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Site Suitability Analysis for New Residential Construction Site using GIS-based Multi-Criteria Evaluation Technique – A case study of Mahalaxmi Municipality, Lalitpur

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Abstract

Most cities in developing countries experience unplanned and haphazard built-up growth as a result of the intense strain of population, which opens the door to urban sprawl by encroaching on large parts of the natural environment. For this, selection of suitable places for residential construction by maintaining ecological balance has become inevitable part for proper urban planning. The goal of this work is to determine the best locations for future residential construction with the least impact on various natural features. It also calculates the amount of various types of suitability which will be transferred from various land use and land cover categories in the near future, which is a novel aspect of this work. Mahalaxmi municipality, Lalitpur, has seen a tremendous growth in built-up features after 2011. Five criteria in all have been used in the work's GIS-based multi-criteria analysis to identify the optimal locations for residential building construction. For determining the weight of criteria, Analytical Hierarchy process(AHP) has been used. Four groups have been created in the final site suitability map: most suitable, moderate suitable, less favorable and restricted region. As a result of this research, the ideal areas for residential construction projects in the near future will be identified, which will be useful for planners, stakeholders, and policy makers.

Keywords

Built-up growth, Urban sprawl, Multi-criteria analysis, Analytical hierarchy process

1. Introduction

Urban development, which can be characterized by changes in spatial characteristics and demographic patterns, is a critical and concerning issue [1]. It also refers to the growing significance of towns and cities as areas where people are concentrated. It is merely an increase in the category of urbanized land created by urban extension. Most of the cities around the world are facing the problem of urban growth though and it is more severe in developing countries like Nepal. It quickly became primarily unplanned built up and caused the open spaces of the natural environment, such as forests, agricultural land, and rural regions, to shrink. Urban sprawl is facilitated by these unplanned, disorganized, and chaotic swaths of built-up growth[2]. It is vital to identify suitable places for the new built-up development and proper usage of various land categories due to the uncontrolled growth of built-up or urban sprawling and unprecedented population rise[3]. Finding the optimum sites or locations for the proposed work while taking ecological sustainability and stakeholders' needs into consideration is the goal of multi-criteria analysis with the aid of a GIS platform. The best and most efficient technique to identify suitable regions is multi-criteria analysis for future urban expansion, which takes into account a variety of factors or parameters that affect one's decision to settle in a location and are given varying degrees of weight. It has become significant because this technique helps to reduce the time as well as effort to manually find out a suitable place and also filtering out the least suitable or not suitable places for the construction of new residential construction sites[4].

In order to determine the weights of a specific criterion in a multi-criteria analysis by pairwise comparison matrix table, Saaty introduced the Analytic Hierarchy Process, or AHP [5]. It is based on a hierarchical structure and allows for better and more transparent attention on each and every criterion. In the GIS-based MCA technique for effective urban land use planning and management, it is a widely utilized technique alongside GPS and remote sensing. AHP can standardize the criteria for land use suitability planning using straightforward mathematical calculations, and it can set the criteria in a structured manner based on the data that is currently available[6]. This makes it much simpler for social science researchers to conduct research because it only requires a small number of steps to determine the weights of a criterion and excludes the use of complicated mathematical calculations. Finally, GIS-based AHP can overlay each of the defined factors that contribute to location-based ranking determination[7]. These factors led to the selection of the AHP approach to determine the weights of various criteria in this work.

