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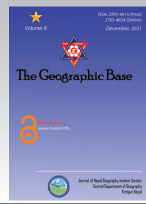

Land Suitability Analysis for Potential Agriculture Land Use in Sambhunath Municipality, Saptari, Nepal

Bikash Kumar Karna [1, 2], Shobha Shrestha [1, *], Hriday Lal Koirala [1]

[1] Central Department of Geography, Tribhuvan University, Kathmandu 66613, Nepal
[2] Department of Survey, Government of Nepal, Kathmandu 66613, Nepal
*** Corresponding E-mail:** shova216@gmail.com

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Abstract

Rapid and unplanned urbanization and haphazard infrastructure development causes pressure on the finite land resource and there is urgent need to preserve the arable land for food security. Land suitability analysis is a technique in which the land quality assessment is performed through interpretation of land properties for allocation of lands for particular use. The present paper attempts to conduct a land suitability analysis to determine the potential sites for agriculture land use in Sambhunath municipality of Saptari district. The criteria/ factors for the land suitability analysis were identified through literatures and modified in the local context through expert opinions and focus group discussions. The evaluation of agriculture land is accomplished using Analytic Hierarchy Process (AHP), Multi-Criteria Evaluation (MCE) and Geographic Information System (GIS). Agriculture suitability index was developed and optimized qualitatively through the strength, weakness, opportunity and threat (SWOT) analysis. Finally, potential agriculture suitability index map is prepared. The analysis shows almost 3139 ha (29%) lands as

highly suitable and 3001 ha (28%) of moderately suitable agriculture land within the municipality. Almost all the suitable agriculture land is located at low land with flat terrain to gentle slope having high natural fertility and mainly in land capability classes I and II. The unsuitable and poorly suitable agriculture land is occupied in the undulating areas and hilly terrain of the Siwalik hill. The study found the GIS tool integrated with MCE-AHP useful in land suitability evaluation process and anticipated that it could act as the planning tool to allocate lands in land use planning for sustainable agricultural practices.

Introduction

Land is one of the basic natural resources on the earth surface for human beings. It is a fundamental factor for the production of food that supports the human life (FAO, 1995). Agriculture land refers to the land area that devoted to agriculture production including arable land for permanent crop land, pasture or range land to support livestock farming, and abandoned land. Globally agricultural land area covered approximately 5 billion hectares or 38 percent of the global land surface whereas in Asia it was 34 percent of the continental extent (FAO, 2020). The population of world is increasing whereas the global per capita cultivatable agriculture land is decreasing. The per capita cultivable land in Asia was 0.21 hectare in 2016 which decreased to 0.13 hectare in 2020 (FAO, 2020). In Nepal, agricultural land covers almost 3.68 million hectare (MoFE, 2018) with 28 percent areas of the country in which 21 percent are cultivated and 7 percent are uncultivated land (CBS, 2013). However, the recent study of Forest Research Training Centre (FRTC) have identified almost 22 percent areas of the country under cultivation (FRTC, 2019; Timilsina et al., 2019) with a per capita of 0.12 hectare in 2019.

Land Suitability Analysis (LSA) is a GIS based process (Jafari & Zaredar, 2010) that applied in the selection of the suitable site for different objectives (FAO, 1976; Pramanik, 2016) and purposes for specific land use. LSA process identifies the area having intrinsic characteristics as suitable or unsuitable; that encounter to the inherent and potential capabilities (Bandyopadhyay et al., 2009; Pramanik, 2016). In this study, LSA is used for land quality assessment through interpretation of land properties for allocation of agriculture land under land use planning. Land quality assessment applies to measures the degree of appropriateness of land for potential land use based on land requirement and its quality (Pramanik, 2016). Multi-criteria evaluation (MCE) is a decision-making tool and used in LSA for handling large amount of spatial information. MCE technique is conducted on the basis of the decision maker's own choice, criteria, weights and assessments of achieving the objectives (Malczewki, 1999). Analytic hierarchy process (AHP) is extensively utilized in land suitability using multi-criterion evaluation in decision making for the various fields. It is used to determine the weight of factors/parameters on pairwise comparisons based on their relative significance (Miller et al., 1998). Further, MCE based AHP has been widely applied in solving complex problems having various parameters across different levels through interaction among these parameters in common characteristics (Tiwari et al., 1999).

