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Research Article

Spatial assessment of agricultural vulnerability in selected municipalities of Karnali Province, Nepal

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ABSTRACT

This study evaluates Agricultural Vulnerability Indexing (AVI) across the selected municipalities of Karnali province of Nepal characterized by difficult terrain, fragile agricultural systems, and increasing climatic stresses. Using a geospatial approach, six indicators: land use and land cover (LULC), drainage conditions, slope stability, market availability, livestock suitability, and road accessibility were analysed at the ward level. Data were collected from multiple sources using a structured checklist for three municipalities: Simikot (Humla), Dullu (Dailekh), and Bheriganga (Surkhet). Each indicator has been categorized on a scale of 1 to 5 based on its contribution to overall vulnerability, and the AVI which was also normalized between 0 and 1 to generate composite vulnerability scores. The findings indicated that there was considerable spatial variation in vulnerability across the 34 assessed wards. As of result, Simikot-1 recorded a very high AVI exceeding 0.8, indicating the most vulnerable ward. Similarly, high vulnerability was also observed in Dullu (Wards 1, 8, 13), Simikot (Wards 4, 7, 8), and Bheriganga (Ward 13), while Dullu-4 and Bheriganga-7 exhibited the lowest AVI scores. Environmental limitations like unstable slopes, poor drainage, limited farmland, and socioeconomic challenges like weak infrastructure, low technology access, and poverty increase vulnerability; yet communities use traditional indigenous, community-based practices resiliently. The study highlights the value of geospatial and temporal analysis for identifying ward-specific vulnerabilities and informing evidence-based planning. The results offer practical guidance for prioritizing interventions and strengthening agricultural resilience and food security in Karnali Province.

Keywords: Agriculture vulnerability, Geospatial data, Climate resilient agriculture, Indicators

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INTRODUCTION

People of Nepal depend on agriculture for their livelihoods which also plays a vital role in the food security of the country (Kalogiannidis *et al.*, 2023; Paudel *et al.*, 2021; Gauchan, 2008). However, this sector is becoming more and more vulnerable due to the consequences of environmental degradation, climate change, and socioeconomic limitations. In terms of Karnali

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province which is one of the least developed areas, where vulnerable ecosystems, poverty, and inadequate infrastructure increase risks to agricultural sustainability and these issues are especially acute (Thapa & Hussain, 2021; Hamal *et al.*, 2025). Likewise, undulated terrain, a strong dependence on subsistence farming, and restricted access to markets and inputs are main problem of this province. On top of that, the majority of farmers use rain-fed agriculture, productivity is extremely vulnerable to risks such unpredictable rainfall, droughts, floods, and landslides (Walker *et al.*). These climatic uncertainties have already added to declining crop yields, seasonal food shortages, and livelihood insecurity (Thapa & Hussain, 2021). Climate projections further suggest that rising temperatures and rainfall variability will intensify these risks, disproportionately affecting smallholder farmers (Pandey *et al.*, 2019; MoFE, 2019).

In addition to this, many rural communities lack access to irrigation, credit, quality seeds, market facilities and extension services, further constraining their ability to cope with shocks (Sharma & Neupane, 2025). Consequently, agricultural vulnerability in Karnali province is not only a food production issue, but also acting as a driver of poverty, migration, and social inequities. Understanding agricultural vulnerability at the local level is therefore critical for designing targeted adaptation strategies and evidence-based policies (Urruty *et al.*, 2016; Das & Goswami, 2021). Even though studies have observed climate change and food insecurity in Nepal, localized vulnerability assessments in Karnali's municipalities remain unusual. Addressing this gap is vital for developing adaptation measures that integrate both biophysical and socio-economic dimensions. Against this backdrop, the present study assesses agricultural vulnerability in selected municipalities of Karnali province by examining livelihood assets, institutional capacities, and exposure to climatic risks, thereby contributing to broader debates on sustainable rural development and climate resilience. Road networks, slope stability, natural drainage system, soil characteristics, and market accessibility are all included in the database of chosen communities using these technologies (Mathenge *et al.*, 2022). The goal of this study is to create and record geospatial data and information platforms for climate-resilient agriculture planning and decision support in the chosen municipalities in Nepal's Karnali province by using these tools.