2. Literature Review

In various literatures, Multi-criteria analysis and the Analytic Hierarchy Process (AHP) have been employed to identify areas that are ideal for future built up development. For instance, [4] provided an overview of the literature on the use of AHP and GIS to analyze the appropriateness of land for future urban growth. All of the criteria were divided up into five classes, and the entire technique was provided piece by piece. Ullah and Mansourian evaluated eligible land for urban land use planning using a multi-criteria decision making model and AHP. For the investigation, they included a variety of variables, including physical, accessibility, and community aspects. They also explained why using the AHP approach to calculate these factors' weights were justified[8]. Weldu and Deribew used a multi-criteria evaluation technique, AHP, and GIS to create a suitability map for the identification of possible sites for the housing development. They used a total of ten criteria and clearly explained the entire AHP calculation [9] . Chougale et al., Kumar and Shaikh also employed the GIS-based multi-criteria evaluation approach in addition to the AHP method to find ideal locations for urban development, and they effectively communicated all of the AHP calculations. As AHP belongs to the subjective model, it is necessary to calculate the weightage for the pairwise comparison of AHP based on data gathered from various experts. However, the majority of the authors have skipped this step and instead assigned Saaty's nine point scale values based solely on their personal opinions. The AHP approach was used to carry out the current task, which was done in accordance with the recommendations made by the experts. The MCDM approaches have been widely used to choose agricultural sites, industrial sites, residential areas, landfill sites, wind farms, disaster zones, health centers, and educational centers in both developed and developing countries [10] [11] [12] [13] [14]. Urban land suitability using Multi Criteria Evaluation (MCE) integrated in Geographic Information System environment has been the subject of several articles. Chen (2014) used this technique to determine Regina, Canada's city Regina's suitability for land use. The use of GIS tools and numerical MCE approaches to find viable areas for urban development of a hill town, Nahan in India, was also demonstrated by Santosh Kumar and Ritesh Kumar (2014). Six criteria were evaluated in that study: slope, road proximity, land use, land values, soil variables, and geomorphology factors (Kumar and Kumar 2014). Similarly, Liu et al (2007) used comprehensive method of GIS and MCE to analyze the suitability of future land use according to specified requirements, preferences and predictions in Hanyang lake area located in Wuhan city. Urban land use planning using GIS and the multi-criteria analysis method was studied by [15] and applied to Lanzhou city and the area in northwest China. Zubaidah (2010) also utilized GIS and multi-criteria evaluation in Malaysia to find acceptable urban school locations. In her research, a set of school siting criteria and a school planning data model were developed using the assessment of decision makers and community perspectives. These tools were then utilized to construct a number of viable sites using a spatial analysis model. According to the aforementioned literature, both developed and developing countries have made extensive use of the Multi-Criteria Evaluation (MCE) technique to address the issue of land use suitability. Lack of GIS specialists, access issues for spatial software and hardware, and a lack of understanding among urban planners were some of the obstacles that prevented developing nations from implementing this useful approach to the same extent as developed ones. Despite the fact that urbanization has a detrimental impact on developing countries and that they must make significant efforts to reduce these consequences and ensure sustainable development. This view is reinforced by Umrikar (2013), who claimed that conducting a land suitability analysis for urban growth is essential for resolving the issue of land availability limits in the face of urbanization's rapid rise.