Geospatial techniques are utilized for identification of potential cultivated land considering different criterion to prioritize the suitable agricultural lands for specific crop production (Pramanik, 2016). The identification of suitable sites of agricultural land requires to consider the geophysical, topological, climatic and environment situation (Bandyopadhyay et al., 2009; Feizizadeh & Blaschke, 2012; Kamkar et al., 2014; Pramanik, 2016) as parameters. In LSA, land use/land cover (LULC) relevant with environmental and geographical data is considered as parameter to determine the suitable agricultural land (Deep & Saklani, 2014; Duc, 2006). Land use, soil type, elevation, slope, aspects, soil moisture, geology, drainage and distance from road are used as parameter in land suitability model for agriculture practices in Darjeeling hilly areas (Pramanik, 2016). Site suitability assessment for potential agricultural development is conducted with physiographic data, climatic (rainfall and temperature) data (Wang, 1994; Pramanik, 2016), physical and chemical properties of soil (depth, moisture, texture, and fertility) as well as physical information such as slope, accessibility and source of irrigation facilities etc. GIS model based on fuzzy set membership function is designed for land quality suitability analysis for a cropping land including three topographical variables as elevation, slope and aspect to derive land suitability index (Baja et al., 2002). MCE-AHP method is utilized in quantitative evaluation for allocation of suitable agricultural land and considered as auspicious process (Chen et al., 2010; Akinci et al., 2013; Khahro et al., 2014). Nowadays, GIS tools and techniques are applied for preparation of various maps that used in the site suitability model (Xu et al., 2012). Integration of GIS, MCE and AHP method are considered as decision support system to generate land suitability maps for agricultural development (Khahro et al., 2014). GIS-MCE-AHP based agricultural land suitability evaluation (ALSE) model is used in determining suitable agricultural land to rubber crops considering geographical, climatic, proximity and socioeconomic factors in Malaysia (Ahmed et al., 2016). These land suitability models could be accomplished by quantitative analysis techniques using limited influencing criterion factors.

In Nepal, development of agricultural land use has a great potentiality for its favorable situation mainly in Tarai region (low land having flat to sloping terrain varies up to 3 degree) and alluvial depositional plain surrounding to river channel in valley and hill area. The internal migration has been taking place from Mountain and Hilly regions to Tarai region mainly in the urban and semi-urban areas along the east west highway. Likewise, haphazard infrastructure development and unplanned settlements could be found in the fertile arable agriculture land. The land issues for increasing population could only be fulfilled by increasing the productivity of land (Mandal, 2013). The increasing agriculture practices could improve the rural economy, promote the diversification of poor farmers as well as prevent the internal migration from hilly areas to the plain lands (Boori et al., 2014). Further, the real estate investors have fragmented the agriculture land for housing and land development towards urbanization (Devkota, 2012) and other purposes. The conversion of agriculture land into concrete structure has been rapidly increased and directly affected on agricultural production (Timilsina et al., 2019). Rapid land development through unplanned urbanization and haphazard infrastructure development creates pressure on the finite land resource, and need the conversion of arable agriculture land for agricultural activities and secure food security to growing population in future. In this context, the present study is an attempt to conduct land suitability analysis in order to identify the potential sites for agriculture use. It also aims to select the parameters in local context for land suitability analysis of cultivation land under land use planning.

Methods and Materials

Study area

Shambhunath municipality located in Saptari District of Province 2 has been chosen as the study area (Figure 1). It was upgraded into municipality on 18th May, 2014. The elevation of the municipality ranges between 81m to 443m above mean sea level (Karna et al., 2021). The extent of municipality is 108.46 km^2 with 12 wards as its sub-units. The municipality office is located at Kathauna Bazar. The municipality falls under Indo-Gangetic Plain and lower Siwalik region. The municipality has comparatively weak geologically formation with alluvial plain in southern part, fine to moderate gained particle mainly coaly sediment material in middle part, and course sediments of gravel and large gained particles in northern part. The municipality falls under subtropical region with the average annual temperature of 24.5°C and a precipitation of 500 mm. The population of the municipality was 38018 with household size of 5.21 in 2017 (MoFAGA, 2018) and a population density of 351 persons per square kilometer.