METHODOLOGY

Study Area

The Karnali province, situated in the western part of Nepal (Figure 1), is the country's largest province by area (27,984 km²), but remains one of the least populated and least developed (CBS, 2021). It shares borders with Tibet (China) to the north, Sudurpashchim province to the west, Lumbini province to the south, and Gandaki province to the east. Administratively, Karnali comprises 10 districts and 79 municipalities, of which 25 are urban and 54 are rural (Shahi, 2023). In this study area 3 palikas were selected. Simikot of Humla, Dullu of Dailkeh and Bheriganga of Surkhet district for agricultural vulnerability analysis and assessment. Simikot rural municipality lies in Humla district in Karnali province of Nepal. The geography of this area is marked by steep slopes, deep gorges, and limited areas suitable for agriculture under severe alpine and sub-alpine climatic conditions. This region is accessible only by irregular air service and long foot trails, with almost no connection road network in Nepal's border which reflecting its extreme geographic isolation. Socioeconomically, Simikot rural municipality is highly marginalized. The economic condition is mostly dominated by subsistence agriculture where farmers grow cold-tolerant agricultural products like barley, buckwheat, millet, and potatoes on limited arable land, often on terraced slopes with traditional tools and negligible irrigation infrastructure. The short growing season, poor soils, and severe winters constrain crop yields. Access to markets, health services, education, and modern

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technologies remains limited. These factors contribute to Humla's low human development outcomes relative to national averages.

Similarly, Dullu municipality located in Dailekh district in the mid-hill zone of Karnali province. It covers approximately 156.77 km², it lies on terraced hills of the Mahabharat range which have a temperate hill climate and more reasonable topography compared to high Himalayan areas. According to the CBS 2021, this municipality had a population of 39,143 people, with a relatively high literacy rate (~74.31 %) shown the wider access to education system. This municipality have rain-fed agricultural system, and the surrounding landscape that provides connectivity to the local marketplaces through feeder roads linking to Surkhet and other parts of the province. Agriculture acts as the primary livelihood, with farmers cultivating rice, maize, wheat, and millet, and rearing livestock. Local efforts and resilient practices, such as organic soil management and pest control are underway in some communities. Its socioeconomic heavily rely on agriculture from small-scale commerce to seasonal migration for employment in some places. In terms of connectivity the services are better than in high mountains and many households still face limited access to irrigation, and advanced agricultural technologies development challenges are still prevailing.

In addition to this, Bheriganga municipality is located in Surkhet district of Karnali province. This municipality covers about 256.20 km² and has a population of 48,203 in 2021, with a literacy rate of ~81.15 %—higher as compared to other municipalities of this province. In terms of geographically, this municipality have more favorable terrain and climate relative to mountainous lands. Some portions of this municipality lie near the Bheri river and fertile valley plains which support varied agriculture practices. This region has better road access and networks, stronger market linkages which proximity to Birendranagar, the provincial capital and major economic hub. The environment in this municipality allows cultivation of crops such as rice, maize, and vegetables, with livestock also playing a key economic role. On top of that, socioeconomic conditions have greatly reflect relatively having greater access to services, markets, and infrastructure than more remote municipalities. The major occupations include agriculture, business, services, and migration near country and cities for labor. However, many households depend on small holder agriculture with challenges in market access, productivity, and climate risks similar to other parts of Karnali province.

The main reason behind the selection of Simikot, Dullu, and Bheriganga by their depiction of distinct agro-ecological zones and variable socio-economic conditions within Karnali province. Simikot represents high-mountain agriculture which is characterized by extreme climatic exposure, remoteness, and low adaptive capacity whereas, Dullu characterizes by mid-hill farming systems with moderate accessibility and transitional socioeconomic conditions then Bheriganga represents valley and lower-hill agriculture. Selecting in these distinct and comparative study of how geography, development status, and livelihood systems interact to shape agricultural vulnerability in one of Nepal's most climatically-sensitive and economically disadvantaged provinces. The analysis emphasizes land use patterns, soil health, and water availability, supporting the identification of suitable crop areas and assessing the impacts of climate variability on productivity. The Bheriganga municipality of Surkhet district (Lowland) municipality represents the terai lowland ecosystem, Bheriganga features flat plains and a subtropical climate. Geospatial analysis here focuses on temperature variations, precipitation patterns, and soil composition, essential for understanding climate change impacts on crop phenology and water availability in the region. By considering these three municipalities, the study integrates geographic, climatic, and socio-economic dimensions of vulnerability in Karnali province. The geospatial approach provides localized insights that are vital for

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designing tailored, climate-resilient agricultural strategies to sustain productivity across diverse ecological zones (Nepal *et al.*, 2021).