3. Research Methodology

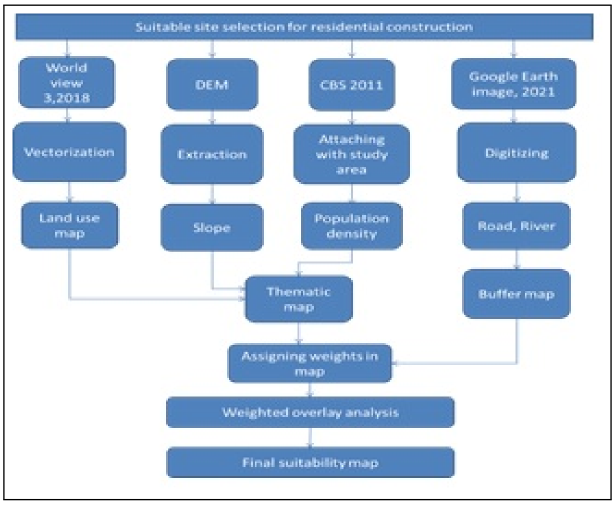

Figure 1: Flowchart of Multi-Criteria Analysis Process

3.1 Selection of criteria

The first stage in determining the ideal region to use for any purpose is to choose appropriate and meaningful criteria, while the ultimate choice of criteria also depends on the data that are available. Researchers choose different criteria for the appropriate location for built-up growth, but all of the criteria may be categorized into four main categories: accessibility, physical, socioeconomic, and environmental concerns. As these have been considered by the majority of scholars, accessibility and physical characteristics are the most important deciding factors, followed by environmental and socioeconomic considerations. For the purpose of identifying a suitable location for a residential development, this work has considered one accessibility factor (distance from road), two environmental factors (land use and land cover types and distance from river), one physical factor (slope), and one socioeconomic factor (population density). The identification of criteria for this work has been done by consulting with the experts (Urban planner, stakeholders of Mahalaxmi municipality) and also from literature review.

3.2 Calculating weightage by AHP

AHP or Analytic Hierarchy Process is a well-known and universally used subjective method to determine weights of criteria in multi-criteria decision-making technique. It can be used to find out weights for qualitative as well as qualitative data. It is based on interview by expert. They are asked to give a score on the basis of Saaty's 1 to 9 ratio scale through pair wise comparison. An expert's judgment is used to compare two criteria in order to show how much more one criterion influences another. A score of 1 must be supplied if two criteria are equally influential or important, and a score of 9 must be given when one criterion significantly influences another criterion in the comparison table (Table 1). After normalizing each value by dividing the actual value to its sum of column value, weights are derived by arithmetic mean method. To determine the degree of consistency of any expert's judgments, consistency ratio (CR) must be calculated after weights are determined. In order to demonstrate if the comparison matrix is consistent or not, Saaty has supplied an index. The formula for determining CR value is,

$$CR = \frac{CI}{RI} \times 100 \tag{1}$$

Where RI is the random inconsistency index of a randomly generated pairwise comparison matrix of rank 1 to 10 and CR is the consistency ratio (CR), CI is the ratio of consistency index . In the formula of consistency ratio (CR), CI is calculated by the following equation.

$$CI = \frac{\mu - n}{n - 1} \tag{2}$$

Where, CI is the consistency index, μ is the consistency vector's simple average, and n is the total number of criteria, According to the consistency ratio's design, if the value is less than 10%, the matrix is considered to be adequately consistent and is acceptable; nevertheless, if it is greater than 10%, it is a symptom of inconsistent judgment.

Table 1: Fundamental scale of absolute numbers for AHP. Source: Saaty, T.L.

Rating Scale	Definition
1	Equal Importance
2	Weak
3	Moderate Importance
4	Moderate Plus
5	Strong Importance
6	Strong Plus
7	Very Strong
8	Very, very strong
9	Extreme Importance

3.3 Preparation of criteria maps

After selecting criteria for suitable site for residential construction, different thematic maps have been prepared. Total five thematic maps have been prepared in a GIS platform as the selected criteria are nine which are mostly in vector data format.

3.4 Integration of criteria maps and final suitability maps

After assigning weights, these criteria maps are then integrated by using weighted overlay tool in GIS platform to get the final suitability map of residential construction sites.

4. Result and Discussion

The identification of acceptable locations for adequate sustainable urban growth has become a vital and important activity for these cities as practically all of the cities in emerging nations are expanding haphazardly. Five parameters were used in the additional study to determine a suitable site, and the combination of these five criteria helped to identify several potential locations for the development of residential construction sites in the future.

4.1 Accessibility factor

The main requirements for setting up new building, whether for residential or commercial uses, are easy transportation around the entire city and greater connectivity with other locations. In this sense, accessibility to roads and airports is crucial, but both have an impact on the frequency with which individuals use this service. People prefer to settle in areas with better road connectivity since building new roads is expensive and the government only builds them where there are many settlements. In this work, to find out the accessibility in the entire area, roads which are accessible to public transportation has been taken into account. Field verification has been done to find out the accessibility of public transportation in these roads.

