Indian Journal of Hill Farming, (2025); 38(3):32-40.

doi: 10.56678/iahf-2025.38.03.06

ISSN: 0970-6429

ijhfonline.org

RESEARCH ARTICLE

Assessment of rice (*Oryza sativa* L.) field conversion to large cardamom (*Amomum subulatum* Roxb.) cultivation in West Sikkim using GIS and farmers' perceptions

Sudeep Gurung[1], Laxuman Sharma[1*], Narapati Sharma[2], Lomash Sharma[1]

Abstract

Conversion of agricultural land from food crops to cash crops has been increasingly common in the Himalayan region. The present study documented the conversion of rice (*Oryza sativa* L.) fields to large cardamom (*Amomum subulatum* Roxb.) cultivation in selected Gram Panchayat Units (GPUs) of West Sikkim during the period 2005 to 2015 by using geographic information system (GIS) techniques and farmers' perception surveys. Land use change was quantified from temporal satellite imagery from Google Earth and analyzed in ArcGIS 10.0. In addition, a field survey of 47 farmers was conducted through structured questionnaires and semi-structured interviews to identify the factors that contribute to land conversion. The results demonstrated a decrease in the area under rice cultivation from 15.16 ha in 2005 to 11.87 ha in 2015. The GIS analysis revealed that 4.27 ha, or 28.3 % of the rice growing area, had been converted to large cardamom cultivation during the study period. Observed land-use changes were confirmed by ground verification of selected sites. The major reasons for conversion identified by the farmers are: inadequate irrigation water, damage by rodents and wild animals, shading by nearby forests, long dry spells, incidence of pests and diseases, and risk of soil erosion on steep slopes. Farmers also perceived that large cardamom cultivation was more lucrative and less labor-intensive than that of rice. The study reveals a drastic shift in cultivation from rice to large cardamom in West Sikkim due to environmental and socioeconomic reasons. Crop diversification could enhance farm income, but continued conversion of rice fields may constitute a potential threat to the local food security and conservation of indigenous rice germplasm. The results offer useful information for sustainable land use planning and policy formulation in the Himalayan region.

Keywords: Land-use change, Crop diversification, GIS, Indigenous rice germplasm, Sustainable agriculture.

Introduction

Sikkim is a Himalayan state in northeastern India with diversified agroecological conditions and rainfed agriculture. Rice (*Oryza sativa* L.) is the principal cereal crop cultivated in the lower and mid-hill regions of the state (Singh *et al.* 2021). Traditionally, rice is grown on well-organized terraced fields with bunds for retaining water and flood irrigation during the monsoon season. In addition to household food security, rice cultivation also helps in the conservation of many indigenous rice germplasms adapted to the specific environmental conditions of the Eastern Himalayas (Kapoor *et al.* 2017; Choudhury *et al.* 2013). However, official statistical data on the area under rice cultivation indicate a substantial decline in the area under rice cultivation in Sikkim, decreasing from approximately 14,740 ha. in 2003–2004 to about 8,700 ha. in 2020–2021despites the improvements in crop productivity (Parikh 2023; Karuppaiyan and Rahman 2007; Gurung and Hannan 2021).

The decline of rice cultivation has been attributed to several factors such as low economic returns, changing rainfall patterns, lack of irrigation facilities, increasing production costs and labour shortages. Meanwhile, farmers have been increasingly adopted high value cash crops as alternative livelihood options. Among these, large cardamom (*Amomum subulatum* Roxb.) has been one of the most important commercial crops in the Eastern Himalayan region commonly known as *bara elachi* (Hindi), greater or large cardamom (English), is a perennial herb, grows upto

[1]Department of Horticulture, Sikkim University, Samdur, Gangtok, East Sikkim, India – 737102

[2]Department of Science and Technology, Government of Sikkim Deorali, Gangtok, East Sikkim, India – 737102

***Corresponding Author:** Laxuman Sharma, Department of Horticulture, Sikkim University, Samdur, Gangtok, East Sikkim, India – 737102, E-Mail: lsharma@cus.ac.in

How to cite this article: Gurung, S., Sharma, L., Sharma, N., Sharma, L. 2025. Assessment of rice (*Oryza sativa* L.) field conversion to large cardamom (*Amomum subulatum* Roxb.) cultivation in West Sikkim using GIS and farmers' perceptions. *Indian J. Hill Farm.*, **38**(3):32-40.

