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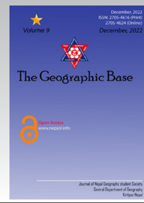

Land Suitability Analysis for Coffee Production in Hilly Districts of Lumbini Province

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Abstract

The government of Nepal has been implementing policies to increase agriculture production by motivating farmers towards farming. This study aims to identify spatially distributed suitable areas for sustainable Arabica coffee production in the Gulmi, Palpa, Arghakhanchi, and Pyuthan districts of Lumbini Province. The multi-criteria analysis was carried out to identify the suitable area for coffee cultivation in the study area, where parameter values were assigned based on Analytical Hierarchy Process (AHP). In the AHP method, the weightage for each parameter for suitability was considered through an expert questionnaire, interview, and field observation. The modeled suitability map was verified through field inventory-based coffee farm points. The result shows different land suitability classes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N) cover an area of 869.0 km2 (16.92%), 1949.0 km2 (37.95%), 280.23 km2 (5.46%), 2037.00 km2 and (39.67%), respectively. The suitable areas are *equally distributed around the study area, while some agglomeration patches were observed in northern Arghakhanchi and southern Gulmi. The findings of this study can be used for coffee production and to gain related economic benefits in the study area. The condition of precipitation, soil characteristics, and topography of the study area are much favorable to Arabica coffee hence farmers need to consider growing Arabica coffee rather than Robusta-type coffee.*

Introduction

Coffee is a major beverage consumed on a global scale (Nzeyimana et al., 2014). It is also an important and emerging cash crop having the potential to provide farmers with employment and income generation opportunities (CB, 2023). This crop is well adapted to the climatic conditions of the mid-hills of Nepal. Thus, the majority of the farmers are attracted to the cultivation of coffee because of demands in the national and international markets (Karki et al., 2018). Coffee plantation is still a new adventure in Nepal. In 1938 AD, a hermit Mr. Hira Giri brought some seeds of Coffee from the Sindu Province of Myanmar (then Burma) and planted them in Aapchaur of Gulmi District for the first time in Nepal. After the approval of the Agricultural Development Strategy (ADS) in 2014, it plays an important role in the national economy, which supports further commercialization (NTCDB, 2016). For the next 20 years, ADS will guide the agricultural sector of Nepal to strengthen agri-business and will purely focus on the cultivation of cash crops for income generation and commercialization. Agriculture is a major source of income for the majority of the population in Nepal (Agriculture in Nepal). Considering the import and export situation ADS has to focus on the growth of coffee seeing a huge expansion over the last decade concerning plantation area and production (NTCDB, 2016).

Currently, irrespective of people's interests in Coffee, Nepal has favorable climatic conditions for farming. Ministry of Agriculture decided to launch Coffee Development Program in the country. The Government provided technical and financial support to the farmers; its cultivation has gradually spread to about 41 districts of the middle hills of Nepal. Lalitpur, Gulmi, Palpa, Syangja, Kaski, Sidhupalchowk, and Kavre, are some districts known for Coffee production, among them 23 being the commercially producing districts (Karki et al., 2018). According to the statistics of the fiscal year 2021/22, 354.90 MT of coffee was produced in 3346 ha of area (NTCDB, 2022). Nepali coffee is mostly produced organically and has been able to create market demand the abroad as well in the country probably because of aroma, taste, flavor, and healthy and suitable environmental conditions where these coffees are produced from hilly slopes (Aoki & Suvedi, 2012)

Considering the global market demands and its consumption nationally, self-dependency on coffee production is important in improving the growth and productivity of coffee. To achieve this goal, we have to determine the alternatives just like determining the potential land for coffee production is one of them (FAO, 2022). Due to the favorable climate with elevation, the environmental condition is quite favorable for Arabica coffee (SMCL, 2023). Various report shows that the annual rainfall between 1000 to 3000 mm and the average temperature of 12-22 degree Celsius is favorable for Arabica coffee (Rono et al., 2016). In the context of Nepal, the hilly regions of Nepal meet the above-mentioned environmental condition. Also, the hilly region of Nepal has suitable soil and relative humidity for Arabica Coffee production (SMCL, 2023). Among many districts in the hilly region, the hilly district of Lumbini Province district is considered the pioneer and has great potential for coffee production (GoN, 2018). Identifying land that is suitable for coffee production is one of the key tasks for achieving self-sufficiency in coffee production. The process of evaluating the potential land resources is known as land suitability evaluation. Determining the type of land use and the developing requirements is the primary task in land evaluation connected to land use (Mugo et al., 2016). If the rural economy and livelihoods of smallholder farmers in Nepal are to anticipate and effectively adjust to expected climate change consequences, choosing the appropriate crop variety for the relevant geographical region, i.e., land suitability, is crucial.