Maps of buffer zones with an interval of 250 meters have been created in order to determine improved accessibility and the optimum placements to the existing roads (Fig. 1), and their significance for built-up expansion has been determined by ranking.

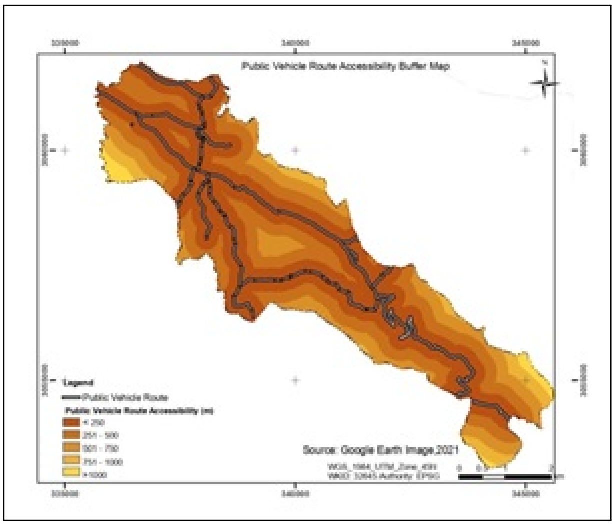

Figure 2: Public vehicle route accessibility road buffer map

4.2 Environmental factors

Finding appropriate locations for any development work requires consideration of environmental variables. Though it's not always practicable, the majority of construction projects have been carried out while protecting the environment. Two environmental parameters, including land use, types of land cover, and distance from rivers, have been used in this study to pinpoint the best locations. A map of land use and cover has been created. It has been categorized into developed land, aquatic areas, vegetation, agricultural land, and wasteland, according to the NRSA guideline from 2006.Existing built-up land has been classified as a restricted category for further research because no more construction of this kind can be done there in the future, even though vertical growth is permitted. However, the major goal of this work is to identify unoccupied spaces. Water bodies are similarly classified as limited land, whereas agricultural land and wasteland have been given precedence for finding acceptable locations for buildings.

