing criteria maps

The criteria maps were created using geospatial methods and shown in (Figure 2). Table 2 lists the effective criteria according to their significance in which the results of some criterion maps are described below.



Landuse Slope

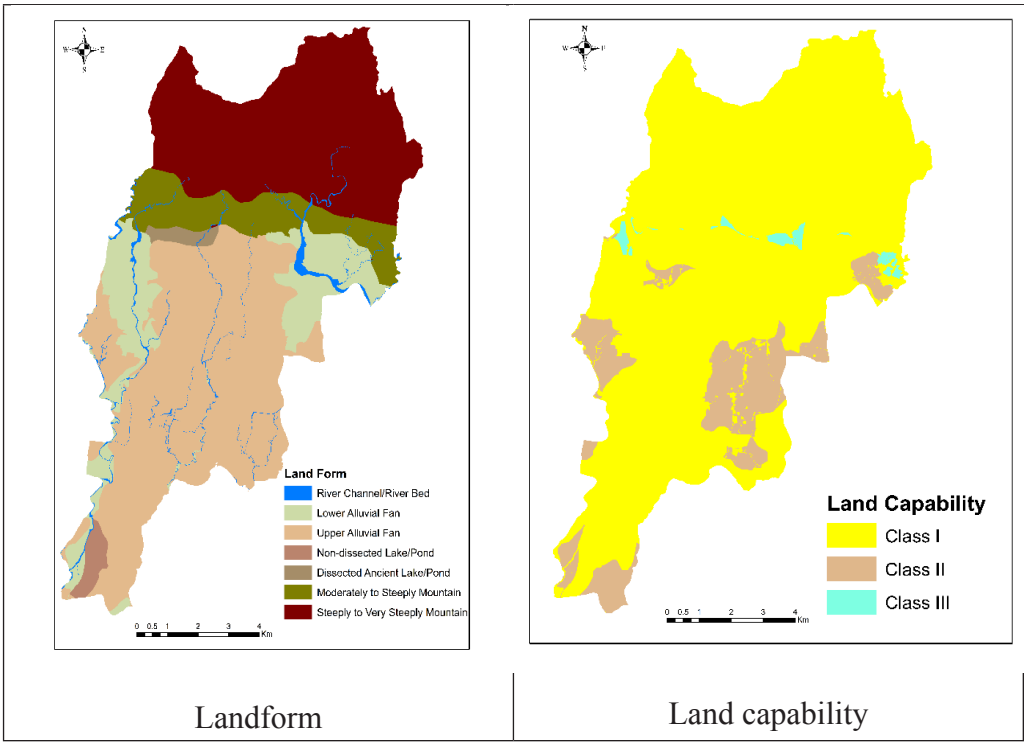


Figure 2: Influencing criteria

Land use: About 3 percent land of having 251 hectares in the municipality is covered with residential areas. The pattern of land cover where residential practices are explained by human-related variables. It is crucial for residential use to manage infrastructure development operations, minimize development costs, improve socioeconomic condition, and increase the built-up area density in sustainable way.

Slope: Flat slope is occurred about 53 percent then highly steep slope area in Siwalik region in northern portion having 22 percent extent that are vulnerable area for residential use. Only 6 percent coverage belongs to moderate slope area having 5.74 sq. km. Similarly, moderately steep slope covers 8 sq. km having 7.72 percent; gentle slope covers 8 sq. km with 7.17 percent, and slightly steep slope covers 6 sq. km with 5.71 percent of municipality extent.

Land form: In the Siwalik region, non-dissected lake ponds account for 43 percent of the land, with steep slopes accounting for 32 percent. The lower terrace, which has alluvial deposits, makes up 11% of the total area. Land form determines how earth

materials and land-forming processes interact to represent formation of landscape and managing terrain stability for development activities in residential area.

Land capability: Land capability Class I covers around 86 percent of the territory, followed by Class II in 12 percent of cases, and Class III in the remaining 2 percent. The concept of land capability depicts the carrying capacities of the soil in connection to the physical makeup of the land and soil formation. It also describes how to use agriculture effectively while adhering to specific restrictions and how to take the necessary steps to conserve land capacity. It is applied for conservation factor for preserving high fertile arable land.

Ranting criteria

Based on its priority level, each criterion's data is divided into subcategories. The subcategories are normalized into uniformly ranking scales with fuzzy membership functions and achieved in 1 to 9 values. The slope angles is reclassified into five groups such as less than 1, 1–5, 5–15, 15–30, and greater than 30 degrees. Likewise, proximity to settlement /business area is categorized into four classes as less than 200, 200-500, 500-1000, and greater than 1000 meters. Land use is categorized as agriculture, residential, commercial, industrial, forest, public use, cultural and archeological, waterbody, and undersigned other use. Proximity to infrastructure facilities is categorized into five groups as less than 200, 200-500, 500-1000, 1000-2000, and greater than 2000 meters. Similarly, proximity to service area are reclassified into five categories as less than 200, 200-500, 500-1000, 1000-2000, and greater than 2000 meters. Land capability is categorized into Class I, Class II, and Class III. Likewise, land system/form is categorized into non-dissected ancient lake, lower and upper alluvial fan, dissected ancient lake, river channel, and steeply to steeply slope. Proximity to strategic road network is reclassified into three categories as less than 200, 200-500, and greater than 500 meters. Similarly, proximity to greenery /recreation area into three categories as less than 500, 500-1000, and greater than 1000 meters. Furthermore, proximity to fault line is reclassified into five categories as less than 500, 500-1000, 1000-2000, 2000-5000, and greater than 5000 meters. Proximity to pollution is categorized into five classes as less than 200, 200-500, 500-1000, and greater than 1000 meters. Population density is reclassified into five classes as less than 200, 200-500, 500-1000, 1000-200, and greater than 2000 persons per square kilometer.