Methods and Materials

Study area

Lumbini Province is located in western Nepal being bordered by Gandaki Province and Karnali Province to the north, Sudurpashchim Province to the west and Uttar pradesh and Bihar of India to the south. Lumbini is the third largest and the most populous province of the country. This province is home to the World heritage Site of Lumbini, where the founder of Buddhism, Gautama Buddha was born. It comprised of both temperate and tropical climates and is diverse in terms of agricultural production potentialities (Province profile). The province is best suited for agricultural production with five core Terai districts, one inner Terai, and 6 other hill districts. Here in this study, Gulmi, Arghakhanchi, Palpa, and Pyuthan districts are considered.

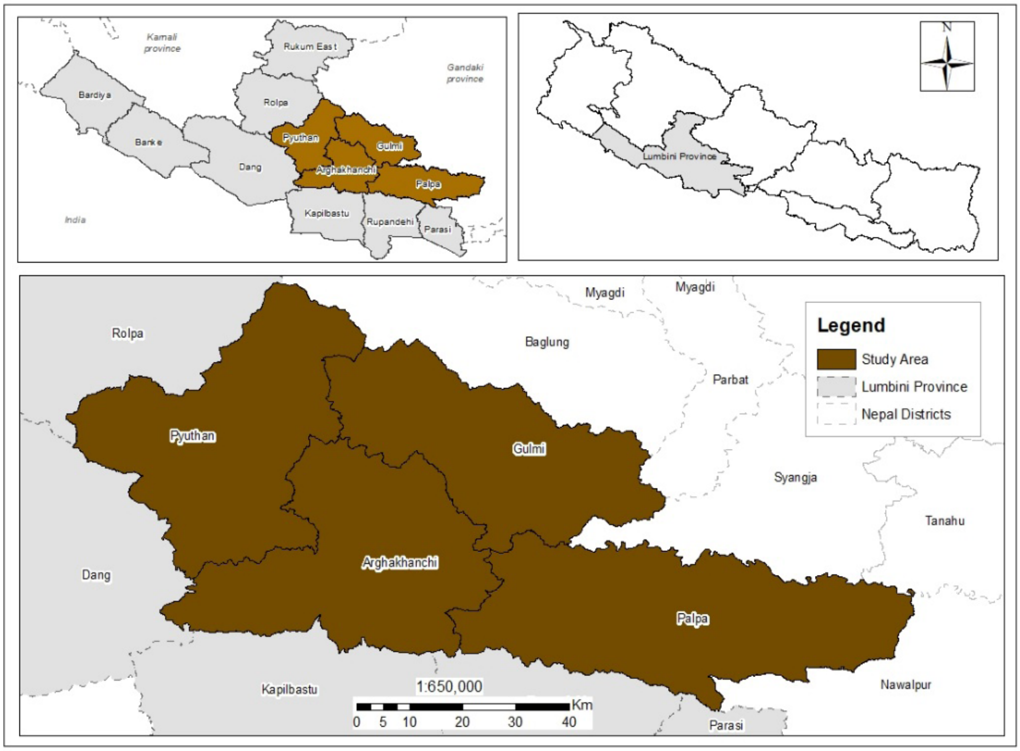

Figure 1. Study Area

The hilly district of Lumbini Province has 163,640 ha of land area suitable for coffee production and produced about 60.2 metric tons of coffee annually (E.Hagen, 2018). The hilly district of Lumbini Province is a pioneer in coffee production in the country with a history of coffee farming going back 75 years, as of 2021 there are 6170 active coffee farmers with a 496.00 ha plantation area. This area lies within an elevation of 800m to 1600m, receiving an average of 111.9 millimeters of annual precipitation (SMCL, 2023). Which has eroded soil and other environmental conditions suitable for coffee production (Hagen, 2018).