Data used

(Table. 1) show the data used, sources, and method for generating influence criterion map to use in the agriculture site suitability analysis.

Similarly, primary data were generated from expert interview and two focus group discussions. Nine key land use professionals from different agencies were involved on indepth-interview. Similarly, 43 persons as respondent were represented in focus group discussion meeting held at Kathauna Bazar and Arnaha Chowk.

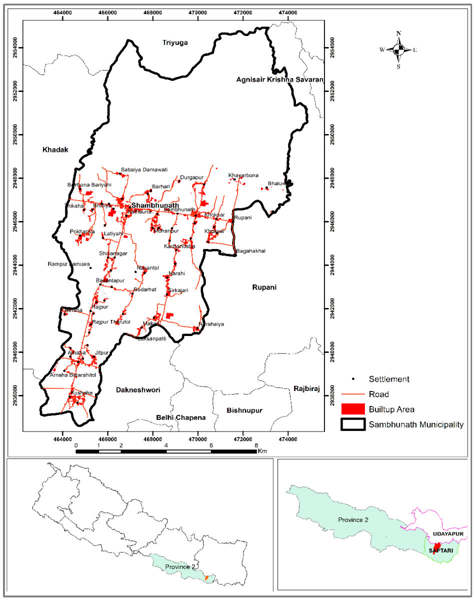


Figure 1. Location map of Sambhunath municipality

Table 1. Data used, sources and methods for preparing maps

Criteria	Data source	Year	Mapping method
Physical Factors			
Slope	Survey Department	1996	Hydrological DEM derived from topographical data and converted into slope with surface analysis
Geology	Department of Mine & Geology	1986	Conversion of analog graphical map into digital polygon and raster layer
Land Form	National Land Use Project	2016	Rasterization
Climatic factors			
Temperature	Department of Hydrology & Meteorology	2003-2018	Interpolation using Kriging
Rainfall	Department of Hydrology & Meteorology	2003-2018	Interpolation using Kriging
Soil characteristics factors			
Natural fertility		2016	Derived from land capability data and rasterization
Soil moisture	National Land Use Project	2016	Derived NDWI index from satellite image
Conservation factors			
Soil types	Survey Department	2016	Rasterization
Land capability	Survey Department	2016	Rasterization
Soil erosion		2021	Spatial modeling using RUSLE model
Human activity factor			
Land Use/ Land Cover	National Land Use Project	2017	Maximum likelihood based supervised classification from satellite image
Proximity to water surface		2017	Derived from land use/land cover map

Selection of criteria

At first, the criteria for agriculture land suitability were identified from the review of literatures. The identified criteria were modified in the local context through interaction with stakeholders and planners (expert interview and focus group discussion). The influencing criteria for agriculture development covers five categorical factors related to physical, climate, soil characteristic, conservation, and human activity variables (Table 2.).

Table 2. List of criteria

S. N.	Criteria	Description
1	Slope	For managing overall ecosystem of terraces and improvement of land and water resources
2	Soil fertility	Availability of soil nutrients that need to crop growth process
3	Land use	Existing condition for agriculture land and different land use
4	Land capability	Capacity of land in terms of arability for different crop requirement
5	Soil moisture	Sufficiency water contains for crop development process
6	Soil type	Soil taxonomy and its age containing soil texture, organic carbon, biological material and other physical aspect
7	Soil erosion	Control management that control land quality and soil degradation
8	Rainfall	For healthy crop growth through regular pattern of rainfall to control moisture contents in soil
9	Geomorphology (land form)	Interaction between land form and earth materials for managing surficial water systems
10	Proximity to water source	support ground water level and provide source aquifer system and availability of irrigation facilities
11	Temperature	Determine the variability of plant productivity and duration of harvesting period
12	Geology	Support availability of surface water for crop development

Standardization of criteria rank

Each criterion is further categorized into its ranks based on their priorities within the criteria's variable. Multi-collinearity method is used to establish correlation between present situations of agriculture land use with variable influencing criteria and further categorized in to sub-categories. These sub categories were rated based on the correlation values as its priority level. The priority values of sub-categories are standardized using the fuzzy membership function for its rank. The rank of the sub-categories varied between 1 to 9 in continuous interval with unsuitable as restricted based on the constraints limit.

