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Land Suitability Determination for Orange Farming in Syangja District, Nepal, using GIS-based Multi-criteria Analysis

Bikram Regmi[a] Ramjee Prasad Pokharel[b]*
[a] [b]Department of Geography, Prithvi Narayan Campus, Tribhuvan University, Pokhara, Nepal.
*Corresponding author and email: ramjeepp@gmail.com; ORCHID: 0009-0004-4285-1740

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Abstract

Land is a gifted resource by nature. It is foundation of life and a major basis for agriculture. Land suitability refers to the degree to which a particular parcel of land is appropriate for human need and purposes such as settlement, cultivation, or other usage. Generally, farming practices are often carried out spontaneously without identifying land suitability. The plantation of horticultural fruit species is also frequently done without determining scientific land suitability analysis. Among horticultural fruits, oranges (Citrus family) are a very popular product in Nepal as well as Syangja district, so, it is necessary to identify suitable land for their cultivation. This study aims to spatially identify the most suitable areas for orange production by integrating edaphic factor, accessibility, and socio-economic factors such as temperature, elevation, slope, soil texture, soil pH, soil depth, and proximity to water sources and roads. This study conducted a scientific Land Suitability Analysis (LSA) *for orange farming in Syangja district using the Analytic Hierarchy Process (AHP) integrated with a Geographic Information System (GIS), based on field survey of 18 locations. The results of the final AHP weighted overlay analysis revealed a balanced distribution, with Highly Suitable land accounting for 25.44 percent (295.26 km²) and Moderately Suitable land for 24.79 percent (287.69 km²). These results confirm that slightly more than half of the district (50.23%) holds the required potential for viable orange production. Conversely, Marginally Suitable and Not Suitable areas comprise approximately 49.67 percent of the total landscape. The reliability of the AHP model was confirmed through field-based Ground Truthing, which indicated a high degree of accuracy with 12 specific locations falling within the highly suitable category and 6 falling within the moderately suitable category.*

Ultimately, these findings serve as a critical spatial planning tool for agricultural development policy, they direct strategic investment toward high potential zones of the study area, like Lalahi and Mayatari, while advising on risk mitigation and essential planning for moderately suitable regions like Changsing to facilitate the sustainable and profitable expansion.

Keywords: Citrus reticulate, AHP, GIS, horticulture farming, Land suitability analysis, Citrus reticulata, Syangja.

Introduction

The agricultural sector in Nepal stands as a vital pillar of the nation's economy, contributing significantly to the Gross Domestic Product (24%) and providing employment to a large number (62%) of people (MOF, 2024). Among horticultural families, citrus fruits, and specifically the Mandarin orange (Citrus Reticulata Blanco (scientific name)), locally known as "Suntala," occupy a prominent position in the mid-hill regions. The cultivation of oranges in the mid-hill regions of the nation is not just an agronomic activity but also a socio-cultural heritage of the people, along with a vital economic lifeline for the communities. This region also offers an advantage due to the specific micro-climatic requirements that the mid-hill region of Nepal provides.

Land Suitability Analysis (LSA) refers to the process of assessment of the potential of land for alternative use (FAO, 1976; Malczewski, 2006). The theoretical background for LSA was formally expressed by the Food and Agriculture Organization (FAO) in "A Framework for Land Evaluation" which provide knowledge about land (FAO, 1976). It covers the concept of land capability, which refers to general land potential and land suitability which describes the land's overall potential for a specific crop (FAO, 1976; Tercan & Dereli, 2020)

However, the expansion of agricultural land use in mountainous regions is full of seen and unforeseen challenges due to the scarcity of necessary arable lands and the fragility of hill slopes. This calls for scientific research supported by the necessary procedures of land use planning and sustainable farming. The conventional method of site selection relies on subjective evidence and convenience. Despite many success approaches, several orange farms still suffer from poor site selection and management. The Syangja district also faces several problems under current orange cultivation practices. Therefore, a systematic analysis of land suitability for orange cultivation could guide better use of land resources in the study area. Sustainable agricultural development requires that land is used according to its capability and suitability so that ecological balance and long-term productivity can be maintained. Therefore, this study aims to spatially identify the most suitable areas for orange production. To

achieve this, the research applies an AHP based Land Suitability Analysis to prepare map and identify potential locations for orange farming. Suitability maps are useful decision-support tools that help policymakers, planners, and farmers determine appropriate areas for establishing orange orchards. This approach can reduce environmental risks and support sustainable orange cultivation in the mid-hill regions of Nepal.