Data Sources

Multi-criteria decision-making analysis integrated with AHP and GIS was used to identify a suitability map (Rono & Mundia, 2016) which includes: Data collection, Data pre-processing and re-classification, AHP, and Spatial analysis. This research was conducted for land suitability of Arabica coffee in the hilly district of Lumbini province by spatial analysis tools, which require consideration of several criteria. The table-1 summarizes the data sets used in the study with categorize as highly suitable, moderately suitable, marginal suitable, and not suitable (Hidayat et al., 2020), while the methodology flow chart is shown in the Figure 2.

Table 1. Data Characteristics table

Land Characteristics	S1 (Highly suitable)	S2 (Moderately suitable)	S3 (Marginal suitable)	NS (Not suitable)
Temperature(ºC)	18-22	14-18	12-14	<12,>22
Rainfall (MM)	1200-1800	1000-1200	1800-3000	<1000,>3000
Elevation (M.S.L)	1000-1500	1500-1700	1700-2000	>2000, <1000
Slope	<8	8-16	16-30	>30
Aspect	N, NE, NW	E, W	SE, SW	S
PH	5.5-6.6	6.6-7.3	<5.5,>7.4	
Nitrogen	>.21	0.1-0.2	<0.1	
Soil texture	Sandy loam, Silty clay loam, clay loam, sandy clay, loam	Sandy clay loam, loamy sandy	clay, loam sand	
Land cover	Crop land, grass land	Bare soil	Forest	Builtup, river