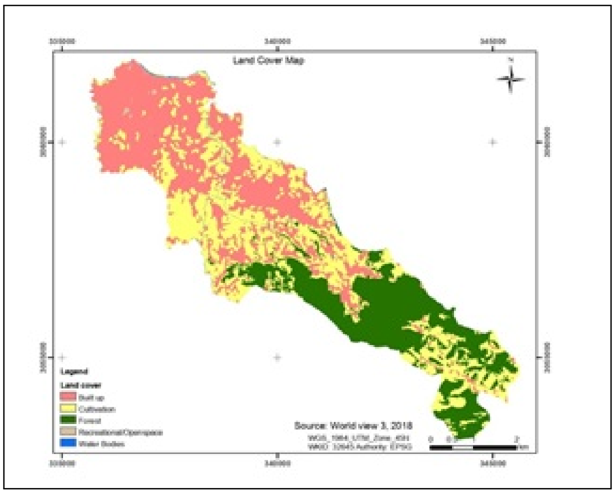

Figure 3: Land Cover Map

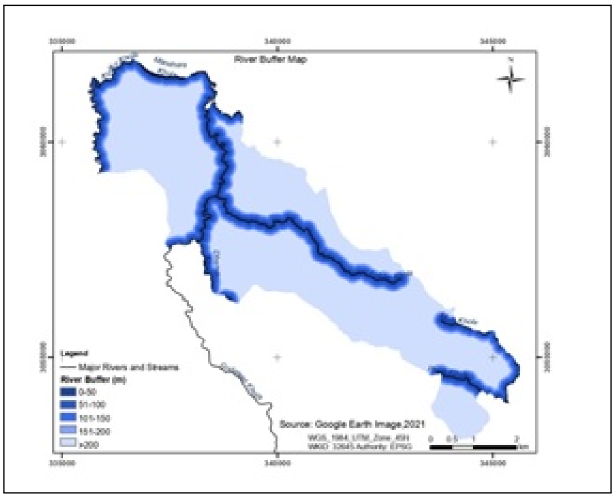

Figure 4: River buffer Map

Mahalaxmi municipality area lies in Kathmandu valley, consequently, there are more rivers overall and they are perennial in nature. Although there is a lot of rain in this area during the monsoon, which makes the rivers more raging, the likelihood of a flood occurring here is lower because it is in a valley region with an average height of 1330 m. Godawari and Hanumante, two significant rivers, run through this region. To assist in determining the best location, buffer zones 50 meters away from current water bodies have been constructed using a rating system from 1 to 5. The region right next to the river is scored as 5, which means it is highly inappropriate, and the area located beyond 250 m, which is ranked as 1, which indicates it is very suitable, because people desire to live in a somewhat higher location with a minimum distance from the river to avoid the flood problem. The municipality's local engineer was consulted before this 50-meter buffer zone was established.

4.3 Physical factor

The primary physical criteria for establishing settlements, particularly on mountainous terrain, are slope. Lands with steep slopes are not suited for building of any kind since they are risky and expensive. Consequently, construction can be done on mild inclines. Despite being in open spaces, these elements hardly have an impact on the development of new constructions. Before undertaking significant built-up projects like retail malls, hotels, townships, high-rise structures, and apartments, it is important to carefully evaluate the geological conditions in the area. This is particularly important for the study area because it is located in an area with a high risk of earthquake according to Nepal's seismic zones and has experienced a tremendous increase in high rise structures, townships, and shopping malls. Five slope zones, ranging in elevation from less than 10 to more than 25, have been assigned to the entire study region. Maximum area is found in the less than 10 slope zone, while only the riverbanks display the more than 25 slope zone, according to a classified slope map. Slopes of less than 10 degrees are ranked one while those of more than 25 degrees are ranked five.

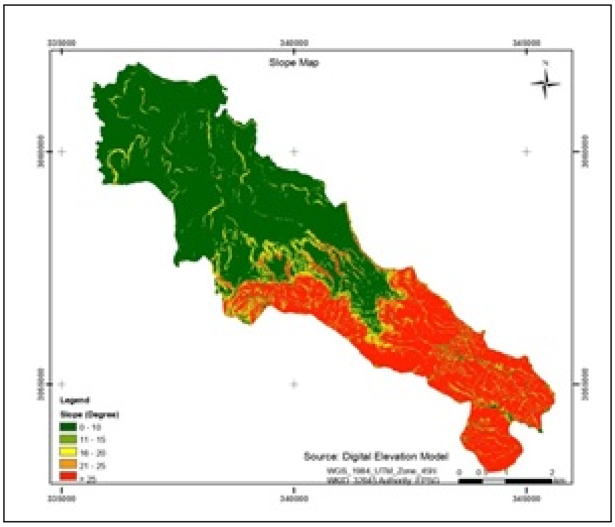

Figure 5: Slope Map

4.4 Demographic factor

Humans always locate a residence that is socially advantageous for them. Due to cultural closeness, the same social group of people frequently live close to one another. But in quickly expanding cities, it is not always feasible. Few individuals want to buy in the city at any price to take use of the civic amenities, while most people want to buy a plot at a lower price that typically lies beyond the city center. But it can be claimed that, for the general populace, land price is a determining element to set up new dwelling building. In addition to these, population density and housing density are crucial elements that affect newly built-up areas because most people choose to live in low- to medium-density areas over crowded ones. This study area shows a tremendous population growth in last decade. It was 62172 in the year 2011 which has turned to almost double in the year 2021, which is 118710, according to Central Bureau of statistics[16]. Population density in administrative wards ranges from 6.02 people per hector in ward number 10 to 141.81 people in ward number 2. The entire region is divided into five groups based on population density for this project (Fig 6) that ranges from fewer than 10 to more than 80 individuals per hector. The majority of people prefer to live in low-density areas, so less than 10 categories have been allocated ranks 1, with 1 being the most ideal for new residential building and 5 being the least suitable.