Source of support: Nil

Conflict of interest: None.

Received: 14/11/2025 **Revised:** 12/06/2026 **Accepted:** 12/06/2026

height of 1.7 to 2.6 m with a leafy stem and subterranean rhizomes cultivated in the swampy places along the side of mountain streams (Prakash *et al.* 2012). It is a major spice used in various culinary purposes, especially in the preparation of sweet meats (Govindarajan *et al.* 1982). Besides, it also has medicinal properties, such as antiulcerogenic effect, hepatoprotective activity, and fungitoxicity (Jafri *et al.* 2001; Dubey *et al.* 2008). Traditionally grown under the shade of Himalayan alder (*Alnus nepalensis* D. Don.), it is widely cultivated in Sikkim, Nepal, Bhutan, Darjeeling and Arunachal Pradesh (Sharma *et al.* 2009). In the year 2010-2011, the total area under large cardamom cultivation in India was estimated to be around 27655 hectares, of which the state of Sikkim covers the area of 23,679 hectares. Sikkim has the largest area and the highest production of large cardamom in India (Negi *et al.* 2018). The cultivars mainly grown in this region are Ramsey, Seremna, Golsey, Ramla, Sawney, Varlangey, and improved varieties like ICRI Sikkim 1 and ICRI Sikkim 2 (Singh *et al.* 2018). Sikkim alone contributes a lion's share to India's large cardamom production, approximately 84%, making the crop an important component of the state's economy (Negi *et al.* 2018). Owing to its high market value and comparatively lower labour requirements, large cardamom cultivation has become increasingly attractive to farmers.

Rice (*Oryza sativa* L.) cultivation in Sikkim has ancient roots, which is cultivated on terraces in terrace at lower and mid hills region of the state. Fifty- two traditional rice germplasm and some improve varieties are reported to be grown in Sikkim (Kapoor *et al.*, 2017). The terraces with bunds are prepared across the slope to facilitate flooding during cultivation. Usually, rice is cultivated in the Kharif (June-November) season. Terrace rice fields are specific to rice cultivation with open space and high sunlight availability. However, of late, there has been a trend of planting cardamom in the rice field, thereby completely abandoning the particular field for rice cultivation. As cardamom is a perennial crop, the potential for re-establishing rice cultivation in these fields diminishes significantly, raising grave concerns regarding the loss of rice cultivation areas and the traditional rice germplasm.

Geospatial technologies, such as geographic information systems (GIS) and remote sensing, are effective tools for monitoring land use changes and evaluating agricultural diversification over time. Expansions of large cardamom cultivation and changing agricultural practices in Sikkim have been recorded in previous studies (Lepcha et al. 2023). However, there is little information on the spatial extent of rice-field conversion to large cardamom cultivation in West Sikkim and the socioeconomic and environmental factors driving the transition. Furthermore, studies combining GIS-based land use assessment with farmers' perceptions are still limited in the region.

It was hypothesized that environmental constraints, particularly declining water availability and changing climatic conditions, together with the socioeconomic advantages of large cardamom cultivation, have significantly contributed to the conversion of rice fields into large cardamom plantations. Therefore, the objectives of the present study were to quantify the extent of rice-field conversion to large cardamom cultivation between 2005 and 2015 using GIS and temporal satellite imagery along with validate the observed land-use changes through field verification and assess farmers' perceptions regarding the factors responsible for the conversion of rice fields into large cardamom plantations in selected locations of West Sikkim.

Materials and Methods

Description of study area

The study was undertaken in selected Gram Panchayat Units (GPUs) of the West district of Sikkim, viz., Berthang, Bermiok, Hee-Yangthang, Martam, and Pechrek. It is located between 88°11'17.894" and 88°15'39.534" East longitudes and 27°17'55.523" and 27°14'4.866" North latitude. It occupied an area of about 2292 ha. of land. The following locations consist of two perennial rivers, viz., *Kalej and Rangsang*. The elevation ranges from 600 m to 1900 m above the mean sea level. The region experiences a humid subtropical to temperate climate and high rainfall from June to September. Paddy cultivation and large cardamom production constitute the major agricultural activities in this area.

