IDENTIFICATION OF POTENTIAL AGRICULTURAL LAND POOLING SITES IN KASKI DISTRICT USING AHP AND GIS

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ABSTRACT

This study identifies potential agricultural land pooling sites in Kaski District using an integrated Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) approach. Agricultural land pooling seeks to address land fragmentation and promote efficient collective farming. The study considered four major criteria—slope, land parcel area, proximity to roads, and irrigation access following the Agricultural Land Pooling Program Implementation Guidelines, 2077, from the Ministry of Agriculture and Land Management, Gandaki Province.

Criteria weights were calculated using AHP as follows: Slope (60.57%), Area (23.18%), Irrigation Access (11.04%), and Road Proximity (5.21%). A GIS-based weighted overlay method was applied to create a suitability map, classifying land into four categories: Most Suitable, Suitable, Moderately Suitable, and Low Suitable. The results revealed that about 48% of the land parcels fall under the "Most Suitable" and "Suitable" categories, mostly located in the district's central and southern regions. Field validation was carried out using Kobo Collect, resulting in an overall accuracy of 82.35% and a Kappa coefficient of 0.76, indicating a strong agreement between the model and ground data. This research demonstrates that combining AHP with GIS is an effective method for land pooling site selection and offers valuable insights for expanding future land consolidation initiatives.

KEYWORDS: Land Pooling, Agriculture Land, GIS, AHP, DEM

1. INTRODUCTION

1.1 Background

Nepal is predominantly an agricultural nation, with around 62% of its population involved in farming activities, according to the Agriculture Census 2022/23. Agriculture accounts for approximately 25% of the country's Gross Domestic Product (GDP) and serves as a major source of employment (Nepal Economic Forum, 2023). The overall economic development of Nepal is closely tied to the performance of its agricultural sector.

This research highlights the adoption of modern agricultural practices, focusing particularly on land pooling — a method known locally as *Jagga Ekikaran* or *Chaklabandi*. Land pooling is a practical approach to combined farming, where individual farmers consolidate their fragmented plots into larger, more manageable unitsThe adaptation to modern agricultural tools and technologies—such as harvesters, cutters, and other mechanized equipment—becomes significantly easier with larger and regularly shaped land parcels. These uniform plots not only facilitate efficient use of machinery but also help reduce both the time and cost involved in agricultural practices, ultimately enhancing productivity and promoting sustainable farming. By doing so, farming can be managed more professionally, incorporating entrepreneurial skills and business strategies. The profits generated are distributed among the landowners according to the size of their original landholding. Through land pooling, farmers gain better access to agricultural resources like irrigation systems, road networks, and markets, leading to enhanced productivity and a higher standard of living. This method enables the transition from traditional farming to more modern, efficient techniques. Furthermore, under the Local Self-Governance Act of 1999, municipalities and local authorities can actively promote and implement land pooling initiatives.

Gandaki Province, one of the seven provinces, places high importance on agriculture and is strongly oriented toward agricultural development. It consists of 11 districts with Pokhara as its capital. According to the Ministry of Agriculture and Land Management, Gandaki Province (2077), Agriculture is the primary source of income for

86% of all household. Despite this 24 percent of cultivable land remains uncultivated where irrigation is available only on 36.15 percent of the area. So, this province has initiated Cooperative based farming in agriculture through land pooling program as Province Pride Project in more than 32 places where six of them lies in Kaski district.

Table 1. Land Pooling programs conducted by the Ministry of Agriculture, Land Management and Cooperatives in Kaski District.

S. N.	District	Land Pooling Location	Land Pooling Area (Ropani)	Name of Cooperative/Group	Number of Beneficiary Farmer Families
1	Kaski	Machhapuchhre Gaunpalika - 3	208	Bhume Srijansil krishak Samuha	67
2	Kaski	Pokhara Mahanagarapalika - 23	137	Dharapani (Kayer) Krishi Samuha	35
3	Kaski	Machhapuchhre Gaunpalika - 3	108	Annapurna Mahila Prangarik Sahakari Sanstha Ltd	31
4	Kaski	Rupa Gaunpalika	85	Polyantar Tankakaja Krishak Samuha	118
5	Kaski	Pokhara Mahanagarapalika - 28	55	Birat Krishi Sahakari Sanstha Ltd	20
6	Kaski	Pokhara Mahanagarapalika - 16, Armala	57	Lekali Krishak Samuha	100

This study mainly concerns identifying potential land pooling sites in Kaski district using AHP model and GIS. The criteria are set according to Land Pooling Program Implementation Guidelines, 2077 approved by the Honorable Council of Ministers on 2077/04/31 for land pooling program in Gandaki province.