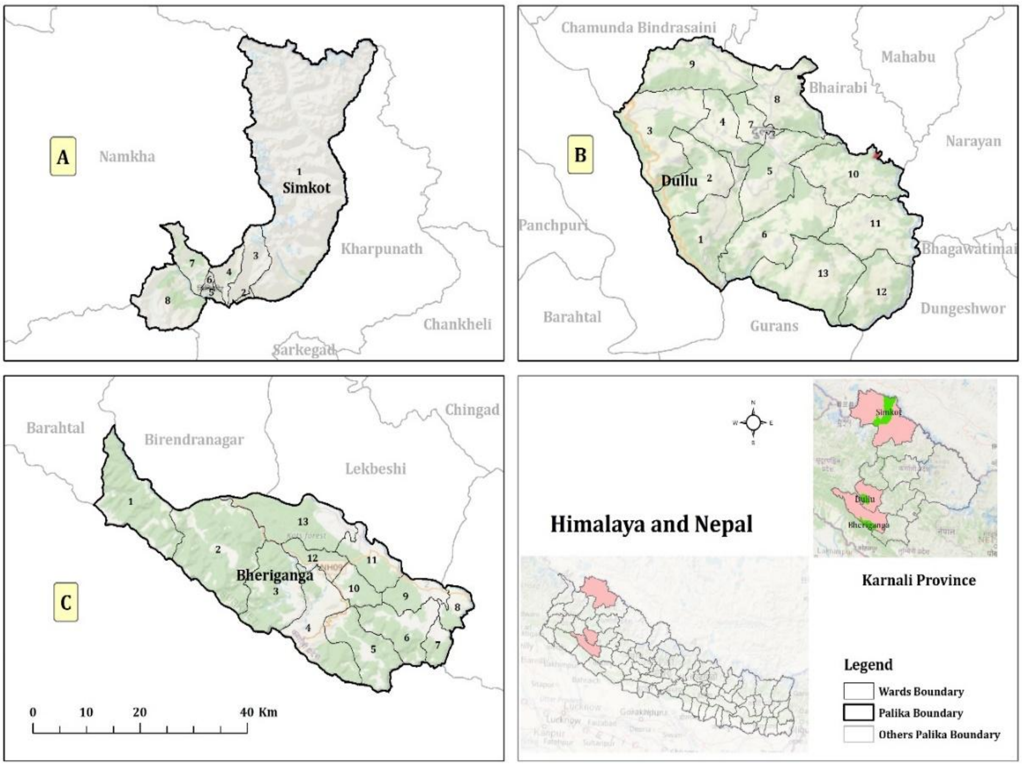

Figure 1: Study site: (A) Simikot, (B) Dullu and (C) Bheriganga municipalities located in the Karnali Province of Nepal

Data and Methods

This study assesses agricultural vulnerability in three selected municipalities of the Karnali province, Simikot, Bheriganga, and Dullu, through the development and application of an AVI (Pleerux, 2013). The methodology is based on the integration of geospatial datasets, statistical scoring, and spatial analysis, with emphasis on both biophysical and socio-economic factors influencing agricultural systems.

Data Sources

Multiple datasets were employed to capture the complex drivers of agricultural vulnerability. Market data acquired from Google maps database was incorporated to analyze proximity, size, demand-supply dynamics, pricing trends, and infrastructure accessibility, providing insights into how market conditions influence agricultural decisions. Land Use and Land Cover (LULC) data acquired from FRTC 2022, were used to evaluate the extent and suitability of agricultural land. Land system and slope data of Land Resources and Mapping Project (LRMP 1986) acquired from Department of Survey, Nepal were also utilized to assess topographical conditions, as steep slopes pose erosion risks while gentle slopes are more suitable for cultivation (Varela *et al.*, 2022).

Additional indicators included road accessibility from Humanitarian data of OCHA, Open Street Map (OSM) database which directly influences farmers' ability to reach markets and input supplies, and drainage system data acquired from LRMP 1986, which identifies areas susceptible to flooding or waterlogging. Livestock data from Agriculture and livestock

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department was also considered, reflecting its importance in income generation, food security, and overall agricultural resilience.

Analytical Framework

The analysis employed Excel, GIS and RS techniques for data processing, integration, and visualization (Bhusal, 2014). GIS tools enabled spatial overlay of different datasets, facilitating the identification of vulnerable zones based on multiple criteria and weighted overlay analysis methods. In some cases, satellite imagery, different raster data related to remote sensing products were used to monitor vegetation health, land cover changes, and climatic variability. Similarly, all the spatial and temporal analysis is done by integration of ArcGIS 10.7 GIS software of ESRI, quantitative analysis is done by Excel. This integrated geospatial approach allowed for a systematic evaluation of agricultural vulnerability across wards and municipalities (Neupane *et al.*, 2021).

Agricultural Vulnerability Index (AVI)

The AVI was constructed to quantify the degree of vulnerability at the ward level by combining six indicators (Pleerux, 2013).