Literature Review

This study establishes its theoretical and empirical foundation by reviewing the agronomic requirements of citrus crops and the evolution of LSA. The study examines the mathematical application of the Analytic Hierarchy Process (AHP) and how it integrates with geospatial technology. It also analyzes global land suitability concepts within specific agro-ecological and administrative contexts.

Akbulak (2010) developed a spatial model to assess land suitability for citrus farming using Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA). In this study, AHP was used to assign weights to critical factors such as soil type, topography, temperature, and rainfall. The results highlighted that coastal and low-elevation regions possessed high suitability. The results also validating GIS-MCDA as an effective decision-support tool for land management and citrus plantation planning. Similarly, Akinci, Ozalp, and Turgut (2013) and Kumar and Jhariya (2017) used GIS and AHP techniques to evaluate land suitability for crops like the Khasi mandarin orange and pineapple. They integrate remote sensing data with soil properties, slope, rainfall, and land-use information for their analysis to identify moderately to highly suitable zones. They found that soil depth and rainfall were the main factors limiting sustainable orange cultivation building on these methods. Arabsheibani and Taha (2020) applied Fuzzy-AHP and Ordered Weighted Averaging (OWA) to determine land suitability for citrus. Their goal was to support sustainable planning by accounting for the complex relationships between different evaluations criteria.

The Food and Agriculture Organization (FAO) provides a structured framework for evaluating land based on its potential for a specific use. According to the FAO (1976), the system is broadly divided into two main orders: Suitable (Order S) and Not Suitable (Order N). Order S refers to land where the expected use will generate enough benefits to justify its application. This order is further divided into three classes: S1 (Highly Suitable), which has no significant limitations; S2 (Moderately Suitable), which has moderate limitations that may reduce productivity or require management; and S3 (Marginally Suitable), which has severe limitations that restrict use. Conversely, Order N encompasses land that possesses inherent characteristics

that make it unsuitable for future use. As these limitations cannot be feasibly overcome under existing economic or technological conditions (FAO, 1976).

The Analytic Hierarchy Process, introduced by Thomas Saaty (1980) is the most efficient Multi-Criteria Decision Analysis (MCDA) technique used in land suitability studies like this for orange production. Land suitability analysis is a multi-criteria problem because land suitability is never determined by a single factor but it is a complex analysis of multiple conflicting criteria. AHP decomposes the decision problem into a hierarchical structure:

The core of AHP is the pairwise comparison matrix. Instead of assigning weights arbitrarily, experts compare two criteria at a time using a standardized scale (1 to 4). The scales are 1) Very low Importance, 2) Low Importance, 3) Moderate Importance and 4) High Importance.

Mathematically,

criteria = n and construct an $n \times n$ matrix A = [aij].

The principal eigenvector of this matrix provides the relative weights of the criteria. A crucial feature of AHP is the Consistency Ratio (CR) check. Human judgments can be inconsistent (e.g., rating A > B, B > C, but C > A). The CR measures this inconsistency. A CR value less than 0.10 (10%) is considered acceptable otherwise the judgments must be revised. In GIS integration, AHP weights are applied to standardized raster layers using the weighted linear combination (WLC) technique to combine different criteria effectively. This method ensures that the final map reflects the importance of each factor based on expert knowledge and clearly identifies suitable areas for orange farming. This study is based on ten different criteria for the land suitability analysis for oranges farming in Syangja. The criteria used in this study were temperature, precipitation, elevation, slope, aspect, soil texture, soil pH and soil depth. Proximity from water bodies to ensure proper hydration of plants and roads access as per expert suggestion.