1.2 Study Area

Kaski district lies at the central of Gandaki province. Spanning an area of 2,017 square kilometres, it is characterized by diverse topography, ranging from flat valleys to steep hills and mountainous terrains. It extends between 27°25' N to 28°30' N latitude and 83°30' E to 84°30' longitude. In terms of terrain, the study area lies in the hilly region of Nepal. The elevation value ranges between 367m -7921m.

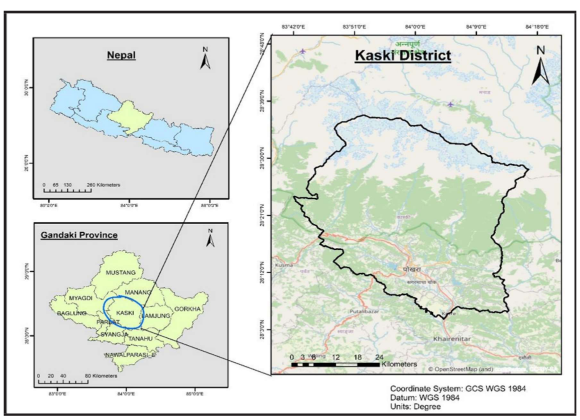

Figure 1. Map of Study Area

2. MATERIALS AND METHODS

2.1 Data Required

Table 2. Data Sources

Data	Resolution	Source	Purpose
DEM	30 m	USGS Earth Explorer	Derived slope from SRTM DEM
Landsat 8	30 m	USGS Earth Explorer	Created LULC map; extracted cropland
Road Network	Vector	OpenStreetMap	Assessed accessibility to land pooling sites
Irrigation	Vector	OpenStreetMap	Access irrigation facility to land pooling sites

2.2 Working Procedures:

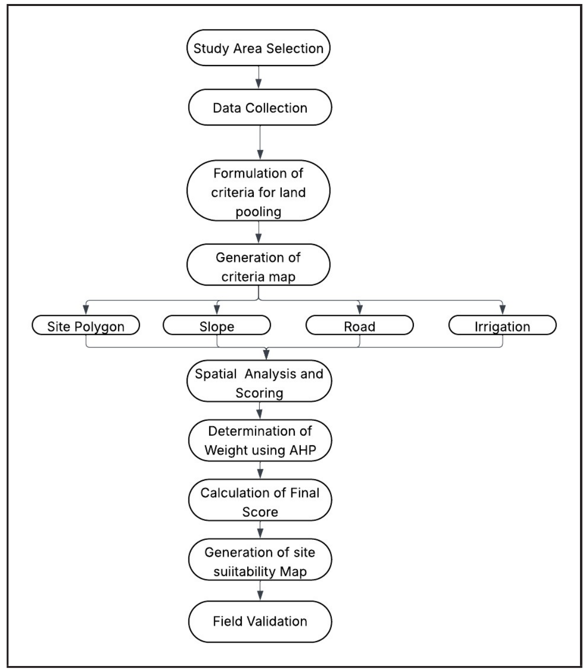

Figure 2: Schematic representation of Methodology

2.2.1 Study Area Selection

Unlike the Terai, where land is flat and well-serviced, the hilly region of Kaski lacks uniform slope, road access, irrigation, and large parcels. This makes it a priority area for identifying suitable agricultural land pooling sites using defined criteria.

2.2.2 Data Collection

DEM, road network, and water sources were collected for spatial analysis along with non-spatial data like the criteria guideline for AHP. Land cover was prepared using Landsat imagery from GEE.

2.2.3 Formulation of Criteria

The criteria and their scoring system were slightly modified from the original guideline to suit the available data and ensure practical applicability in the study area.