Data sources and image acquisition

Temporal satellite imagery available through Google Earth Pro was used to evaluate land-use changes from 2005 to 2015. Historical images selected for each study year were based on clarity, cloud-free conditions and availability. Rice cultivating areas and land converted to large cardamom plantations were interpreted visually from high-resolution images.

Ancillary information was collected from field observation and existing secondary sources, including administrative boundaries, roads, rivers, and topographical features.

GIS Mapping and digitization procedure

Manual digitization of the study area boundary, rice fields, roads, rivers and other relevant land features was done from Google Earth imagery using polygon, line and point features. Separate vector layers were prepared for the years 2005 and 2015. The digitized layers were exported as Keyhole Markup Language (KML) files and were imported into ArcGIS 10.0 for further spatial analysis. Manual on-screen digitization was employed because of the small study area and the high spatial resolution of the imagery. Care was taken to ensure

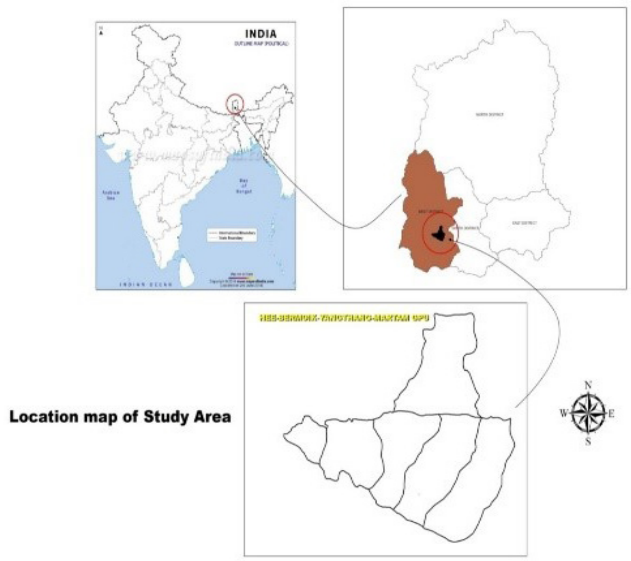


Fig 1: Location map of study area

consistency in digitization by maintaining similar mapping scales during interpretation of both image years.

Analysis of land use change

The land use changes were identified by overlaying the digitized layers of rice fields of 2005 and 2015 in ArcGIS 10.0. The areas under rice cultivation for the two years were calculated using ArcGIS geometry tools. The extent of land converted from rice cultivation to large cardamom plantation was determined through overlay analysis and comparison of areas.

The percentage change in rice cultivation area was obtained by:

Percentage Change (%) = [(Area in 2015-Area in 2005)/Area in 2005] * 100

Converted areas identified through GIS analysis were mapped and field verified.

Ground validation and validation

Field visits were undertaken in March 2018 to validate the GIS-based interpretation. Ground truthing was performed at 28 sites identified as converted areas based on analysis of the satellite images. Land use observed at each site was recorded and compared with GIS interpretation.

Field observations validated the conversion of identified locations from rice cultivation to large cardamom plantations. The validation process increased confidence in the veracity of the interpreted land-use changes.

Farmer survey and sampling procedure

For a better understanding of farmers' perception regarding conversion of rice fields into large cardamom cultivation, a field survey was conducted during March 2018 in Hee-Yangthang, Bermiok and Martam-Pechrek GPUs.

Multistage sampling was used. Initially, the villages where the conversion of rice fields into large cardamom plantations was reported were identified through secondary information and field observations. Then purposively surveyed the farmers who had converted rice fields into large cardamom plantations.

The study involved 47 respondents from different age groups and genders. Data were collected through a structured questionnaire and semi-structured interviews. Information on the size of landholding, cropping pattern, area converted, cultivars grown and perceived reasons for land use conversion were recorded.

Data analyses

The survey data were coded, tabulated and analyzed using descriptive statistical methods. Frequencies and percentages were calculated to summarize the demographic characteristics of the respondents and the factors that influence land conversion.