Methods and Materials

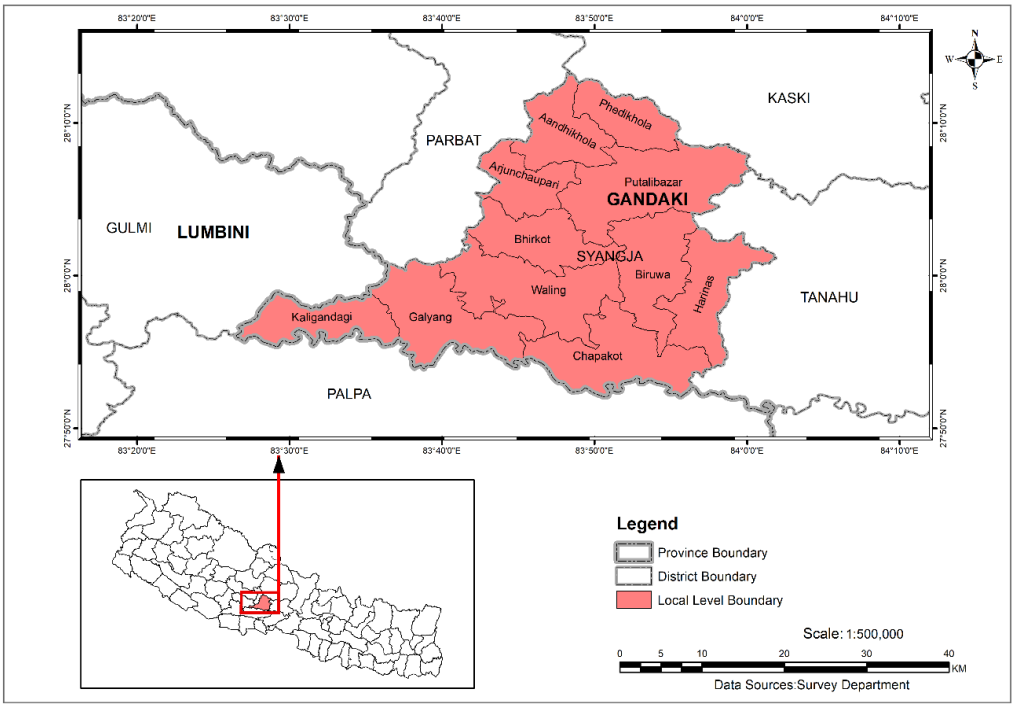
Study Area

Syangja district is one of the hilly districts of the Gandaki Province of Nepal. It is well known for its scenic landscapes, green valleys, and strong agricultural activities.

The district lies between the 27° 52' N to 28° 13' North latitude and 83° 27' E to 84° 46' East longitude. The elevation of the area varies greatly, ranging from about 366 meters at the confluence of the Kaligandaki River in Keladi to about 2470 meters at Panchase Lekh (Figure 1).

Figure 1

Location map of the study area



Sources: Survey Department, Nepal, 2020

The total area of the district is approximately 1,164 square kilometers, and it has rugged and diverse terrain typical of the Mahabharat range. Syangja District produces a variety of horticultural crops. However, this study mainly focuses on identifying suitable areas for orange cultivation in the future.

Most parts of the district are rural, where settlements are commonly found along hillsides, river valleys, and terraced farmland. Agriculture remains the main source of livelihood for local people. Among agricultural activities, the district is particularly famous for the cultivation of citrus fruits, especially mandarin oranges.

Methods

This study uses analytical approach to identify suitable locations for orange farming in the Syangja. A multi criteria decision support system was applied to evaluate different affecting factors for the determination of land suitability. It combines the Analytical Hierarchy Process with Geographical Information System to analyze and prioritize land suitability criteria. The integration of expert views with spatial analysis indicate potential areas for orange farming. This analysis is based on land evaluation framework developed by the Food and Agriculture Organization (FAO). The approach follows a step by step process which integrates spatial

information with qualitative information of expert opinions. Suitability criteria were carefully selected and organized into three main categories such as climate, soil and topographical proximity aspects. The soil related criteria include texture, pH value and soil depth which reflect the soils' capacity to support nutrient availability and healthy plant root development. The topographical proximity criteria such as elevation, slope, aspect and distance were included because they influence drainage, sunlight and accessibility. The spatial data were integrated based on multiple sources including satellite dataset such as MODIS, CHIRS and STRM which was collected from global and national institutions like ISRIC, NARC and Survey Department of Nepal. Advanced spatial interpolation techniques specially Kriging and resampling was applied by making all data layers reliable. Finally, all datasets were standardized to common spatial resolution of 30 meters. This integration and standardization significantly improved the accuracy and reliability of suitability assessment for orange farming. The values are defined based on literature, experts' and farmers' suggestions. Ten criteria are standardize into four class such as highly suitable (S1) moderately suitable (S2), marginally suitable (S3) and not suitable (NS) (Table 1).