Determination of criteria weight

AHP technique is used to identify the importance of competing criteria and used to calculate the weight of each criterion with a scale of importance in consultation with expert's opinion and interaction of local stakeholder. A performance matrix is generated through reciprocal pair wise comparison. In pairwise comparison, each combination of criteria characterizes different attributes based on the specific characteristics (Saaty, 1977; Shahabi & Hashim, 2015). These characteristics explain the substantial influence on the productivity, feasibility, or sustainability for the agricultural land use practices. Each combination of criteria relationshipis ranked with a 9-point rating scale in the entries on the performance matrix. The reciprocals values of rating scale represent the value in inverse comparisons of one another criteria (Table 3.).

Table 3. Pair wise comparison rating scale (Saaty, 1980)

Intensity of importance	Description	Description
1	Equal importance	Two activities contribute equally favorable
3	Weak importance of one over another	Experience and judgment slightly favor one activity to another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	When compromise is needed

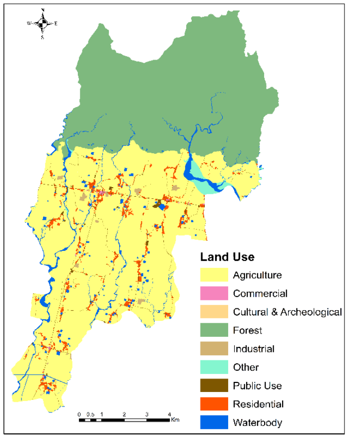
The weight of criterion is computed in numerical values after pair wise comparison of all interrelated combination of criteria in AHP method. Estimating weights are tested in terms of consistency ratio. If the consistency ratio is within 0.1, it is considered as limited acceptance level of the performance matrix; otherwise rejected the pairwise relationship of criterion. Finally, the weight of the criteria is computed based on acceptable performance matrix relationship and maintains the sum of factor weights sum to be 1 that meet the requirement of weighted linear combination (WLC) procedure (Eastman, 2006).

Computation of land suitability level

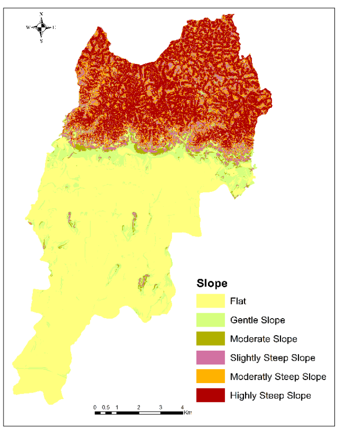
Land suitability level is computed from the weight and rank of influencing factors in GIS through weighted overlay function using WLC algorithm by multiplying the weight assigned for each attribute factor by the scaled value given to the alternative on that attribute classes of factor, and summing the products over all attributes value as score. Based on the WLC result, suitability index level is categorized on the computed score. The highest score represented the highly suitable class and lowest score as unsuitable land. Suitability index is divided into five levels of suitability classes: A score of 9-10 for highly suitable (S1); 8-9 for suitable (S2); 6-8 for moderately suitable (S3); 4-6 for marginally suitable (S4); and less than 4 for unsuitable (N) (FAO, 1993). Thus, generated suitability map of agriculture land is qualitatively assessed through SWOT process with the strength and opportunity, incorporating weakness and minimizing threats in land allocation process to determine the potential site for agriculture land use.

Results and Discussion

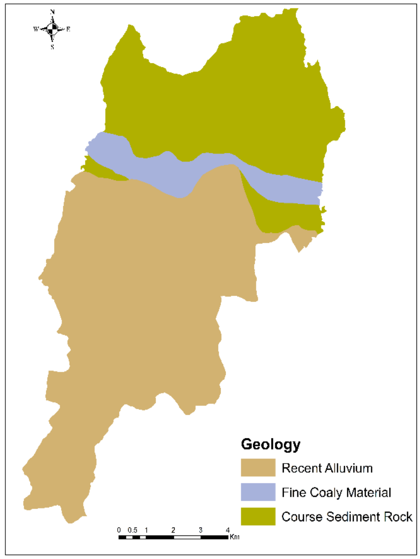
The maps produced using geospatial techniques are presented in (Figure. 2).