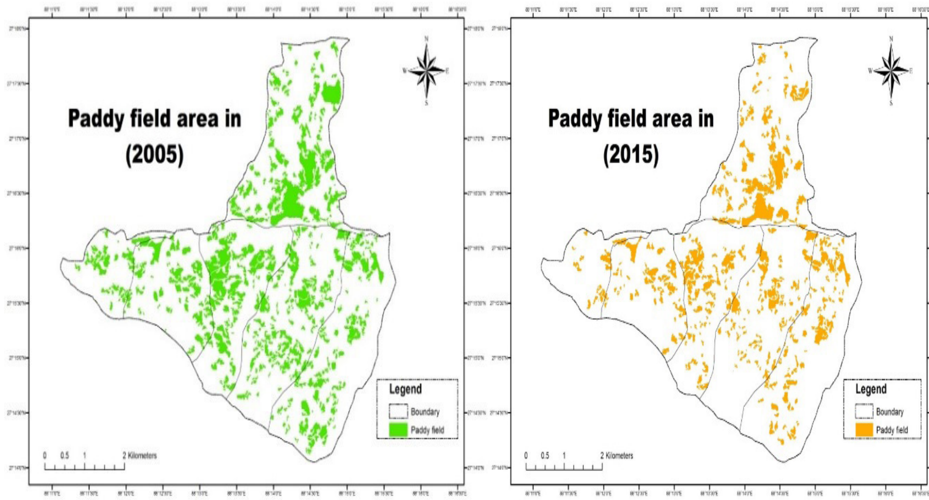
The extent of crop diversification and the major environmental and socioeconomic drivers of conversion of rice fields into large cardamom plantations were assessed using GIS-derived spatial data and survey results.

Result

GIS-based assessment of rice field conversion

Spatial analysis of temporal satellite images and GIS-derived vector layers indicated a substantial decline in rice cultivation area in the study region between 2005 and 2015. In 2005, rice cultivation was done in 15.16 ha of the total study area of 2,292 ha, and decreased to 11.87 ha in 2015 (Figure 1a and Figure 1b). The estimated reduction includes a loss of 3.29ha of rice growing area in the study period. Overlay analysis of the digitized layers of rice fields for the years 2005 and 2015 showed that a total area of 4.27 ha of rice-fields have been converted into large cardamom plantations. This area of conversion accounted for 28.3% of the total rice cultivation area reported in 2005, reflecting a marked transition from food-crop production to cash-crop cultivation (Figure 2).

A total of 117 rice-field polygons were delimited by image interpretation and digitization. 57 of these sites showed evidence of land-use conversion. A random selection of 28 converted sites was made for verification of the GIS interpretation during field surveys. Ground verification confirmed that all selected sites were converted from rice to large cardamom plantations and demonstrated strong agreement between field observations (92.86%) and GIS-derived results. The spatial pattern of converted areas indicated that land use change was concentrated at locations where the suitability of rice cultivation was declining and the adoption of large cardamom as a commercial crop was increasing. The results clearly show



(a) **(b)**

Figure 2: (a) Rice field in the study area in the year 2005. (b) Rice field in the study area in the year 2015.

a continuing trend of agricultural diversification in West Sikkim, where rice cultivation is gradually being replaced by large cardamom plantations due to environmental and socioeconomic factors (Fig. 3 and Table 1).

Farmers' perceptions of rice field conversion to large cardamom cultivation

Demographic characteristics of respondents

The survey was conducted in the selected Gram Panchayat Units of West Sikkim with a total of 47 respondents. Demographic characteristics of the respondents are presented in Table 2. Male respondents constituted 80.85% of the total sample, whereas females accounted for 19.15%, indicating that agricultural decision-making and farming activities in the study area are predominantly managed by men. The age distribution revealed that the highest proportion of respondents belonged to the 46–55 years age group (27.66%), followed by 36–45 years (23.40%), 26–35 years (21.28%), 18–25 years (14.89%), and above 55 years (12.77%). These findings indicate that middle-aged farmers are the principal stakeholders involved in agricultural production and land-use decisions.

In terms of education, almost half of the respondents (48.94%) had primary education, 38.29% had secondary level education, and only 12.77% had education beyond the secondary level. The relatively low level of educational attainment may influence the adoption of improved agricultural practices and decision-making on land use change. The majority of the respondents (55.32%) had farm holdings of size greater than 1 ha, while 40.43% had less than 1 ha of land. Only 4.26% of the respondents had cultivated leased land. Moreover, 95.74% of the respondents owned their own land, which indicates a high level of land ownership in the study area. The analysis of cropping pattern showed that 76.59% of the respondents followed mixed farming of large cardamom, rice and vegetables. On the other hand, 14.89% cultivated only rice and large cardamom and 8.52% cultivated large cardamom as a mono crop. The prevalence of mixed cropping systems suggests that farmers are gradually diversifying their agricultural enterprises, while still maintaining some level of food-crop cultivation (Table 3).