Each indicator was carefully prepared to capture localized conditions:

- *Market Availability* ($Market$)*:* Classified by settlement type, with towns representing low vulnerability, villages moderate vulnerability, and hamlets high to extreme vulnerability.
- *Livestock Resources* ($Livestock$)*:* Categorized based on population and distribution, with most wards falling under very low vulnerability, while only a few showed extreme vulnerability.
- *Land Use and Land Cover* ($LULC$)*:* Evaluated by extent and suitability of agricultural land, with larger agricultural areas considered less vulnerable.
- *Slope Stability* ($Slope$)*:* Classified according to erosion risk and cultivation potential, with steeper slopes associated with higher vulnerability.
- *Drainage Systems* ($Drainage$)*:* Evaluated for waterlogging and flood susceptibility, influencing land productivity and crop selection.
- *Roads* ($Road$)*:* Assessed based on accessibility, connectivity, and distance to markets, directly impacting transportation and agricultural logistics.

Each factor was classified into vulnerability levels, Very Low, Low, Moderate, High, and Very High (Extreme), and assigned a score on a 1–5 scale, where 1 = least vulnerable and 5 = most vulnerable. For example, wards with extensive agricultural land were categorized as very low vulnerability, while those with limited agricultural land were categorized as extreme vulnerability. Similarly, towns with stable and accessible markets were scored as low vulnerability, whereas remote hamlets with poor market access were classified as high or extreme vulnerability.

The Total Vulnerability Score (TVS) for each ward was calculated as:

$$\text{TVS} = \text{Drainage} + \text{Slope} + \text{Market} + \text{LULC} + \text{Livestock} + \text{Road} \ldots\ldots\ldots\ldots \text{(i)}$$

Given six indicators, the minimum possible score is 6 (least vulnerable), while the maximum score is 24 (most vulnerable**).**

To standardize the results, a Normalized Vulnerability Index (NVI) was derived:

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$$NVI = \frac{(TVS-6)}{18} \text{ ……………… (ii)}$$

This transformation yields values between 0 (least vulnerable) and 1 (most vulnerable), ensuring comparability across wards and municipalities.

Interpretation of AVI

The classification of normalized index values into ordered vulnerability classes (Very Low to Very High) using equal intervals is a recognized approach in agricultural and climate vulnerability mapping. The normalized values were grouped into four vulnerability categories (Ravetz, 2005; Gbetibouo & Ringler, 2009).

Table 1: Grouping of normalized values into four vulnerability categories

Score	Vulnerability
0.00 – 0.20	Very Low
0.20 – 0.40	Low
0.40 – 0.60	Moderate
0.60 – 0.80	High
0.80 – 1.00	Very High (Extreme)

This classification allows for a nuanced assessment of agricultural vulnerability at the ward level, highlighting priority areas requiring interventions in infrastructure development, market integration, and sustainable land management.

RESULTS AND DISCUSSION

Land Use and Land Cover

The Land Use and Land Cover (LULC) condition in relation to agricultural vulnerability varies between wards, as shown in Figure 2(A). The data from Bheriganga, Dullu, and Simkot indicates that the level of “Vulnerability” varies according to LULC characteristics. Ward 1 in Bheriganga is designated as "Highly Vulnerable", which implies that there are many possible issues and/or threats to agriculture because of how the land is used. In contrast, ward 13 in Bheriganga is identified as "Very Low Vulnerability", which indicates that this location has a more favorable LULC environment for agricultural production. Ward 1 in Dullu has a designation of "Low Vulnerability", which shows a more moderate amount of Risk to Agriculture due to the relatively stable LULC environment. Additionally, ward 12 in Dullu is classified as a "Very Low Vulnerability", which identifies this ward as having suitable LULC for agricultural production. All Wards in Simkot (Wards 1, 2, 3, 4, 6, 7, & 8) are classified as "Extreme Vulnerable", which suggests adverse LULC conditions present significant risks or limitations to Agricultural production. Ward 5 is classified as "High Vulnerability" due to the presence of moderate risk and challenges associated with LULC affecting agricultural production. By examining agricultural vulnerability regards to LULC characteristics across different wards, it is evident that agricultural conditions and challenges differ from one part of a district to another, thus providing clear opportunity for institute specific interventions that enhance agricultural resilience and sustainability (Karki *et al.*, 2022).