2.2.4 Generation of criteria maps using GIS

Slope, road network, and irrigation source maps are not shown, as they were directly derived from reliable sources like USGS (DEM) and OpenStreetMap, requiring only minimal processing for use in the analysis. The Land Use and Land Cover (LULC) map for the project was created using Landsat imagery. The classification was conducted using the Random Forest (RF) algorithm in Google Earth Engine. To distinguish cropland accurately, other major land cover types such as water, vegetation, settlement, bare land, and snow were also classified. These classes helped exclude non-agricultural areas and improve the accuracy of cropland identification. These land cover classes were chosen to represent the major surface features of Kaski district relevant to land pooling analysis. Although land cover was not used directly as a criterion, it was essential for identifying cropland parcels, which were required for the area-based criterion. Therefore, the land cover map was included to show how cropland parcels were extracted for further analysis.

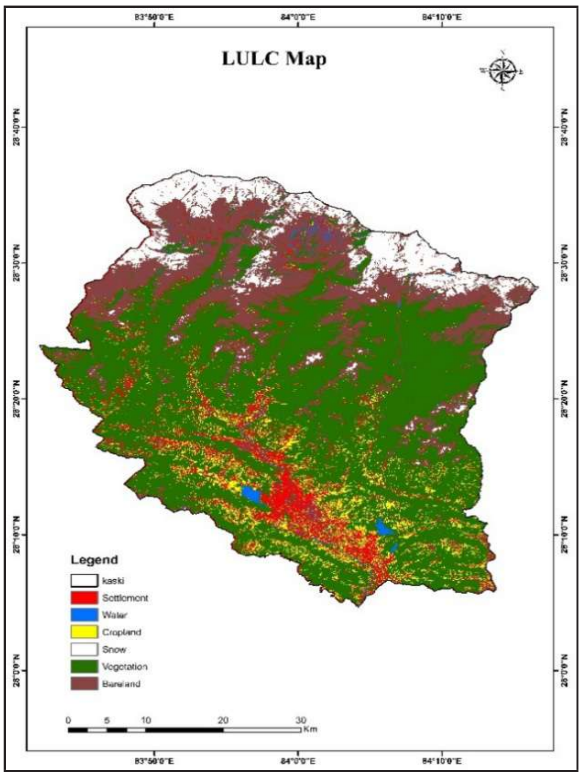

Figure 3: LULC Map of Kaski District

From this imagery, the crop land was extracted and used as a separate layer. This crop land layer was then overlaid on Google Earth Pro, which provided high-resolution satellite imagery for more precise analysis. Using Google Earth Pro's digitizing tools, polygons were manually created to represent the boundaries of the agricultural fields. These digitized polygons were subsequently used to generate a site polygon map, which serves as a key component in the spatial analysis for identifying suitable sites for land pooling.

The confusion matrix below summarizes the performance of the classifier:

Table 3. Confusion Matrix of LULC

Classes	Water	Settlement	Cropland	Snow	Vegetation
Water	22	2	1	0	1
Settlement	2	18	3	0	1
Cropland	0	1	34	0	0
Snow	0	0	0	24	1
Vegetation	0	0	1	0	55
Bare Land	1	2	0	0	3

Table 4. Accuracy Assessment

	Water	Settlement Area	Cropland	Snow
Producer Accuracy	78.57%	60.00%	77.27%	92.31%
Consumer Accuracy	82.14%	62.50%	90.00%	92.31%
Overall Accuracy		81.04%		
Kappa Coefficient		74.20%		

2.2.5 Spatial analysis and scoring

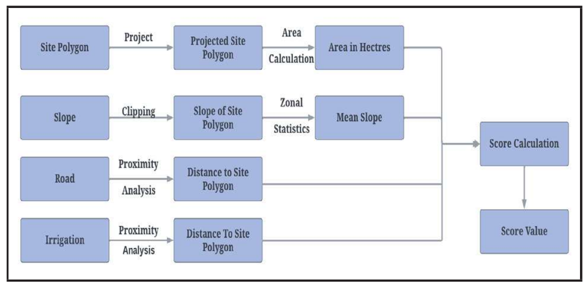

Figure 5. Methodology for Spatial analysis and Scoring

Site polygon analysis

To calculate the area of site polygons for analysis, the data must first be projected into an appropriate **Projected Coordinate System (PCS)** such as UTM, to ensure accurate area measurements. Once reprojected, we use the area calculation tool within the software. The area is typically calculated in hectares.