Table 1

General criteria and factors that were used in the study

Criteria uses for Suitability	S1 (Highly Suitable)	S2 (Moderately Suitable)	S3 (Marginal Suitable)	NS (Not Suitable)	Source
Elevation (M.S.L)	1000-1300	800-1000	1300-1600	>1600, <800	SRTM
Temperature (ºC) (Flowering Period)	18-21	15-18	14-15	<14,>21	Station Data + MODIS
Precipitation (mm)	1200-1800	900-1200	600-900	<600,>1800	Station Data + CHIRPS
Soil Texture	Sandy Loam, Loam	Silty Loam	Clay Loam	Heavy-Loam, Pure sand, Red compacted soil	NARC
Aspect	N,NE	NW,W,E	All remaining		SRTM
Soil depth(Cm)	>200	150 – 200	100 - 150	< 100	NARC

Slope (degree)	<15	15-30	30-45	>45	SRTM
Soil pH	5.5-6.5	6.5-7.0	.5-5.5	< 4.5 and > 7.0	NARC
Water Proximity(m)	0 – 500	500 – 800	800 - 1000	< 1000	Survey Department of Nepal
Road Proxmity KM)	0.05 – 2	2 – 4	4 – 6	< 6	Survey Department of Nepal

Source: Criteria adopted from FAO, 1984; Nzeyimana et al., 2014 and categorized as per expert suggestion.

Weightage and Prioritization (AHP)

Using a pairwise comparison matrix, weights were assigned based on expert knowledge and empirical evidence. The analysis achieved a Consistency Ratio (CR) of 6.9 percent, well within the acceptable threshold (<10%), ensuring logical reliability. The criteria differ due to their weightage; therefore, the study based weightage percentages on elevation (17), temperature (17), precipitation (14.6), soil texture (12.6), aspect (12.1), soil depth (10), slope (6.7), soil pH (5.2), water sources (2.7), and road access (1.2).

Spatial Processing & Analysis

The approach uses a Weighted Overlay approach to produce the final suitability index. The spatial reasoning follows the formula: $S = \sum_{i=1}^{n} Wi \; x \; Xi$

Where *Wi* denotes factor weight, and *Xi* denotes the normalized suitability score. Each variable will then be ranked into four classes: Highly Suitable (4), Moderately Suitable (3), Low Suitability (2), and Unsuitable (1). This process enables various data, like Soil pH and Road distance, to be calculated and mapped as a thematic map.

Validation & Output

For applicability, the accuracy assessment (Ground-truthing) validation was incorporated into this process. Therefore, in this study, potential sites for orange farming were identified using a GIS-based AHP model by integrating and analyzing ten parameters: elevation, temperature, precipitation, soil texture, soil depth, aspect, slope, soil pH, water source, and road access.

Results and discussion

Existing orange farming

Orange farming has been practiced in the Syangja District for a long period. Based on farmers' experience, commercial orange production has been carried out in various locations designated as Orange Super Zones. In this district, production and market management activities are being conducted by registered institutions at both the farmer and cooperative levels. However, the prevalence of subsistence farming has limited the commercialization of orange cultivation. The data provided from Ministry of Agriculture and Livestock Development, Prime Minister Agriculture Modernization Project, project implementation unit Syangja, shows that orange trees planted across 2200 hectare, producing an annual yield of 1950 metric tons of oranges with 14.46 metric ton per hectares for fiscal year 2080/81 (MoALD, PAMP PIU Syangja, 2025).

The spatial distribution pattern of this cultivation varies across the district. Traditionally, orange farming has been practiced even in low-productivity areas due to the lack of proper identification of truly suitable locations within the district. The resulting potential locations are presented here as suitable areas for orange cultivation. The data layers and various criteria used for identifying suitable locations are shown in figure 2.