Farmers' perceptions of factors driving land conversion

The survey revealed different environmental and socioeconomic factors affecting the conversion of rice fields into large cardamom plantations (Table 4 and Fig. 4). The most frequently cited factor was insufficient water

Table 1: Summary of rice field conversion to large cardamom cultivation in West Sikkim (2005–2015).

Sl. no.	*Parameters*	*2015*	*2015*	*Change*
1.	Rice cultivation area (ha)	15.16	11.87	-3.29
2.	Area converted to large cardamom (ha)	-	4.27	28.3%
3.	Number of rice-field polygons	117	-	-
4.	Converted locations identified	-	57	-
5.	Ground-truthed locations	-	28	92.86%

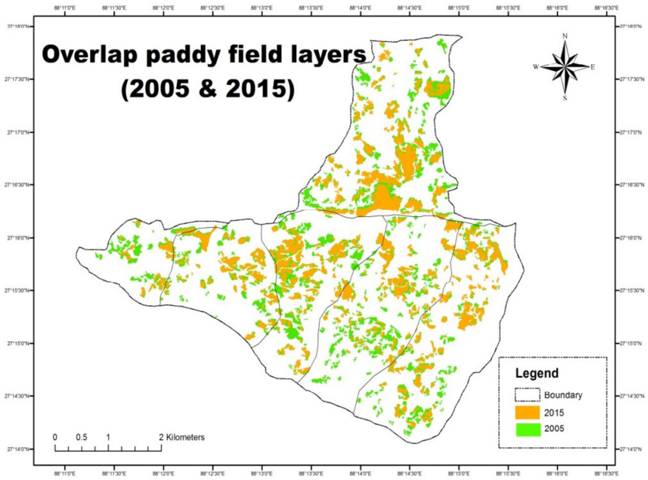


Figure 3: Overlap rice field layers of 2005 and 2015

for rice cultivation, identified by 27 respondents (57.45%). Rice production in the study area is heavily dependent on monsoon rains and flood irrigation and is therefore highly vulnerable to erratic rainfall patterns and water scarcity. This made large cardamom cultivation a more viable option for many farmers under the changing climatic conditions.

19 respondents (40.43%) pointed out rodent and wild-animal damage as a major reason for the abandonment of rice cultivation. 17 respondents (36.17%) opined that the rice productivity was negatively affected by the increased shade from the surrounding vegetation and forest cover. 16 respondents (34.04%) cited prolonged dry spells during the monsoon season. This is an indicator of the increasing concern about climate variability and its effects on traditional farming systems. Shade from neighboring vegetation and forest cover had a negative effect on rice productivity. Sixteen respondents (34.04%) stated that there were prolonged dry spells in the monsoon season, which is an increasing concern linked to climate variability and its impact on traditional farming systems. Pest and disease infestation were identified by 15 respondents (31.91%) as an important factor affecting the reduction of rice productivity and profitability. Furthermore, 11 respondents (23.40%) pointed out that steep slopes and the risk of soil erosion and landslides discouraged the continuation of rice cultivation, particularly in areas where adequate water management structures were not available. Economic factors have also been important in land use in addition to environmental considerations. According to the respondents, large cardamom cultivation requires relatively less labour, fewer intercultural operations and provides higher economic returns than rice cultivation. These advantages have urged the farmers to convert some of their rice fields into huge cardamom plantations.

Overall, the study reveals that the transformation of rice fields into large cardamom cultivation in West Sikkim is driven by a combination of environmental challenges and economic incentives. The findings indicate the increasing significance of crop diversification as an adaptive strategy in response to changing climatic and socioeconomic conditions.