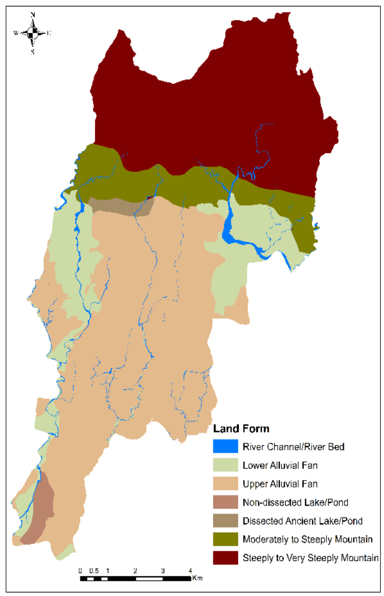
(a) Land Use



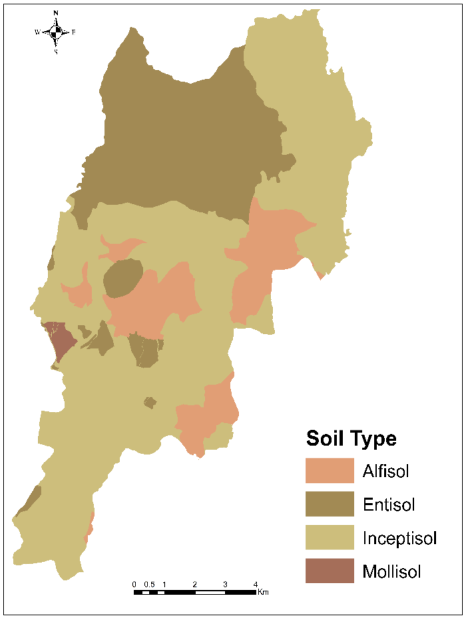
(b) Slope



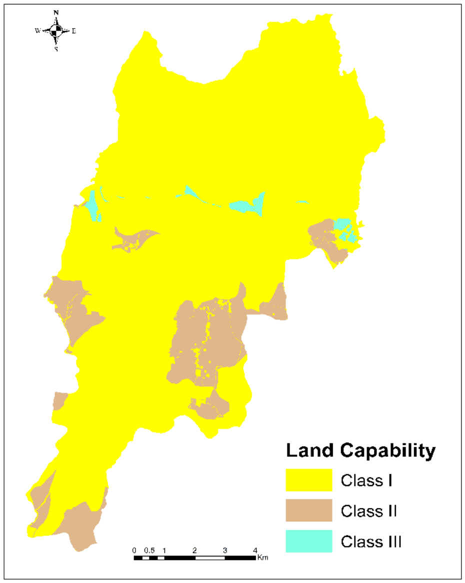
(c) Geology



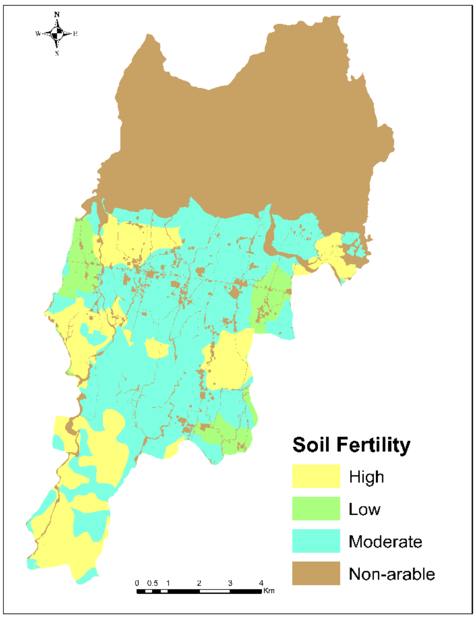
(d) Land Form



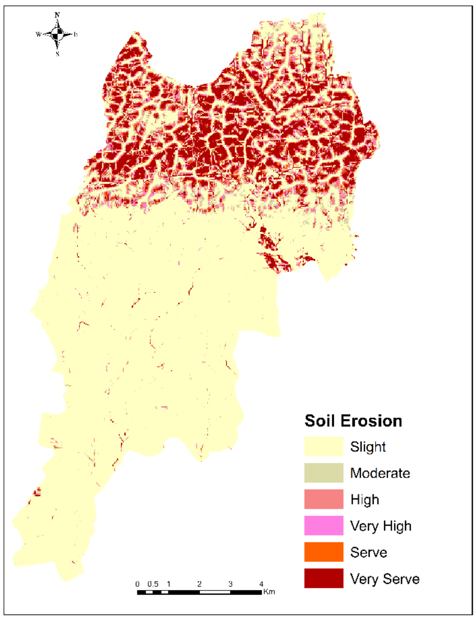
(e) Soil Type



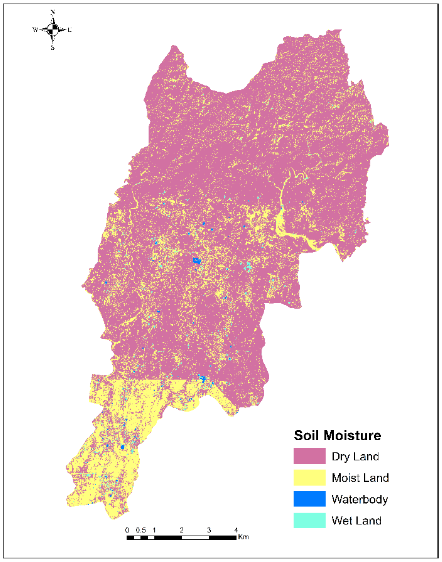
(e) Land Capability



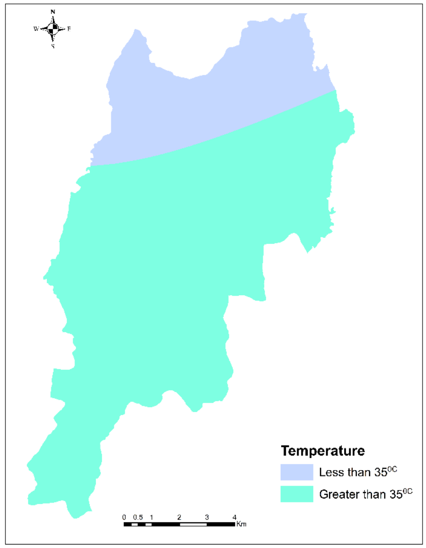
(f) Soil Fertility



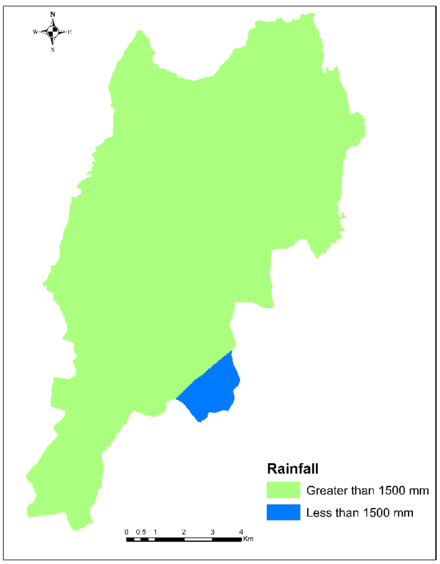
(h) Soil Erosion



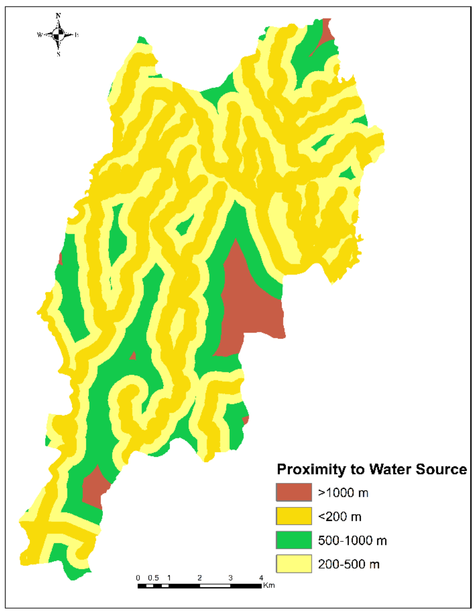
(i) Soil Moisture



(j) Temperature



(k) Rainfall



(l) Proximity to Water Source

Figure 2. Influencing criterion

Effective criteria are selected on the basis of their importance and are described below.

Land Use: Agriculture land use is found to be dominated land use having 5609 ha (52%) followed by forest area with 41 percent in the municipality. It is human related variable that explain the pattern of land cover where agriculture practices exist. For agriculture use, it is an important driving force to increase food productivity and economic growth; conflict from unplanned land development and urbanization; and require for control management practice to conserve land quality and cultivable land.