Table 2

Suitability result

Suitability Class	Area ($km^2$2)	Percentage of Total Area
Highly Suitable	295.26	25.44
Moderately Suitable	287.69	24.79
Marginally Suitable	288.34	24.85
Not Suitable	289.21	24.92
Overall Total Area	1160.50*	100.00

Sources: Based on figure 3

Figure 2

Data Layers of study area

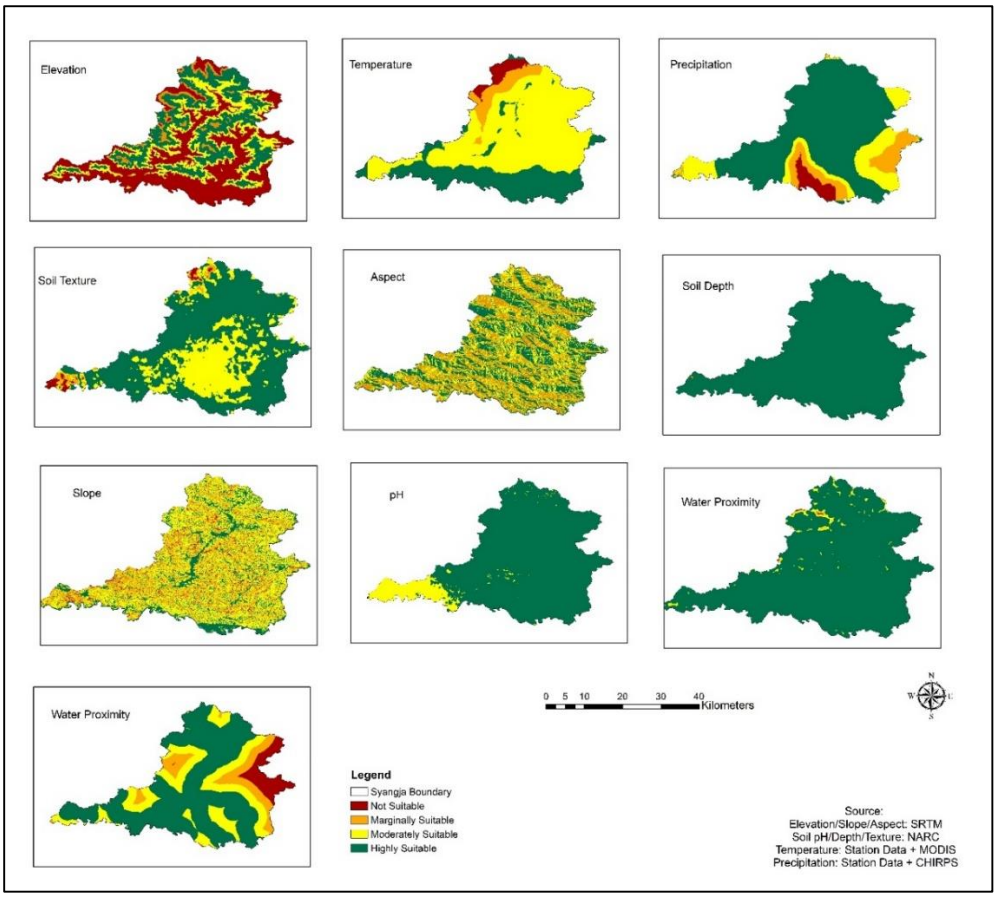
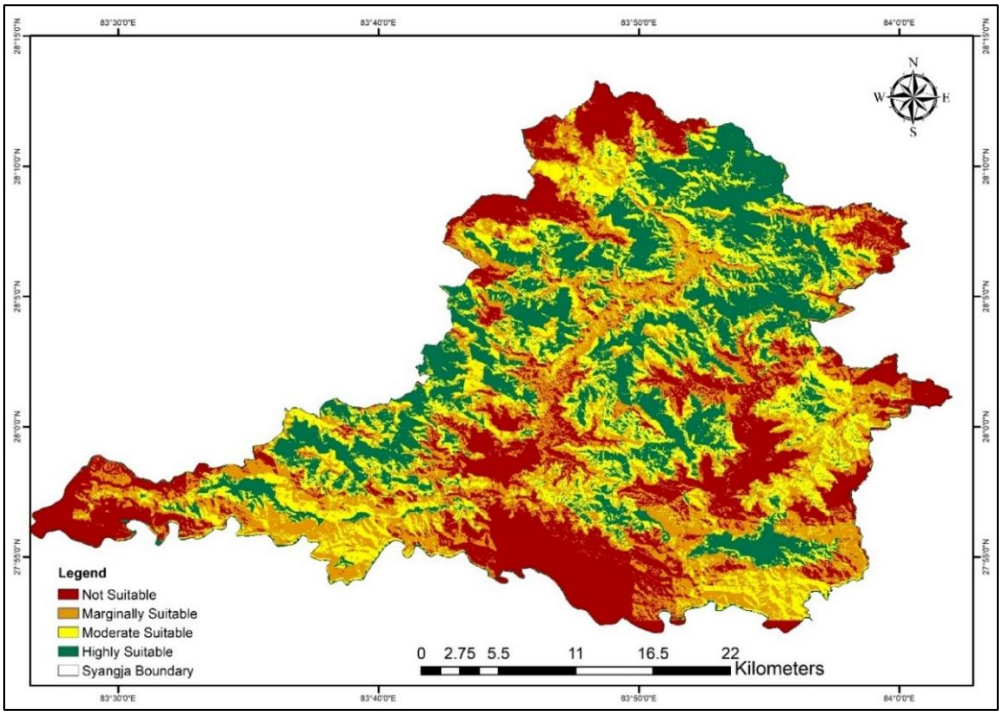