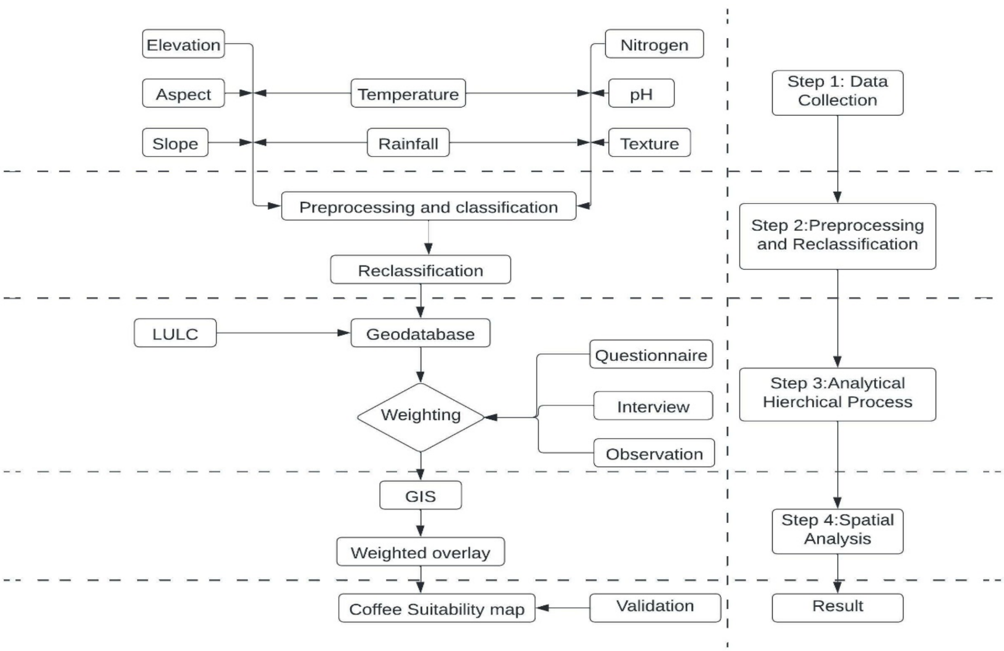

Figure 2. Overall methodology of the study

Data collection

At first, different datasets affecting potential coffee farming were gathered. These criteria include elevation, slope, aspect, rainfall, temperature, nitrogen, pH, texture, and land cover. In this research, datasets were obtained from primary and secondary sources. For example, the temperature and rainfall records were obtained from the Department of hydrology and Meteorology (DHM). Vertex Alaska DEM (Digital elevation model) was downloaded from the Alaska satellite facility (ASF Data Search (alaska.edu)) with 12.5m resolution from which we generated the elevation, slope, and aspect map of the study area, nitrogen, and pH data downloaded from the NARC (Soil Map | NARC), soil texture data from the FAO (FAO/UNESCO Soil Map of the World | FAO SOILS PORTAL | Food and Agriculture Organization of the United Nations) and land cover data from ICIMOD (ICIMOD - International Centre for Integrated Mountain Development) with 30m resolution. Sample point data were collected in existing coffee farms utilizing handheld GPS receivers, which were overlayed in the final suitability map for validation purposes.

Data pre-processing and re-classification

The preprocessing, categorization, standardization, and reclassification of numerous data sets were the part of second phase of the study. Noise reduction, data cleaning, void removal, and other preprocessing steps were followed by the projection of the data into Modified Universal Transverse Mercator (UTM) zone 44N and WGS84 datum for standardization and clipping to the research area extend. Later, the resolution of different raster's data sets was converted into the same resolution with the resampling technique in GIS. After resampling, various thematic maps of the study were generated using QGIS. These thematic maps were rasterized and reclassified into four suitability classes i.e. highly suitable, moderately suitable, marginally suitable, and not suitable as per the data characteristics table using the spatial analyst tool in QGIS. They include rainfall maps, temperature maps, elevation maps, slope maps, aspect maps, pH maps, nitrogen maps, and soil texture maps. In addition, they were provided score values ranging from numeric value 1 to 4 as per the relevance of each re-classification.

Analytic hierarchy process

After re-classification, all data sets were imported to feature class and raster formats in a geodatabase. It was able to standardize the numerous criteria into a single standard by using data from the geodatabase. To calculate the weights of the criterion based on a shared standard using the Saaty scale of numbers 1 to 9, the analytical hierarchical process (AHP) was utilized. The scale employs the numbers 1, 2, 3, 5, 6, 7, 8, and 9 to represent the relative importance of preference intensities i.e., equal importance, equally to moderate, moderate to strong, strong to very strong, very strong to very, and extreme importance (Saaty, 1984). The eigenvectors were produced using the geometric mean approach, normalized, and computed as percentage weights. Pairwise comparison matrices for the criteria were created.

In the form of a Pairwise comparison matrix the 11 expert group questionnaire responses were analyzed, allowing us to determine the relevance of each criterion's weight, which should always add up to 1 per hierarchical category. Due to the possibility of inconsistencies in the PMCs of the experts, the allowable inconsistency values are determined using the consistency ratio (CR). The CR must be less than 0.1 for the consistency of the matrix to be considered acceptable (Triantaphyllou & Mann, 1995), otherwise, the AHP may provide incorrect results. The Easy AHP in Excel was used to accomplish each of the aforementioned computations. At first, we have to input those expert responses in the AHP table individually which gives weight for each parameter as like the table and finally AHP summarizes that 11 individual weightage to obtain the final weight for each criterion which we can see in the table-2 in which temperature stand in rank 1 with 30.87 % influencing which is followed by rainfall with 22.63 %, Elevation with 15.18 %, land cover with 8.06 %, slope with 7.66 %, soil texture with 4.54 %, the aspect with 4.03 %, pH with 3.56 % and nitrogen with 3.48 %.