Drainage System

Figure 2 (A) also presents agricultural vulnerability in terms of the drainage system across different wards in Bheriganga, Dullu, and Simkot, revealing varying levels of vulnerability. In Bheriganga, Wards 1, 5, 10, and 12 are categorized as low vulnerability, indicating relatively favorable drainage conditions for agricultural activities. Wards 3, 4, 6, 7, 8, 9, 11, and 13 fall

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under the moderate vulnerability category, suggesting some drainage-related challenges or risks that may moderately impact agriculture. In Dullu, several wards, including 1, 3, 4, 6, 7, 8, 9, 10, and 11, are classified as low vulnerability, indicating generally favorable drainage conditions. Wards 12 and 13 are categorized as moderately vulnerable, reflecting moderate challenges or risks related to drainage. In Simkot, Wards 1, 2, and 5 are classified as low vulnerability, suggesting favorable drainage conditions for agriculture. Wards 3, 4, 6, 7, and 8 fall under the moderate vulnerability category, highlighting moderate drainage-related challenges that may affect agricultural activities. This agricultural vulnerability based on the drainage system shows varying levels of risk and challenges that may impact agricultural productivity and sustainability in these wards. Such information can guide targeted interventions and strategies to address drainage-related issues and enhance agricultural resilience in vulnerable areas (Paudel *et al.*, 2021).

Livestock

Figure 2(B) presents agricultural vulnerability in terms of livestock farming across different wards in Bheriganga, Dullu, and Simkot. The analysis reveals varying levels of vulnerability, represented by Livestock Suitability Ratings (LSR). In Bheriganga, most wards are categorized as moderately vulnerable, indicating a relatively stable and manageable environment for livestock rearing; however, Ward 13 stands out with a low vulnerability rating, suggesting more favorable conditions for livestock farming compared to other wards in Bheriganga. In Dullu, Ward 7 is classified as highly vulnerable, reflecting potential challenges or risks associated with livestock management in that ward. Wards 10, 11, and 13 are categorized as low or very low vulnerability, highlighting differences in suitability for livestock farming across the district. In Simkot, several wards, including 1, 3, 4, 5, and 6, are classified as highly vulnerable, indicating significant challenges or risks for livestock rearing. Wards 7 and 8 are categorized as low vulnerability, suggesting relatively favorable conditions for livestock farming compared to other wards in Simkot. This agricultural vulnerability in terms of livestock farming highlights the diverse conditions and challenges faced in each ward, providing valuable insights for targeted interventions and strategies to enhance livestock management and resilience. Such information can guide decision-making and resource allocation to support sustainable livestock farming practices (Darjee *et al.*, 2023).

Availability of markets

Figure 2(B) also presents agricultural vulnerability in terms of market availability across different wards in Bheriganga, Dullu, and Simkot. Market availability provides insights into the accessibility and stability of markets for agricultural products. In Bheriganga, Wards 1 and 2 are categorized as having high market availability, indicating robust and accessible markets for agricultural produce. Most other wards are classified as having moderate market availability, suggesting reasonably stable market conditions, but with potential limitations compared to high-availability wards. In Dullu, Wards 1, 2, and 9 are categorized as having high market availability, reflecting strong market access and opportunities for agricultural products. Ward 7, however, is classified as very low market availability, highlighting limited access to markets for agricultural produce in that ward. In Simkot, Ward 3 stands out with low market availability, indicating restricted or unstable market conditions for agricultural products. Wards 2, 6, 7, and 8 are categorized as very low market availability, reflecting significant challenges in accessing markets for agricultural produce. This agricultural vulnerability in terms of market availability highlights the varying levels of market access and stability across different wards, providing valuable insights for planning and decision-making to enhance market connectivity and opportunities for agricultural producers in vulnerable areas. Such information can guide interventions and strategies to improve market access, promote

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market linkages, and strengthen the resilience of agricultural markets in these regions (Pandey, 2019).