Figure 2 shows the different data layer maps and based on ten parameters, the weighted overlay illustrates the suitable sites for orange farming in the study area, as shown in figure 3.

Figure 3

Land suitability area of Syangja District



Source: Based on figure 2 different cover area is shown in table 2.

Figure 3 and table 2 identify locations suitable for the future expansion of orange farming under the Super Zone program. This AHP map shows an almost evenly distributed pattern of land suitability across the district. The findings indicate that highly suitable land (Highly Suitable), meaning the most appropriate land for commercial orange cultivation, covers nearly one-third of the district's total area 25.44 percent (295.26 km²). These areas possess favorable climatic, topographic and other biophysical conditions as well as good accessibility. Similarly, moderately suitable areas (Moderately Suitable) occupy about 24.79 percent (287.69 km²) of the district. These areas have high potential, and if issues such as inadequate irrigation or soil-related limitations are addressed, they can be converted into highly suitable land for orange farming. Likewise, the marginally suitable and not suitable classes each account for approximately one-quarter of the district's total area. In the Syangja district, land not suitable for orange farming covers 24.92 percent (289.21 km²). Due to the risk of low yields and high investment costs, these areas are not appropriate for orange cultivation and are unlikely to produce good results. However, to promote orange cultivation in the district, the PMAMP have prepared a plan to increase

capacity by planting orange trees over approximately 100 hector of new orchard area (MoALD, PAMP PIU, 2024).

The AHP analysis shows that more than 50 percent (582.95 km²) of the Syangja district is either moderately or highly suitable for orange farming. This confirms why the Syangja district is recognized as a major area for orange production and clearly indicates, through figure 3 where resources should be concentrated to achieve maximum success.

The result shows that four suitability classes (highly suitable, moderately suitable, marginally suitable and not suitable) are almost evenly distributed. Data shows that each suitability covering about 25 percent area of the district. Among these, moderately suitable area covering 24.79 percent (287.69 km²) which offers the greatest potential for further expansion of orange cultivation. The limitations in this area can be managed and improvements such as soil treatment, improved irrigation facility, road access and easier market access could facilitate this land with more suitable orange farming.