Table 2. Weightage Table

	Rainfall	Temperature	Elevation	Slope	Aspect	Soil texture	pH	Nitrogen	Land cover	Weight (%)
Rainfall	1	1/3	$3\frac{1}{3}$	$3\frac{5}{6}$	$4\frac{7}{9}$	$5\frac{1}{7}$	5	$4\frac{7}{8}$	$3\frac{3}{7}$	22.63
Temperature	3	1	$3\frac{3}{5}$	$4\frac{3}{7}$	$4\frac{1}{2}$	$5\frac{1}{7}$	5	$4\frac{2}{3}$	$4\frac{2}{5}$	30.87
Elevation	1/3	2/3	1	$3\frac{2}{5}$	$4\frac{1}{7}$	$3\frac{3}{4}$	$4\frac{2}{9}$	$3\frac{5}{8}$	$3\frac{1}{2}$	15.18
Slope	1/4	2/9	2/7	1	$1\frac{3}{7}$	3	$3\frac{2}{3}$	$2\frac{2}{3}$	7/8	7.66
Aspect	1/5	2/9	1/4	5/7	1	1	1	1	4/9	4.03
Soil texture	1/5	1/5	1/4	1/3	1	1	$1\frac{3}{7}$	$2\frac{4}{5}$	3/8	4.54
pH	1/5	1/5	1/4	1/4	1	2/3	1	$1\frac{2}{9}$	1/3	3.56
Nitrogen	1/5	1/5	2/7	3/8	$1\frac{1}{9}$	1/3	5/6	1	1/3	3.48
Land cover	2/7	2/9	2/7	$1\frac{1}{7}$	$2\frac{2}{7}$	$2\frac{5}{7}$	3	3	1	8.06

Spatial analysis

Before beginning the raster overlay process, we first prepare suitability maps for the individual criteria, such as elevation suitability, slope suitability, aspect suitability, rainfall suitability, temperature suitability, nitrogen suitability, pH suitability, texture suitability, and land cover suitability. After obtaining individual suitability maps, we processed them together to produce the final suitability map. We obtained the final suitability map for the cultivation of coffee after executing weighted overlay features of those datasets with their weightage in GIS tools. The MCDA used in this study was specifically designed to identify the four suitability indices (highly suitable, moderately suitable, marginally suitable, and not suitable) for coffee plantations using the parameter (Table-2) obtained from literature and their weightage percentage that was obtained from AHP through expert responses, observation, and interview.

Having determined weights (influencing percentage), a GIS-based model was created and combined with the weighted overlay tool. The weighted overlay is a typical GIS analytic approach widely used for solving multi-criteria issues employing several criteria, such as creating surfaces reflecting site suitability and travel cost (Jankowski, 1995). Where we input raster data of nine parameters together with their weight percentages as per the table-2, which are obtained from AHP with their value and scale. All input raster's for this feature must be integers. Before being utilized in a Weighted Overlay, a floating-point raster must be transformed into an integer raster. The conversion may be done efficiently with the help of the reclassification tools. An evaluation scale is used to assign a new value to each value class in an input raster. When a scale value is set to restricted, the output weighted overlay result for that cell is given a value equal to the evaluation scale's minimum value, minus 1. If there are no inputs to a Weighted Overlay with cells of No Data, we could use No Data as the scale value to exclude certain values. The weights of each criterion that are obtained from the Analytical Hierarchy Process as per the table-2 are the inputs provided to the respective criterion in a weighted overlay tool of GIS. Criteria maps were merged based on these weights that generate a new map showing the suitability of coffee production, which is also the final result of this research work.

Results and Discussion

Rainfall suitability

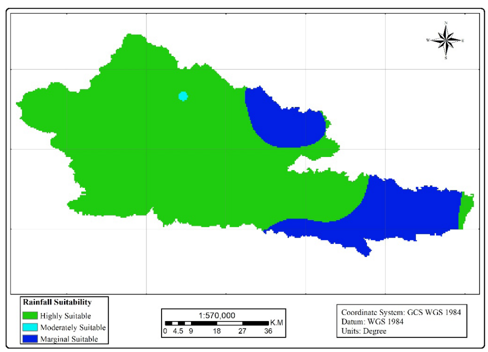

Figure 3. Rainfall suitability map

As shown in the figure-3, which is represented by different colors, the previously classified rainfall map has been reclassified according to the data characteristics table as highly suitable, moderately suitable, and marginally suitable. The majority of the region is highly suited for coffee cultivation in terms of rainfall.