Table 2: Demographic characteristics of respondents in the study area (n = 47)

Characteristic	*Category*	*Frequency (n)*	*Percentage (%)*
Gender	Male	38	80.85
	Female	9	19.15
Age group (years)	18–25 (Very Young)	7	14.89
	26–35 (Young)	10	21.28
	36–45 (Middle-aged)	11	23.40
	46–55 (Above Middle-aged)	13	27.66
	>55 (Old)	6	12.77
Education level	Primary	23	48.94
	Secondary	18	38.29
	Above Secondary	6	12.77
Farm size (ha)	Landless (Lease)	2	4.26
	< 1 ha	19	40.43
	> 1 ha	26	55.32
Land tenure	Own	45	95.74
	Lease	2	4.26
	Both	0	0.00

Table 3: Cropping pattern of respondents in the study area (n = 47)

Cropping Pattern	*Frequency (n)*	*Percentage (%)*
Large cardamom	4	8.52
Large cardamom + Rice	7	14.89
Large cardamom + Rice + Vegetables	36	76.59
Total	47	100.00

Table 4: Farmers' perceptions of factors influencing conversion of rice fields to large cardamom cultivation

Factor	*Frequency (n=47)*	*Percentage (%)*
Lack of water for rice cultivation	27	57.45
Rodent and wild-animal damage	19	40.43
Shady conditions	17	36.17
Prolonged dry spells	16	34.04
Pest and disease infestation	15	31.91
Risk of soil erosion and landslides	11	23.40

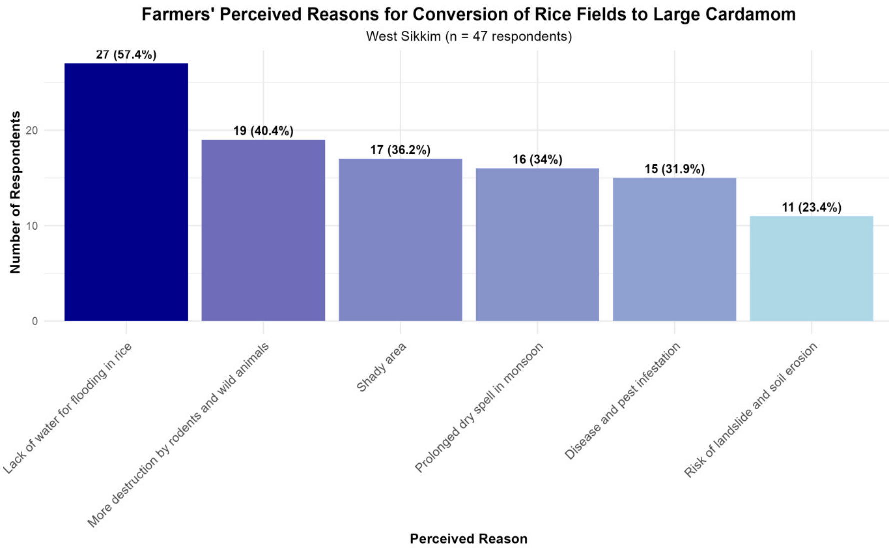


Fig 4: Farmer's perception for conversion of rice field to large cardamom cultivation

Discussion

This research evaluated the significant land-use change from rice (*Oryza sativa*) to large cardamom (e.g., *Amomum subulatum* Roxb.) associated with some areas of West Sikkim. GIS-based analyses of Landsat imagery indicated that 28.3% (4.2781 ha and 15.1623 ha) of the rice fields were converted into large cardamom plantations between the years 2005 and 2015. Furthermore, the socioeconomic/biophysical assessment of the area, for this part of the Eastern Himalayan region, demonstrated deep agroecological land-use change corresponding to new socioeconomic and climatic preferences (Borah *et al.*2025; Belay and Lebeza 2024). Bhutia *et al.* (2018) demonstrated considerable land transitions across Sikkim, particularly since the beginning and onset of the Sikkim Organic Mission and the shift of farmers' interest to high-value cash crops like cardamom.

According to farmers, the main reason for crop diversification, particularly for large cardamom, was a lack of assured irrigation. Paddy cultivation requires consistent and abundant water to flood the terraces, which is increasingly becoming difficult in the Himalayan region due to unpredictable rainfall patterns and climate change (Lepcha *et al.* 2021; Negi *et al.* 2018; Vaidya *et al.* 2019). Farmers observed that without adequate irrigation infrastructure in place for assured irrigation, relying on paddy cultivation in rainfed conditions became inherently risky. The farmers' observations are consistent with the previous literature, which reported crop diversification as an adaptation method widely implemented by rainfed farmers (Makate *et al.* 2016). It is corroborated that erratic monsoons and increasing temperatures are significant drivers for farmers discontinuing water-intensive crops (Vasily *et al.* 2020).