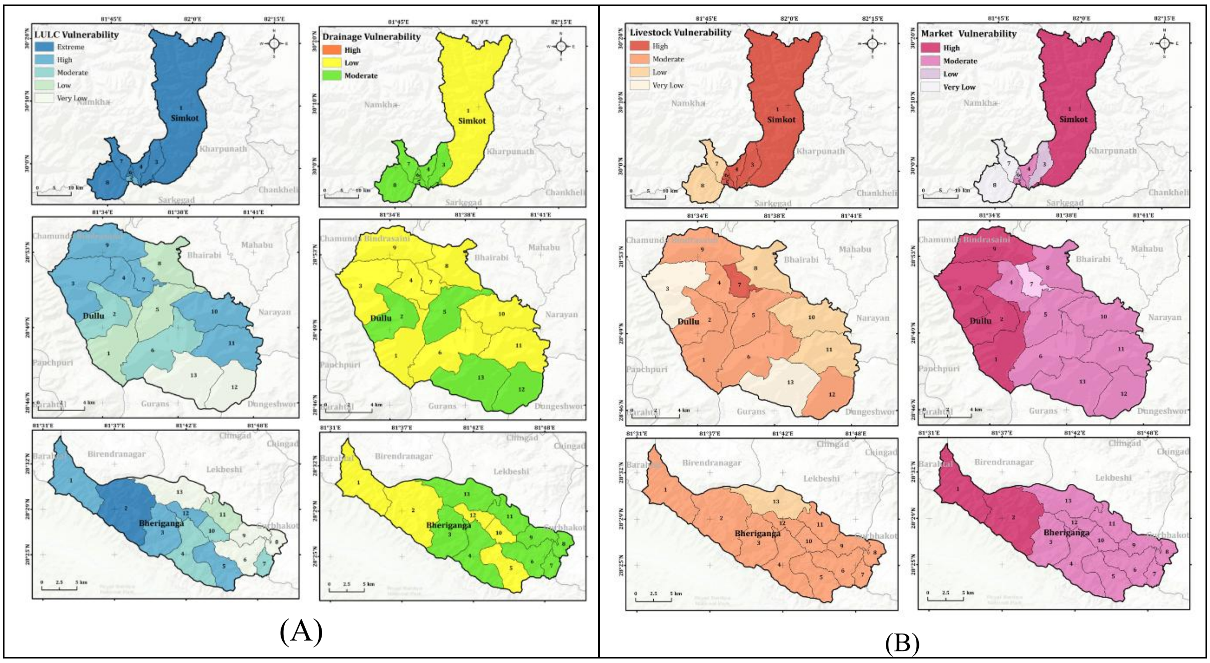

Figure 2: (A) Availability of agriculture land (LULC) and drainage vulnerability in the municipalities; (B) Livestock and market vulnerability of the municipalities

Road accessibility

Figure 3 (C) presents agricultural vulnerability in terms of road accessibility across different wards in Bheriganga, Dullu, and Simkot, providing insights into the ease of transportation and connectivity for agricultural activities. In Bheriganga, Wards 1, 9, 10, and 13 are categorized as having low road accessibility, indicating potential challenges or limitations in transportation infrastructure that may affect agricultural logistics and market access. Wards 6, 8, and 11 have moderate road accessibility, suggesting relatively better transportation options compared to low-accessibility wards. In Dullu, Ward 1 is classified as having very low road accessibility, highlighting significant challenges in transportation infrastructure for agricultural activities. Wards 4, 7, and 9 have high road accessibility, indicating better connectivity and transportation options for agricultural produce. In Simkot, Wards 1 and 2 are categorized as having extreme road accessibility, reflecting excellent transportation infrastructure and connectivity for agricultural activities. Wards 3, 4, 5, 6, 7, and 8 have high road accessibility, highlighting favorable transportation options and connectivity for agricultural products. This agricultural vulnerability in terms of road accessibility reveals the varying levels of transportation infrastructure and connectivity across different wards, providing valuable insights into the challenges and opportunities associated with agricultural transport. Such information can guide infrastructure development, logistics planning, and market access strategies to enhance resilience and sustainability in areas with varying road accessibility (Bhatt *et al.*, 2019).,

Slope

Figure 3(C) also presents agricultural vulnerability in terms of slope across various wards in Bheriganga, Dullu, and Simkot. Slope ratings provide insights into the suitability of land for agricultural activities based on steepness. In Bheriganga, Wards 6, 9, and 11 are categorized as having high slopes, indicating challenging terrain that may pose risks or limitations for agriculture. Wards 10 and 12 are classified as having low slopes, suggesting more favorable

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land gradients for agricultural activities. In Dullu, several wards, including 2, 3, 12, and 13, are categorized as having high slopes, representing steep terrain that may present significant challenges for agriculture. Wards 6, 8, 9, 10, and 11 have low slopes, indicating more suitable land gradients for farming. In Simkot, Wards 1, 4, and 5 are classified as having high slopes, highlighting challenging terrain that may affect agricultural practices, while Wards 2, 3, 6, 7, and 8 have low slopes, suggesting relatively favorable conditions for agriculture.