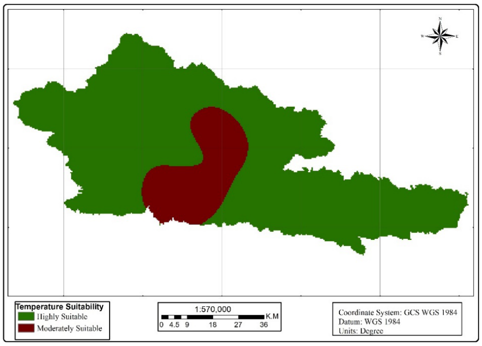

Figure 4. Temperature suitability map

Temperature suitability

According to the data characteristics table, the classified temperature map is further reclassified as highly suitable and moderately suitable, as shown in the figure-4, which is represented by different colors. In terms of temperature, the majority of the area is highly suitable for coffee production.

As shown in Figure-5, which is represented by various color, the previously classified elevation map has been reclassified as highly suitable, moderately suitable, marginally suitable and not suitable based on data characteristics table. Much of the region is not suitable for coffee cultivation in terms of elevation.

Elevation suitability

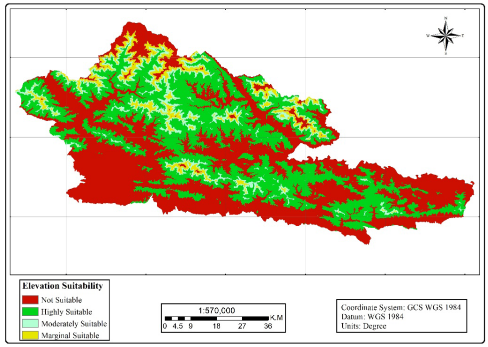

Figure 5. Elevation suitability map

Slope suitability

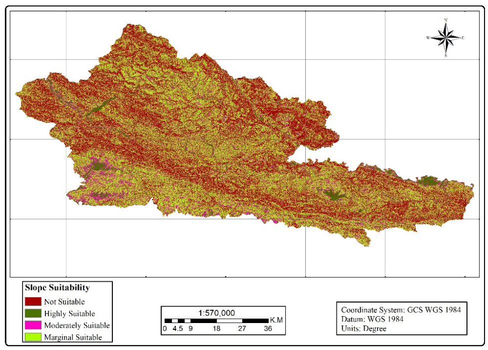

Figure 6. Slope suitability map

The slope of the research area was divided into four suitability classes based on the required slope for Coffee Arabica production. These classes fell into the categories of being extremely, somewhat, barely, and not acceptable. When compared to the others, the majority of the research area was only marginally favorable for coffee cultivation, according to the slope suitability analysis.

Aspect suitability

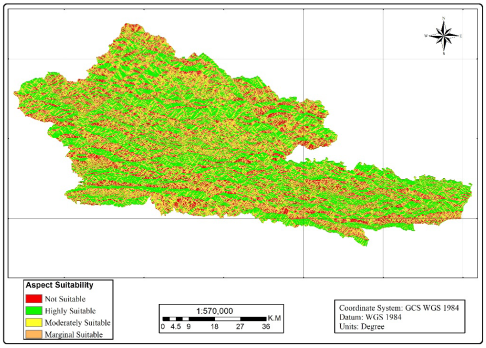

Figure 7. Aspect suitability map

Various factors are weighted differently when it comes to coffee cultivation. The amount of solar radiation that the coffee plant may receive for growth is clearly indicated by aspect, which has its own significance in coffee production. Aspects of the study region were divided into four appropriateness classes based on aspect analysis for Coffee Arabica production. These were the classes of "highly suitable" (direction/orientation towards north, northeast, and northwest), "moderately suitable" (the east and west face direction), "marginally suitable" (the southeast and southwest direction), and "not suitable" (the south direction). According to an analysis of aspect appropriateness, the majority of the research area was superior to the others in terms of its suitability for coffee growing.

As shown in Figure-8, The research area's soil texture, which ranges from sandy loam to clayey loam, was divided into four suitability groups based on the texture requirements for producing coffee Arabica.

Soil texture

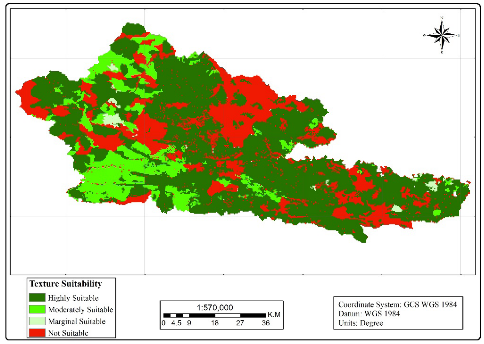

Figure 8. Texture suitability map

These classes fell into the categories of being extremely, somewhat, barely, and not acceptable. According to the results in Figure-8, 39% of the territory is not suitable for growing Arabica coffee, whereas 37% of it is highly suitable in terms of texture.