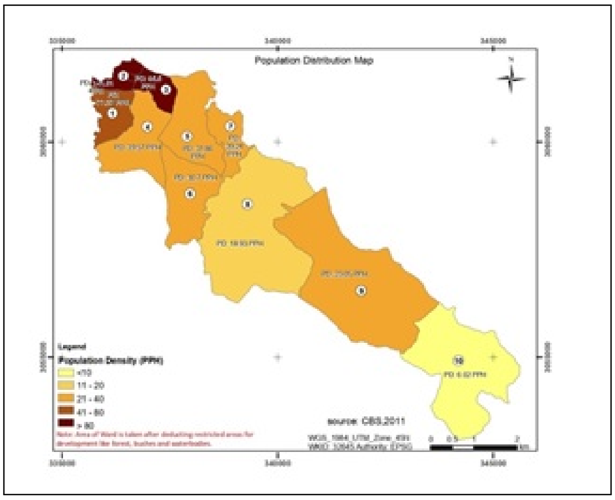

Figure 6: Population Density Distribution Map

4.5 Pairwise comparison matrix and normalized pairwise comparison matrix

As we have taken five criteria for the analysis, so, a total of 10 questions have been asked to the experts. Then, the values have been filled up by two aforesaid experts following Saaty's 9 point scale. The two experts' combined scores were selected as the average for further study. There are 25 boxes in the pair-wise comparison matrix table, and we have filled 10 of them with the information from the interview. Due to the equal influence of the same criteria, the diagonal value will always be 1. The reciprocal value of the corresponding major value is then used to fill in the rests. The second step after creating a pair-wise matrix table to determine each criterion's final weight is to create a normalized pair-wise comparison matrix table. Each value in the pair-wise matrix table was divided by the corresponding total column value to produce the normalized value. Then the arithmetic mean approach has been applied row-wise to determine the weight of each criterion. Road has the most influence on where individuals choose to build their homes, followed by land use, population density, and distance from rivers. Slope has the least impact. The normalized pair-wise matrix table makes it abundantly evident that accessibility is a key consideration when making decisions about future built-up areas.

Table 2: Pairwise comparison matrix by AHP (Expert 1)

Criteria	DR	LU	DFR	SL	PD
DR	1.000	2.000	7.000	8.000	3.000
LU	0.500	1.000	4.000	5.000	2.000
DFR	0.142	0.500	1.000	2.000	0.250
SL	0.125	0.200	0.500	1.000	0.250
PD	0.333	0.500	4.000	4.000	1.000

Table 3: Normalized pairwise comparison matrix and computation of criterion weightage (Expert 1)

Cate-gory	DR	LU	DFR	SL	PD	Weig-htage	Ra-nk
DR	0.47	0.50	0.42	0.40	0.46	0.453	1
LU	0.23	0.25	0.24	0.25	0.30	0.258	2
DFR	0.06	0.06	0.06	0.10	0.03	0.066	4
SL	0.05	0.05	0.03	0.05	0.03	0.045	5
PD	0.15	0.12	0.24	0.20	0.15	0.176	3
Sum	1.00	1.00	1.00	1.00	1.00	1.00	

LU Land use land cover, PD Population density, DFR River, DR Road, SP Slope

It is necessary to check the degree of consistency of the judgments. Before going to calculate the value of CR, the value of consistency index (CI) and μ should be calculated.

CI = (μ-n) / (n-1) = (5.09468-5) / (5-1) = 0.02367

CR = CI / RI * 100 = 0.02367/1.12 * 100 = 2.1133%

The result of consistency ratio (CR) is less than 10%, so it can be said that the judgment is consistent and it is allowed for the further analysis.