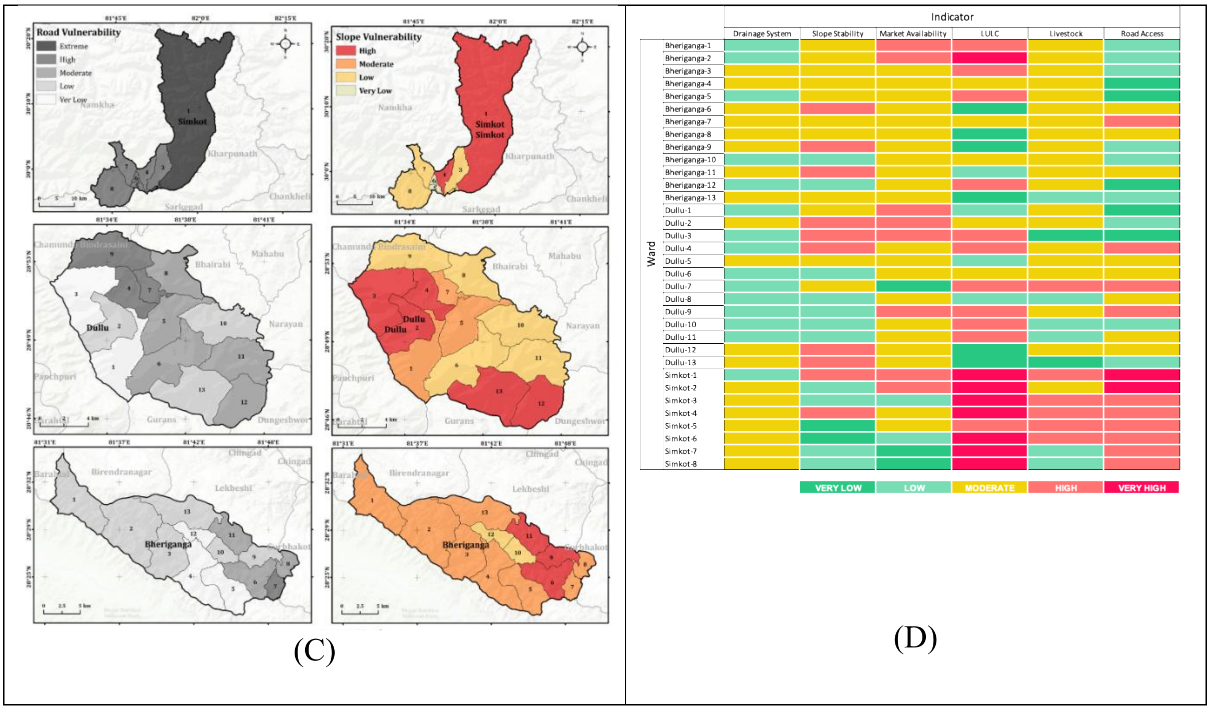

Figure 3: (C) Road and slope vulnerability of the selected municipalities; (D) Comparison of the wards for different indicators' vulnerability

This agricultural vulnerability in terms of slope reveals the diverse range of land gradients across different wards, providing valuable insights into the challenges and opportunities associated with terrain suitability for agriculture. Such information can guide land management practices, soil conservation efforts, and agricultural planning strategies to enhance resilience and sustainability in areas with varying slope conditions. (Neupane *et al.*, 2021).

Composite AVI

Figure 3 (D) compares wards of Bheriganga, Dullu, and Simkot municipalities across six indicators of agricultural vulnerability: drainage system, slope stability, market availability, LULC, livestock, and road access. The results reveal diverse conditions across wards, highlighting both opportunities and constraints for agriculture. For instance, some wards in Bheriganga and Dullu show favorable market availability, but limited road access, while Simkot wards often have strong LULC suitability, but face challenges in slope stability and drainage. This ward-level comparison illustrates the heterogeneity of vulnerabilities and provides valuable insights for designing targeted interventions to enhance agricultural resilience.

Figure 4 presents a composite AVI to provide an overall measure of vulnerability for Bheriganga, Dullu, and Simkot municipalities based on the six indicators. It shows notable spatial variations in AVI. In Bheriganga, most wards fall under low to moderate vulnerability, with relatively favorable market access, but limited road infrastructure. Dullu displays mixed

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conditions: some wards perform well in markets and LULC, but struggle with drainage and road access, creating moderate to high vulnerability in several areas. Simkot shows higher overall vulnerability, driven by steep slopes, drainage challenges, and livestock constraints, despite strong LULC ratings. The composite AVI highlights how these interacting factors shape agricultural risks, providing valuable insights for targeted interventions and resilience planning.

The AVI using six key indicator factors provide a holistic understanding of the strengths and weaknesses of different wards, offering insights for more informed and sustainable agricultural development. The analysis of livestock suitability showed varied conditions across wards. Some areas have favorable environments for livestock rearing, while others face significant challenges due to low or very low suitability. These variations highlight the need for targeted livestock management strategies, such as improved fodder availability, veterinary services, and better breed selection, to strengthen productivity in vulnerable areas.

Road accessibility emerged as another critical factor. Wards with poor road networks face serious barriers in transporting agricultural products, accessing markets, and securing essential inputs like seeds and fertilizers. On the other hand, wards with high accessibility benefit from smoother agricultural logistics and greater market integration. This suggests that investments in rural road infrastructure can directly enhance agricultural resilience by reducing isolation and improving farmers' opportunities. The drainage system analysis provided important insights into water management. Wards with high or extreme vulnerability to drainage issues risk waterlogging, flooding, or poor soil drainage, all of which can reduce crop productivity. In contrast, areas with more favorable drainage still require effective water management practices to optimize farming. This indicates that drainage improvement, irrigation planning, and flood-control measures should be part of local agricultural strategies. The slope conditions of different wards also played a significant role. Areas with steep slopes face erosion risks and limited land for cultivation, requiring soil conservation and terracing practices. Conversely, wards with gentler slopes provide more favorable land for farming, but still demand careful land management to avoid long-term degradation.