Slope: Large extent occurs on flat slope less than 1^0 with 53 percent followed by high steep slope in northern portion of municipality with 22 percent area. Likewise, gentle slope and slightly steep slope occupied 7 percent, moderate slope covers 6 percent, and remaining 5 percent area is covered by moderately steep slope.

Geology: Indo-Gangetic plain containing alluvial formation covers 58 percent areas followed by sediment rock material with 34 percent and remaining parts contains course coaly materials. Geological formation balances the ground water table. For growing the crop development, it requires ground water to support availability of surface water that maintained by chemical and physical aspects of soil through geological intervention.

Geomorphology: Non-dissected lake pond area is dominating landform that covers 43 percent areas followed by 32 percent steep slope landform in Siwalik region. The lower terrace having alluvial deposits covers 11 percent areas. Geomorphology (landform) establishes the interaction between land-forming processes and earth materials that govern the associated soil formation and surface water systems for crop growth requirement.

Land Capability: Almost 86 percent areas are covered by the land capability Class I followed by 12 percent by Class II and remaining 2 percent by Class III. Carrying capacities of soil with respect to physical structure of land and soil formation are represented by land capability. It also explains the suitable use for agriculture practices with certain limitation and necessary measures for land capacity conservation.

Soil Type*:* Inceptisol soil covers almost 58 percent areas followed by 28 percent of Entisol soil, 13 percent Alfisol and remaining as Mollisol soil. Soil explains on the formation of soil profile, soil taxonomy and its age containing soil texture, organic carbon, biological material and other physical aspect that support crop development process.

Natural soil fertility: Almost 78 percent lands are moderately fertile and 16 percent areas are highly fertile. Higher the fertility rate there is less requirement of chemical fertilizer and lower fertility areas require more fertilizers for crop development.

Soil moisture: Almost 77 percent areas characterized by dry moisture, about 21 percent land moist and only 1 percent land covers wet moisture. Moisture explains the availability of water contains in soil that require to grow yields by consumption of water intensity. Generally, moist moisture is sufficiency for crop development process. Too little (dry) moisture causes yield loss and plant death; too much (wet) moisture causes root disease and wasted water for yield production.

Soil erosion*:* Almost 72 percent area lies in slightly erosion deficiency having splash and sheet erosion. About 5 percent area occurred in moderate deficiency of rill soil erosion and remaining area are high soil erosion rate having gully erosion and mass movement. Soil erosion causes the soil degradation conditions through decreasing contents organic matter, loss of soil structure and poor internal drainage mechanism. It reduces the natural soil fertility rate that required for intensive crop production.

Rainfall*:* Whole area characterized by 1500 mm precipitation annually. The precipitation (rainfall) increase the soil moisture contains rate and regulate the water cycle for productivity. The regular rainfall pattern is vital to healthy plants, too much or too little rainfall has harmful for crop requirement.

Temperature: Almost 76 percent areas characterized by an average maximum temperature of 35^{0}.C Temperature play a vital role in the variability of plant productivity and duration of harvesting period. Higher temperatures lead to lower plant productivity whereas lower temperatures takes more time for harvesting the crops particularly in high elevation areas.

Proximity of Water Source: Almost 43 percent areas have closeness to water source within 200m. Likewise, 34 percent land occurs within 200-500m from water source. Proximity of water source provides the sufficiency of surface water for agriculture production through irrigation facilities. It also supports ground water level; nearer the source aquifer system provide sufficiency of water needs for crop growth and reciprocal to distance proportionally.

Rank criteria value

Each criterion data is sub-categorized based on its priority level. The sub-categories are standardized into ranking scale with fuzzy membership function and obtained values from 1 to 9 uniform interval level and restriction as constraints area in all criterion maps (Table. 4).

Table 4. Ranking for sub-categories of criteria

Influencing criteria	Sub-category Class	Priority rating	Rank	Remarks
Slope	<1	Highly suitable	9	Higher value is better suitability
	1-5	Suitable	7	
	5-15	Moderate suitable	5	
	15-30	Poor suitable	3	
	>30	Unsuitable	1	Lesser value is low suitability

Criterion weight

Different combination of criteria is formulated in pair wise relationship and analyzed based on influencing criteria. AHP method is used to compute the weight of each influencing criteria (Table 5.). The computed pair wise weights are evaluated in terms of the consistency ratio and 0.06 value was found as acceptable limit for the judgment.