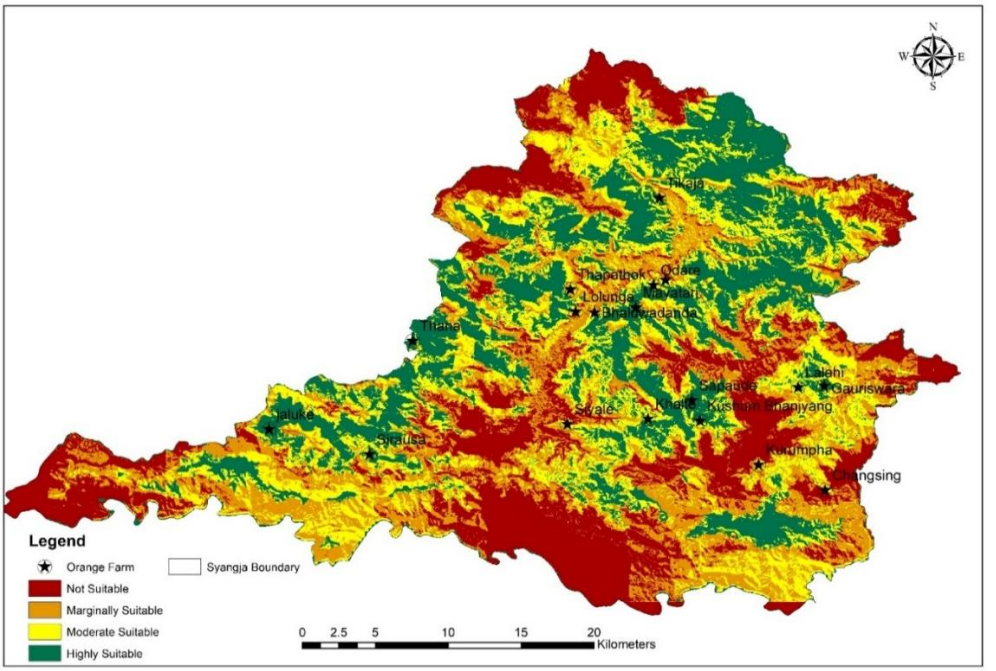
Accuracy Assessment

This study uses ground-truth (field-based) data to verify the results of the LSA model, confirm the existing locations of orange cultivation, and validate the accuracy of the land suitability map. It includes the existing orange farming locations of 18 specific orange farms or reference points that were observed in the field study (Figure 4).

Out of the 18 sites surveyed during the field study, 12 locations such as Sirausa, Jaluke, Thana, Lolunga, Bhaluwadanda, Mayatari, Tikaja, Sapaude, Kushum Bhanjyang, Gauriswara, Lalahi and Kurumpha, are successfully practicing orange cultivation and are identified as suitable areas. The suitability map also shows similar results for these locations. However, areas such as Thapathok, Khalte, Siyale, Rangkhola, Odare and Changsing require further assessment for orange cultivation. Out of the total field-visited sites, 12 fall under the Highly Suitable category and 6 fall under the Moderately Suitable category.

Figure 4

Accuracy assessment map of orange farming in Syangja district



Therefore, the ground reality supports the results of the Land Suitability Analysis, making field verification an important component of confirming suitable locations and validating the model's results. Thus, the weighted overlay results indicate which sites are suitable for further orange farming in the study area.

Conclusion

This study successfully identified and mapped land suitable for orange farming within the Syangja district. This study applied a Land Suitability Analysis (LSA) model that integrates Geographic Information Systems (GIS) with the Analytic Hierarchy Process (AHP). The research adhered to the established FAO land evaluation framework. The findings underscore that land suitability is not determined by any single variable. Land suitability is the outcome of complex interactions among the ten distinct parameters. Using the AHP method, expert opinions were applied to assign appropriate weights to different suitability factors. These factors were analyzed within a GIS environment. The study provides a scientifically sound and practical method for identifying the best areas for orange cultivation in mountainous regions like Syangja district.

The analysis classified approximately 25.44 percent (295.26 km²) of the district as highly suitable for production. When combined with moderately suitable land the

total potential area spans 50.23 percent (582.95 km²) of the district. Data shows that more than half of the area of Syangja districts is very suitable for orange farming. It supports the orange super zone program which has been seen during filed observations in place like Lalahi, Sirausa and Mayatari. However, marginally suitable (288.34 km²) and not suitable (289.21 km²) areas also cover large part of the district. These areas require careful land-use planning. The validation of the AHP model was performed through ground truth. Total 18 existing orange farms were cross-referenced with the suitability map. The validation results show that among 18 existing orange farms, 12 farms are located in highly suitable zones and 6 in moderately suitable ones. Therefore, intensive investment in less suitable areas should be approached cautiously and alternative crops seems to be more practical there. Overall, the results highlight Syangja district as a key orange producing region and provide a strategic spatial framework to promote sustainable development and resource management in Nepal's mid-hill horticulture sector.

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