Table 4: Pairwise comparison matrix by AHP (Expert 2)

Criteria	DR	LU	DFR	SL	PD
DR	1.000	1.000	6.000	8.000	3.000
LU	1.000	1.000	4.000	6.000	2.000
DFR	0.166	0.250	1.000	2.000	0.250
SL	0.125	0.166	0.500	1.000	0.200
PD	0.333	0.500	4.000	5.000	1.000

Table 5: Normalized pairwise comparison matrix and computation of criterion weightage (Expert 2)

Cate-gory	DR	LU	DFR	SL	PD	Weig-htage	Ra-nk
DR	0.38	0.34	0.38	0.36	0.46	0.387	1
LU	0.38	0.34	0.25	0.27	0.31	0.312	2
DFR	0.06	0.08	0.06	0.09	0.03	0.068	4
SL	0.04	0.05	0.03	0.04	0.03	0.042	5
PD	0.12	0.17	0.25	0.22	0.15	0.187	3
Sum	1.00	1.00	1.00	1.00	1.00	1.00	

LU Land use land cover, PD Population density, DFR River, DR Road, SP Slope

CI = (μ-n) / (n-1) = (5.1013-5) / (5-1) = 0.02532

CR = CI / RI * 100 = 0.02532/1.12 * 100 = 2.2614%

Since the consistency ratio (CR) result is less than 10%, the judgment can be deemed consistent and further investigation is permitted.

4.6 Average weight of criteria

For the preparation of final suitability map, the average weight of the criteria as given by two experts is taken. Normalization is done for the calculation of average weight. The criteria weight used is given in the table below.

Table 6: Average weight of criteria

Criteria	Avg Weightage (%)
Distance from road	42.075
Land Use	28.555
Population Density	18.195
Distance from river	6.73
Slope	4.415

4.7 Analysis of final suitability map

The final weights for each criterion have been determined, thematic and buffer maps have been created in the GIS platform. All of the maps have been integrated, the sub-layers of each map have been reclassified to convert to a scale of 5 for land suitability, and suitable sites for future built-up development have been identified using a weighted overlay analysis tool (Das, Bhattacharya et al. 2013). Four categories—restricted or not suitable, highly suitable, moderately suitable, and less suitable— have been assigned to the final suitability map. 8.62%, or 2.27 sq. km, No such new development is permitted within the region that falls under the restricted zone, which includes existing built-up land and water bodies. The 14.66% or 3.86 sq. km. of the very appropriate zone is substantially larger than the limited zone. The majority of the highly appropriate zone is made up of wastelands and agricultural land. The area with the highest percentage, 48.59% or 12.79 sq. km, is somewhat acceptable region. The less desirable area is 28.07 or 7.39 sq. km.

Table 7: Different suitability categories and their area

Suitability Categories	Area (in sq.km)	Area (in %)
Highly suitable	3.86	14.66
Moderately suitable	12.79	48.59
Less favorable	7.39	28.07
Restricted	2.27	8.62

Table 8: Summary of criteria, sub criteria, ranking and weightage

S.N	Criteria	Public Vehicle route accessibility buffer (PPH)	Rank-ing	Weig-ht (%)
1	Public Vehicle Route Accessibility	$\leq$ 250 250−500 500−750 750−1000 $\geq$ 1000	5 4 3 2 1	42.08
		Land use	Score	Weight
2	Land Use	Built up Cultivation Forest Recreational Water bodies	3 5 0 3 0	28.56
		PPH	Score	Weight
3	Population density	$\leq$ 10 10−20 20−40 40−80 $\geq$ 80	5 4 3 2 1	18.20
		River Buffer (m)	Score	weight
4	Distance to River	0−50 50−100 100−150 150−200 $\geq$ 200	1 2 3 4 5	6.73
		Slope	Score	weight
5	Slope	0−10 10−15 15−20 20−25 $\geq$ 25	1 2 3 4 5	4.42