Slope analysis

The slope map is generated using Digital Elevation Model (DEM) data. To assess the slope for each individual site polygon, zonal statistics are applied, with the mean method used to calculate the average slope within each polygon. This approach allows for a detailed analysis of the topography across the study area, helping to evaluate the suitability of different sites for land pooling based on their slope characteristics.

Road analysis

Proximity analysis is performed using the near tool to calculate the Euclidean distance between each site polygon and the nearest road. This analysis helps in assessing the accessibility of the sites, which is an important factor in determining their suitability for land pooling.

Irrigation analysis

Proximity analysis is performed using the near tool to calculate the Euclidean distance between each site polygon and the nearest waterway. This analysis helps in evaluating the availability of water resources in land pooling sites.

Score Evaluation

Python codes are used in field calculator of attribute table to calculate score for each criterion based on their sub-criteria. Scores are given based on the following sub-criteria set by Ministry of Agriculture and Land Management, Gandaki Province.

Table 5. Sub Criteria for land pooling

Criteria	3=Highest Importance	2=Average Importance	1=Slight Importance
Area	>150 ropani	50-150 ropani	<50 ropani
Slope	0-5Â°	5-10Â°	>10Â°
Road	<100m	100-250 m	>250 m
Irrigation	<50 m	50-100 m	>100 m

2.2.6 Determination of weights using AHP

The Analytical Hierarchy Process (AHP) is a widely used multi-criteria decision-making tool that helps in solving complex problems by structuring them into a hierarchical model consisting of a goal, criteria, and alternatives (Saaty, 1980; Roig-Tierno et al., 2013). It facilitates decision-making in situations where multiple criteria and sub-criteria are involved, especially in cases where interactions between factors are significant (Feizizadeh et al., 2014; Tiwari et al., 1999). AHP is particularly effective in handling both qualitative and quantitative data, allowing the assignment of weights to various decision criteria through pairwise comparisons (Bunruamkaew & Murayama, 2011) AHP allows us to give each factor a **weight** based on its importance and then combine all the results to choose the best option. AHP works very well with **GIS (Geographic Information System)** to create **suitability maps.** These maps help in selecting the best location for things like farming or planning land use (Triantaphyllou & Mann, 1995; Boroushaki & Malczewski, 2008; Bunruamkaew & Murayama, 2011). Because it is both **simple and powerful,** AHP is often used in land suitability analysis for agriculture (Chen et al., 2010a; Akıncı et al., 2013).

The AHP method involves the following key steps and equations:

1. Pairwise Comparison Matrix (PCM):

   Construct a matrix A= [a_{ij}], where

a_{ij}= importance of criterion i and j, using Saaty's scale (1-9)

2. Normalize the matrix:

Divide each element by sum of its column:

$$a'_{ij} = \frac{a_{ij}}{\sum_{\{i=1\}}^{\{n\}} \{a_{ij}\}}$$

3. Compute weights:
Average each row of the normalized matrix:

$$W_i = \frac{\sum_{\{j=1\}}^{\{n\}} \{a'_{ij}\}}{n}$$

4. Calculate
Multiply PCM by weight vector - divide result element wise by weights - average:

$$\lambda_{max} = \frac{\sum \frac{(A.W)_i}{W_i}}{n}$$

5. Consistency Index (CI):

$$CI = \frac{\lambda_{max} - n}{n-1}$$

6. Consistency ratio (CR):

$$CR = \frac{CI}{RI}$$

where RI=Random Index. If CR<0.1, consistency is acceptable.

Table 6: AHP Matrix

Criteria	Area	Road	Slope	Irrigation	Criteria Weight
Area	1	5	0.25	3	0.2318
Road	0.2	1	0.125	0.3333	0.0521
Slope	4	8	1	6	0.6057
Irrigation	0.333	3	0.1667	1	0.1104
Sum	5.5333	17	1.5417	10.3333	

This Calculation yield the following results:

λmax = 4.1494

Consistency Index (C.I) = 0.0498

Consistency Ratio (C.R) = 0.0553

Since, the CR (0.0553) is less than 0.1, the pairwise comparison matrix is consistent and Valid for use in AHP.