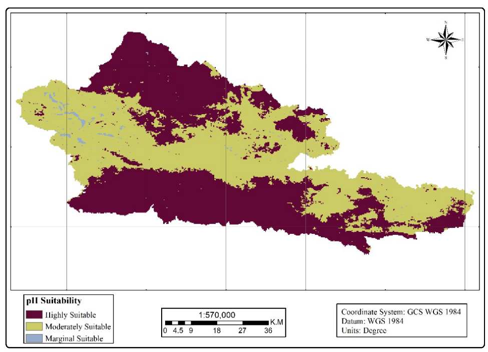

Figure 9. pH suitability map

pH suitability

The research area's pH was fall into three appropriateness classes based on the pH requirements for producing Coffee Arabica. These lessons were extremely, somewhat, and barely suitable.

According to the findings in Figure-9, the northern and southern portions of the study region are very favorable for production of Arabica coffee, whereas the center portion of the study area is only moderately suitable.

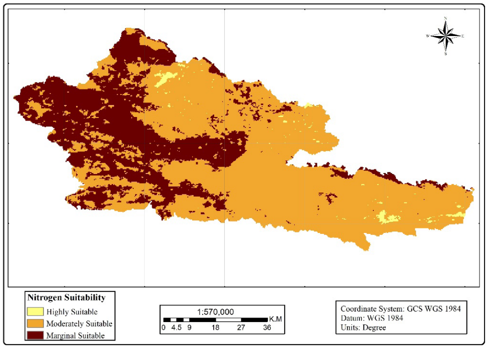

Figure 10. Nitrogen suitability map

Nitrogen Suitability

Nitrogen in the research region was fell into three appropriateness classes based on the nitrogen requirements of Coffee Arabica production. These classes were very suited, fairly suitable, and marginally suitable. Figure-10 shows that the bulk of the region, particularly the eastern portion of the research area, is moderately appropriate for coffee Arabica cultivation in terms of nitrogen.

The most recent land cover statistics for the research area were collected from the ICIMOD website, which is the land cover for 2019. The overall size of the study area was found to be 5135.27 Sq.k.m. in the Land cover data.

Land cover

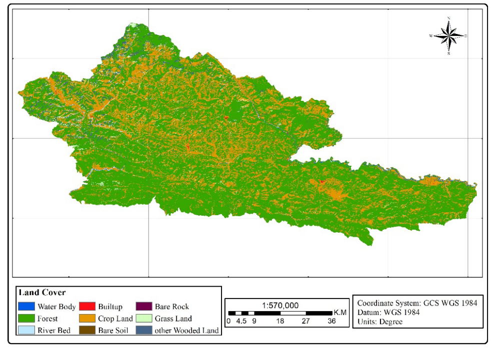

Figure 11. Land cover map

The land cover data covers nine types of land cover data: water body, forest, river bed, built up, crop land, bare soil, bare rock, grass land, and other wooded land, with forest covering the majority of the area followed by crop land.

Land Suitability and validation

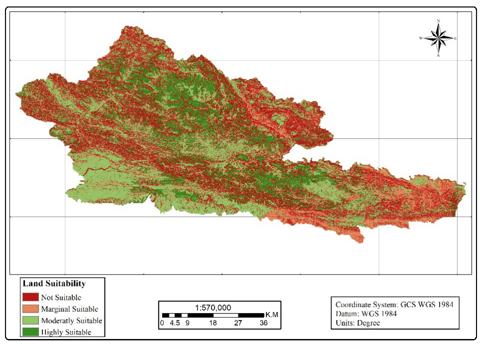

Figure 12. Land suitability area

As seen in figure-14, Vertical bars with different pattern is used to represent different suitability classes with their respective area (Figure 12). Within the study area 16.92% region is highly suitable 37.95 % region is moderately suitable 5.46 % region is marginal suitable and 39.67 % region is not-suitable.