5. Conclusion

In the rapidly urbanizing world of today, most emerging-nation cities see a chaotic, irrational build-up of population. It is now required to do a suitability study or acceptable site selection for proper urban development due to the problem of haphazard growth inside a constrained area. This issue can be solved by utilizing the simple and cost-effective GIS-based multi-criteria analysis with analytic hierarchy process, which can identify a number of appropriateness categories in a selected area. The system was successfully tested in determining the optimum land suitability for residential construction in Siliguri (India), Hong kong, Sana city (Yeman) and various other parts of the globe.

Mahalaxmi municipality has been chosen to identify the finest areas for future built-up development with the aid of specialists due to the enormous population expansion in Kathmandu and its surrounds. The core city area of Kathmandu valley provides fewer opportunities for people to settle. Thus people are willing to settle in the outskirts of Kathmandu valley. Hence the population of the municipalities like Mahalaxmi, Kirtipur, Budanilkantha has increased this decade which is testified by the preliminary population census report of 2021.

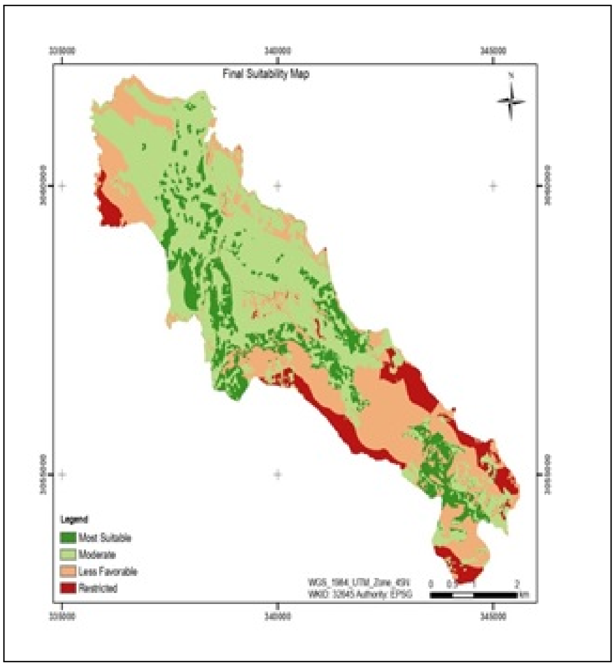

Figure 7: Final suitability Map

So this research calculates the quantity of various types of suitable land that will be transferred from various land use categories in the near future which makes it novel and innovative. This research reveals that just 14.66% of the area has been identified as extremely suitable territory, which has been scattered widely and some distance from the central city. This area includes mostly the agricultural land and the waste land. For the development of residential construction site, waste land should be given more priority than the agricultural land. The largest area has been defined as moderately acceptable land, which is 48.59% for new building. This location will be most beneficial for residential use because it is less expensive than the very appropriate category. Despite the fact that the AHP technique has been used in numerous academic works to establish how different criteria should be weighted, this study has run across some restrictions. Using AHP becomes practically impossible when there are more than nine criteria since pairwise comparisons demand n (n-1)/2 comparisons. Another problem is that we cannot complete the pairwise comparison matrix by adding more decision-makers or experts because doing so will confuse the weighting system of the matrix. Therefore, we are limited to including two experts from various fields in this research. Along with these advantages, this type of regional planning work is helpful for planners, policy makers, stakeholders, etc. since it enables them to identify areas where intense development initiatives can be carried out in a straightforward and efficient manner. The output of this research can be used by Mahalaxmi municipality for various purpose. The land which is identified as restricted in this research, can be used for some other purposes by the municipality rather than using it for built up development. Municipality can encourage people to settle in the highly or the moderately suitable area by revising the land values in such areas or by introducing certain scheme. Hence the research has found its own way of contributing to the overall planning and development of Mahalaxmi Municipality.

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