Similarly, market availability strongly influences farmers' ability to sell produce and sustain incomes. Wards with good market access can benefit from robust opportunities, while those with low market access remain disadvantaged, affecting both productivity and profitability. Strengthening local markets, cooperatives, and market linkages is essential to address these disparities. Finally, LULC assessment highlighted the diversity of land utilization patterns. Sustainable land use practices are vital for balancing agricultural productivity with environmental conservation. Integrating biodiversity-friendly farming and efficient land management will help build resilience to climatic variability.

It is important to note that this study excluded climatic data due to the small study area and the limitations of low-resolution datasets; however, climate factors such as rainfall and temperature are crucial in larger-scale studies where high-resolution data can provide valuable insights into climate change impacts and adaptation strategies. Overall, this study shows that agricultural vulnerability in the selected municipalities which shows a clear picture of Karnali province is shaped by interconnected factors. Addressing these challenges requires a multi-dimensional approach, combining infrastructure development, sustainable land management, improved market access, and tailored livestock and water management strategies. Such an integrated approach can strengthen agricultural resilience, productivity, and long-term sustainability in the province.

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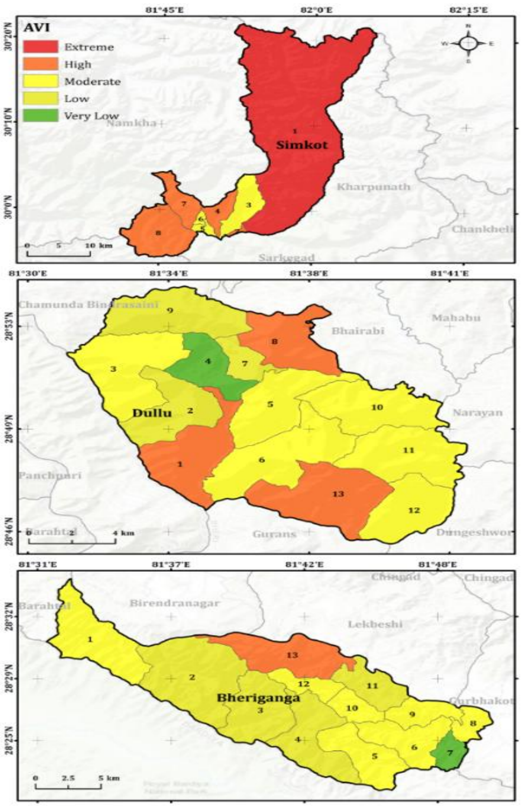

Figure 4: Composite AVI of Bheriganga, Dullu, and Simkot municipalities

CONCLUSIONS

This study determines that agricultural vulnerability index of selected municipalities of Karnali province is formed by the combined influence of biophysical and socio-economic factors, rather than any single determinant. Key indicators—including livestock suitability, road connectivity, drainage conditions, slope characteristics, market accessibility, and land use/land cover—interact to define the exposure, sensitivity, and adaptive capacity of farming communities. Livestock-related findings highlight the need for improved management systems to better support household nutrition and income. Limited road access underscores the role of infrastructure in enabling farmers to reach markets, inputs, and services. Similarly, drainage and slope conditions affect water availability, erosion risks, and the overall suitability of land for cultivation, while market availability reflects disparities in livelihood opportunities across settlements. LULC patterns point to the importance of sustainable resource use and climate-resilient land management. Integrating these dimensions provides a comprehensive perspective on agricultural vulnerability and offers actionable insights for planning. Strengthening rural infrastructure, enhancing market linkages, promoting sustainable land and water management, and supporting livestock-based livelihoods are essential pathways to reduce risk and build resilience. Ultimately, mitigating agricultural vulnerability in Karnali province requires coordinated efforts among policymakers, development practitioners, and local communities. By combining geospatial evidence with local knowledge, future interventions can more effectively promote sustainable livelihoods and long-term agricultural resilience across diverse ecological zones.

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Author's contribution
BM, SRG, PRA, KPA and ST contributed for conceptualization, methodology, data curation, formal analysis and writing original draft. All authors read and approved the final manuscript.

Conflicts of Interest
The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Ethics Approval Statement
This study did not involve human or animals. Prior to conduct this study, approval from relevant local authorities was obtained. This study was conducted in accordance with local regulations and ethical guidelines. No protected or endangered plant or animal species were harmed during this study.

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