A field survey was carried out (Figure 15) to verify the suitability map. First, the Agriculture Knowledge Centre Gulmi, NTCDB Tea & Coffee Extension Office, Baddanda, Pyuthan, and other sources provided information on 41 existing coffee farms in the research region.

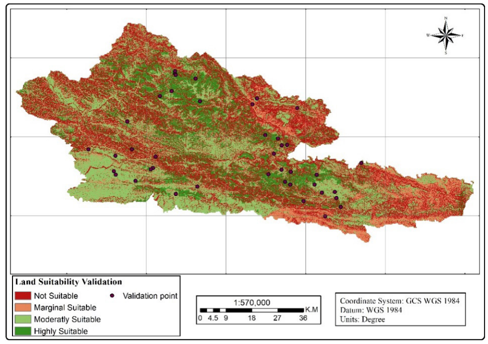

Figure 13. Land suitability validation

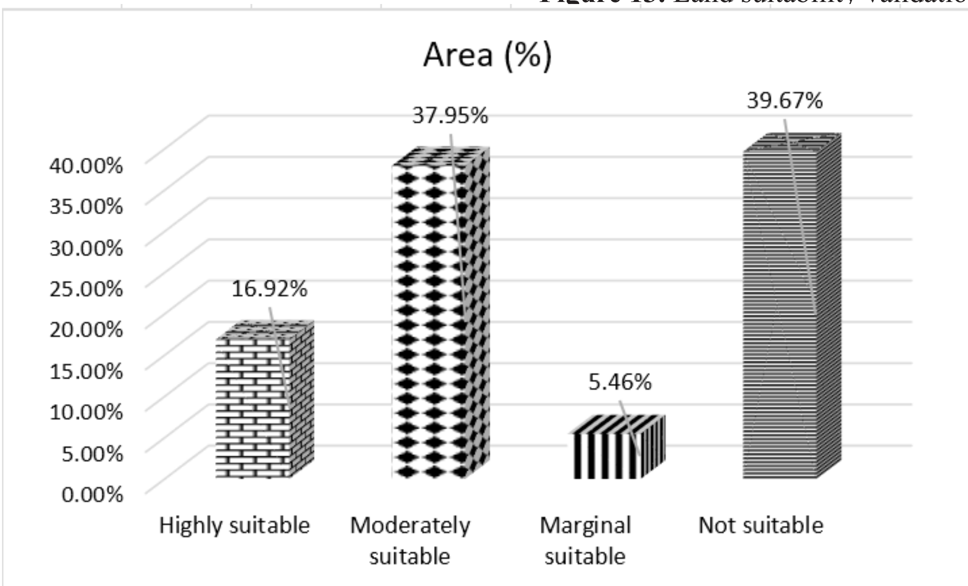

Figure 14. Land suitability area (%)

A GPS survey was conducted after obtaining the list of coffee fields to obtain the GPS coordinates of the coffee fields. The suitability map that was created and examined was then overlaid with the GPS data. Of those GPS coordinates, 35 (85.4%) points were located in highly, moderately, and marginally appropriate areas and 6 (14.6%) points were located in an unsuitable zone.

Figure 15. Photographs taken during field verification

Some locations that were discovered to be unsuitable areas had banana agriculture or had trees planted alongside the coffee. These point though were in low altitudes, were suitable because shades were provided to create coffee friendly environment either by planting bananas or other trees.

Conclusion

This study analyzes the coffee sustainability areas in the Hilly district of Lumbini Province of Nepal. The analysis was done based on various parameters i.e., elevation, slope, aspect, rainfall, temperature, and land-cover; suitability values for these parameters were determined through a literature review and experts' opinions. Later on, multi-criteria decision analysis was done in a GIS environment. This study concludes that 16.92 % area of the total area is highly suitable, area of 37.95 % is moderately suitable, area of 5.46 % is marginally suitable and area of 39.67 % is not suitable for Arabica coffee. This study recommends a similar study considering shadow presence. Besides that, similar types of coffee suitability analysis help to expand production area and can be instrumental to having better economic conditions with the increase in coffee export

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