Table 5. Weight of influencing criteria

S.N.	Criteria	Weight
1	Slope	0.1565
2	Soil fertility	0.1509
3	Land use	0.1121
4	Land capability	0.1067
5	Soil moisture	0.0996
6	Soil type	0.0900
7	Soil erosion	0.0638
8	Rainfall	0.0540
9	Geomorphology (Land Form)	0.0515
10	Proximity to water source	0.0470
11	Temperature	0.0349
12	Geology	0.0329

Agriculture land suitability map

Land suitability map for agriculture development is generated from weighted overlay tool using WLC procedure in GIS environment from the computed weights and relative ranks of criterion with its sub categories (Figure 3.). Almost 3139 ha (29%) lands are found under suitable category followed by moderately suitable land with 3001 ha (28%) in the municipality. Similarly, 2669 ha (25%) land are unsuitable for agriculture practices. Likewise, 2007 ha (18%) lands as poorly suitable and 43 ha (0.40%) as highly suitable for agriculture use in the municipality.

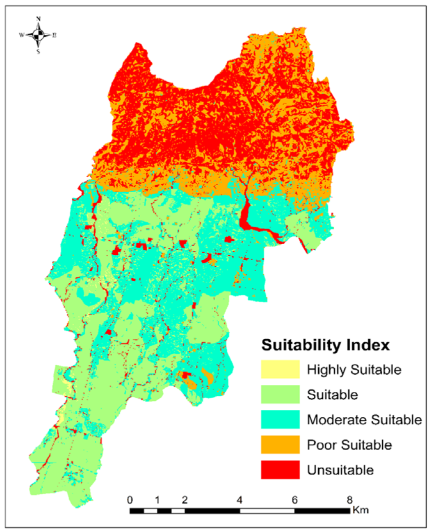


Figure 3. Land suitability map of agriculture

Potential agriculture use

Potential areas for agriculture practice are analyzed based on the land characteristic and its suitability index value under land suitability class (Table. 5).

Table 6. Potential agriculture land characteristics

Suitability class	Land characteristic	Potential use
Highly suitable (S1)	Flat terrain less than 1^0 slope having very high value of soil moisture and natural fertility rate with land capability class I and good drainage capacity	Mostly suitable for intensive agriculture practices if irrigation facilities are available
Suitable (S2)	Flat terrain less than 1^0 slope having well soil moisture and natural fertility rate with land capability class I and good drainage capacity	Well suitable for favorable agriculture practices if irrigation facilities are available
Moderately suitable (S3)	Slope as nearly flat ($0\text{-}3^0$) having medium soil moisture and highly natural fertility rate with land capability class II and good drainage capacity	Suitable for agriculture practices with proper management and availability of irrigation facilities
Marginally suitable (S4)	Gentle slope between $1\text{-}5^0$ having medium soil moisture and natural fertility rate with land capability class II and good drainage capacity	Less suitable for agriculture practices with efficientprotection from drainage and soil erosion
Unsuitable (N)	Steep and highly steep slope greater than 5^0 having poor soil moisture and medium natural fertility rate with land capability class III and high soil erosion	Not suitable for agriculture practices, area under forest, bare exposed soil and rock, barren land,and settlement

Most of the suitable agriculture lands are found at flat terrain and gentle slope in low land form with a high fertility, good drainage capacity and under land capability Class I and II. The unsuitable and poorly suitable agriculture lands are occurred in the undulation terrain having poor drainage condition with high rate of soil erosion particularly in Siwalik hill areas.

Conclusion

The criteria for the present study are identified in the context of Nepal and local situation of Sambhunath municipality. These criteria could be applicable for land use suitability analysis of potential agriculture development in different part of Nepal as well. GIS tool integrated with MCE-AHP is found suitable in land suitability evaluation of agriculture land. Use of a mix of quantitative and qualitative technique was feasible and appropriate in delineating potential sites for agriculture practices. It provides a framework for land suitability analysis of agriculture land use that could be relevant and acceptable by local people and stakeholders.

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