2.2.7 Calculation of Final score

The final suitability score for each site polygon is calculated using the weighted overlay formula. Instead of using the weighted overlay tool in GIS directly, the formula is applied manually in the attribute table. A new field named "Final Score" is added to the attribute table, and the Field Calculator is used to apply the formula:

Final Score = ∑ (Weight of Criterion× Criterion Value)

This approach integrates multiple criteria, such as slope, proximity to roads, and proximity to waterways, by assigning weights to each factor based on their relative importance determined through the AHP process.

2.2.8 Generation of Site suitability map

The calculated final scores for each site, based on individual criterion values and their respective weights were integrated into a GIS-based weighted overlay analysis, which classified the study area into four suitability classes: Low Suitable, Moderately Suitable, Suitable, and Most Suitable. The final suitability map illustrates the areas prioritized for land pooling based on the selected criteria.

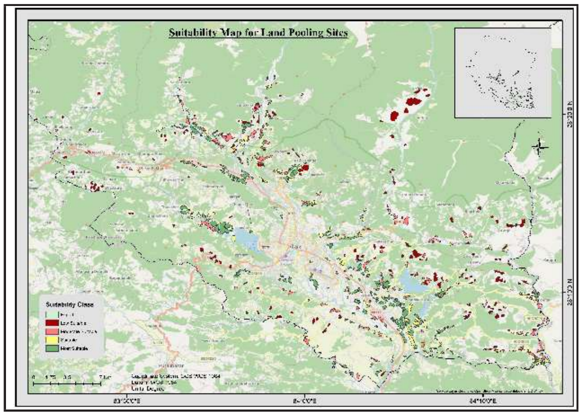

Figure 6. Final Suitability Map for land pooling Sites in Kaski District

2.3 Findings:

The map reveals that most suitable and suitable lands are scattered in the central and southern parts of the Kaski district, particularly around Pokhara Valley. These areas are characterized by relatively flat terrain, good irrigation access, and proximity to existing infrastructure, making them highly viable for land pooling initiatives.

On the other hand, a significant portion of the district (36.75%) falls under low suitability areas. These regions, mostly in the northern and eastern hilly zones, are constrained by rugged topography and lack of accessibility, which pose challenges for large-scale land pooling projects.

The moderately suitable areas, while limited in area (15.38%), might still be potential targets for small-scale or community-led initiatives if complemented with infrastructure development.

Table 7. Area of Suitability Class

Class	Number of Polygon sites	Area in Hectares	Percentage(%)
Most Suitable	168	970.66	22.69
Suitable	154	1077.14	25.18
Moderate Suitable	124	657.89	15.38
Low Suitable	178	1572.24	36.75

2.4 Field Validation and Accuracy Assessment

To validate the suitability classification model, a field verification was conducted. The observed data from the field were compared with the model-predicted classes using a confusion matrix (contingency table). The field data were collected using **Kobo Collect** and the results were analysed using accuracy assessment metrics.

For field validation, a total of 32 ground truth sample sites were selected using stratified random sampling to ensure balanced representation from each suitability class. The sites were distributed among the classes of Most Suitable, Suitable, Moderately Suitable and Low Suitable, with each class containing approximately 8 to 9 sample sites. This approach was adopted to ensure that all categories were adequately represented during the accuracy assessment, enhancing the reliability of the validation results. The location of the sample sites is shown in the map below.