Weight criteria

In pair-wise relationships, various combinations of criteria are created and examined according to the influencing factors. The weight of each influencing factor is determined by using the AHP technique. The calculated pairwise weights are assessed with consistency ratio and found to be the value of 0.09 which is within the acceptable threshold limit. The computed weight of the influencing criteria is described in Table 5.

Table 5: Influencing Criteria Weight

S.N.	Criteria	Weight
1	Slope	18.72
2	Proximity to existing residential and commercial area	11.88
3	Proximity to service area	11.30
4	Land use	9.83
5	Proximity to infrastructure facilities	9.07
6	Population density	8.41
7	Proximity to strategic road	7.12
8	Proximity to greenery area/recreation	6.02
9	Geomorphology	5.01
10	Land capability	4.68
11	Proximity to fault line	4.37
12	Proximity to pollution (air/noise)	3.59
	Total	100.00

Suitable index map of residential use

The selected criteria's with its ranks and weights are used for preparation of the residential suitability map and shown in Figure 3. The municipality's residential suitability index map shows that suitable land makes up 527 hectares (5%) of the total area, and moderately suitable land makes up 4107.80 ha (38%). Correspondingly, the highly suitable land is occupied comparatively very low having 0.19 ha only. In both urban and semi-urban locations, the most favorable residential growth sites are found along major road network and its junction where as in rural areas, the most favorable residential growth sites are occurred surrounding existing communities.

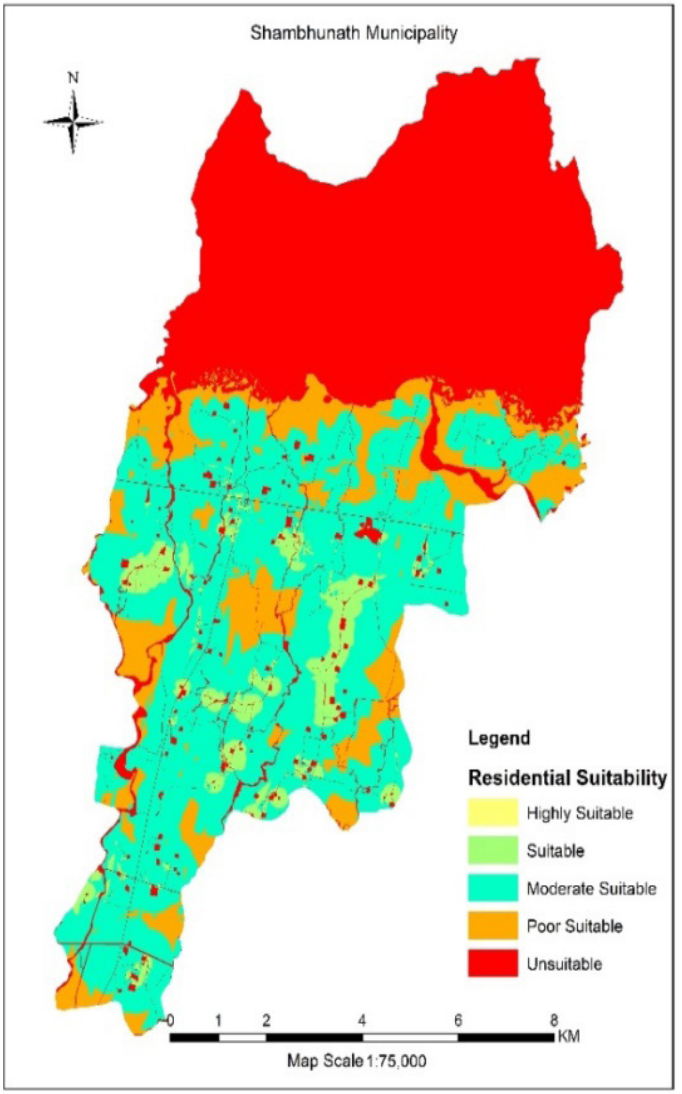


Figure 3: Residential suitability map

Conclusion

In the context of Sambhunath municipality, the factors for residential areas are established as identified in the local situation. These factors might be used in land use suitability assessments of potential residential area in different part of Nepal as well. The suitable residential growth areas is occurred mostly around the existing settlements

in rural areas, and along the major road network in urban and semi-urban areas. Also, GIS tool integrated with MCE-AHP is effectively applied in the process of analyzing the appropriateness of residential land for human habitation and serves as a planning tool and used in land use planning and land development. It provides a framework for residential land use analysis that could be appropriate and acceptable by community members and stakeholders.

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