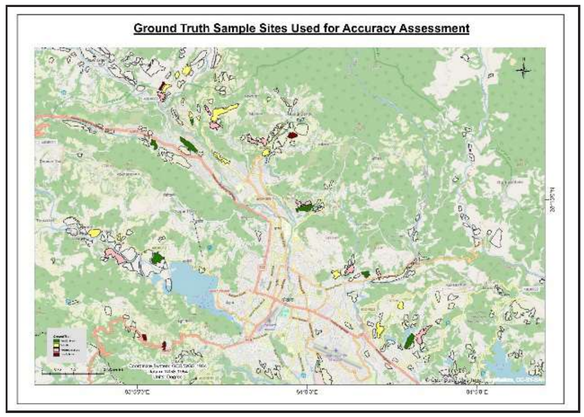

Figure 7. Ground Truth sample site Map

2.4.1 Confusion Matrix (Contingency Table)

The following matrix represents the comparison between the classification results (Model) and the field data (Ground Truth):

Model \ Field	Most Suitable	Suitable	Moderate Suitable	Low Suitable	Row Total
Most Suitable	7	2	0	0	9
Suitable	0	9	1	0	10
Moderate Suitable	0	1	8	0	9
Low Suitable	0	1	1	4	6
Column Total	7	13	10	4	34

This yields the following accuracies:

Accuracy Metric	Most Suitable	Suitable	Moderately Suitable	Low Suitable
Producer's Accuracy	100.00%	69.23%	80.00%	100.00%
User's Accuracy	77.78%	90.00%	88.89%	66.67%
Overall Accuracy	82.35%			
Kappa Coefficient	0.7597			

The field validation of the classification results yielded an overall accuracy of 82.35% and a Kappa coefficient of 0.7597, indicating strong agreement between the classified map and the ground truth data. Most classes achieved high producer's and user's accuracies, with only minor misclassifications. These results confirm that the classification is reliable and suitable for supporting decision-making in the project.

3. CONCLUSION AND RECOMMENDATIONS

3.1 Conclusions

The integration of AHP and GIS in this study has proven to be an effective method for identifying and evaluating potential sites for agricultural Land Pooling within the Kaski district. The final suitability map revealed that nearly half of the analysed area falls under the 'most suitable' and 'suitable' categories, indicating promising zones for future land pooling initiatives. These areas are largely concentrated around relatively flatter terrain with better access to irrigation and infrastructure particularly around Pokhara and its surroundings.

The study highlighted the dominant influence of topographic factors, with slope being the most critical determinant of suitability. The use of a systematic AHP approach provided an objective basis for assigning relative importance to various physical and infrastructural factors, ensuring a balanced and transparent evaluation process.

These results offer significant insights into spatial planning for sustainable land management, especially in a geographically diverse region like Kaski. Moreover, the spatial visualization capabilities of GIS make it easier for planners and decision-makers to interpret complex geospatial relationships, prioritize development zones, and implement policies that align with long-term sustainability goals.

In conclusion, this project provides valuable insight and groundwork that can support policy-level decision-making. The identified suitable areas can serve as reference locations for future land pooling implementation. Therefore, the findings of this research can be highly useful to the Ministry of Agriculture and Land Management of Gandaki Province as a technical basis for promoting and executing land pooling programs at the local and provincial levels.

3.2 Recommendations

Based on the limitations identified during the project in Kaski district, several key recommendations can guide future improvements. First, the model should be enhanced by incorporating additional parameters such as socio-economic factors, land tenure, soil quality, and aspect data, which can provide a more holistic understanding of land suitability. Precision in digitizing parcel boundaries is also crucial and should be achieved using high-resolution satellite imagery or field-verified cadastral datasets. Furthermore, irrigation data should be refined to distinguish between seasonal, permanent, and partial water sources, relying on field verification or official government records rather than generalized OpenStreetMap (OSM) layers. Lastly, to increase the reliability and accuracy of the suitability model, a larger number of field verification sites should be selected across all suitability classes.

The identification of potential land pooling sites through this study should be utilized to improve local-level land use zoning. Land should be categorized into agricultural and residential zones more effectively, with areas deemed suitable for land pooling preserved primarily for agricultural use. Residential development should be discouraged in such zones to protect valuable farmland. This approach should be adopted to support the sustainable management and preservation of agricultural land in the Kaski district, thereby contributing to improved land use planning and long-term food security.

ACKNOWLEDGEMENTS

We sincerely thank the Department of Geomatics Engineering, Pashchimanchal Campus, for the opportunity to undertake this 4th-year project. Our heartfelt gratitude goes to the Ministry of Agriculture and Land Management, Gandaki Province, for their support in providing the necessary data and valuable guidance throughout the project. Their assistance was crucial to the successful completion of our work.

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