The change in land use is also due to economic reasons. Large cardamom is a perennial crop and need less intercultural operations, reducing labour requirement when compared to other crops, particularly rice, which will have a better cost: benefit ratio in case of large cardamom. This aligns with similar conclusions that cardamom provides better income security to smallholders in mountainous areas (Sharma *et al.* 2009). Furthermore, comparable studies in other literature indicated that large cardamom is a good "high-value, low-volume" cash crop with excellent agroecological features for the same farmers who faced stiff terrain in the Himalaya mountains (Wangchu 2024). The benefit-cost ratio for cardamom in Sikkim is higher than that of rice cultivation (Negi *et al.* 2018; Pundibari 2020). There is even evidence of tribal farmers in and around North Sikkim shifting to cardamom due to its durability and economic potential in organic farming (Partap *et al.* 2014).

Demographically, most respondents were middle-aged males having basic education and moderate agricultural area, reflecting one of the typologies that is familiar in much national survey work (Barcus and Brunn 2009; Morrell *et al.* 2000). This demographic group is often the most responsive to policy, market signals, and climate advisories (Davis *et al.* 2010).

More than half of the farmers in this study had adopted mixed cropping systems to include rice and vegetables, as well as cardamom. This represented a longer-term transition in which diversification was coexisting and evolving along traditional systems of agriculture, which have been reported in Nepal and Bhutan (Lhamo *et al.* 2026). There are advantages to this shift, but there are also risks, and arguably the greatest risk to agriculture from change is loss of agrobiodiversity; perhaps chief among these threats is that of genetic erosion of indigenous rice germplasm. Sikkim has traditionally grown over 65 indigenous rice varieties (Kapoor *et al.* 2017; Chettri *et al.* 2026), and many of these are endangered because of land-use alternatives. These rice varieties often have useful adaptive traits, such as drought and pest tolerance and poor soils (Fukai and Cooper 1995; Mackill *et al*. 2010), and any loss of these rice varieties would not only reduce genetic resources but also limit food sovereignty and resilience (Jarvis *et al*. 2011).

Traditionally, cardamom is grown under the shade of the nitrogen-fixing plant *Alnus nepalensis.* While nitrogen-enhancing crop systems can initially increase soil fertility (Sharma *et al*. 2008; Rai *et al*. 2022), longer-term research raises concerns about nutrient mining, the depletion of soil carbon stocks, and inadequate pest control (Dubey *et al*. 2008). Cultivation of a single crop in the same piece of land potentially disrupts natural equilibrium, increases the prevalence of fungal diseases, and increases the need for pollination services (Leul *et al*. 2023; Saxena *et al*. 2005). Sikkim has maintained its 100% organic certification since 2016, when it is restricted from using pesticides for pest and disease management (Bhatt and John 2023).

Moreover, destructive rodent incursions, erosion of soil, largely due to steep slopes, and declines in rainfall variability may also have changed farmers' interest in rice farming (Kapoor *et al*. 2017; Makate *et al*. 2016; Sharma *et al*. 2008). These results are in accordance with Romeo *et al*. (2022) finding that smallholders in mountainous areas often diversify into perennial high-value crops in situations of climatic and topographic constraints. Diversification can suit farmers and provide greater income and resilience (Giannarakis *et al*. 2023) but can also reduce the potential for crop variety and dependence on a commercially competitive market (Pingali & Rosegrant, 1995; Belay *et al*. 2017).

Conclusion

The present study assessed the conversion of rice (*Oryza sativa* L.) fields into large cardamom (*Amomum subulatum* Roxb.) plantations in selected areas of West Sikkim using GIS-based land-use analysis and farmers' perception surveys. Results showed a significant reduction in rice cultivation area from 2005 to 2015, with an estimated 28.3% of rice-growing area converted to large cardamom cultivation. The results suggest that environmental factors such as inadequate irrigation water, prolong dry spells, rodent and pest damage, and shading effects, combined with higher economic returns and lower labour requirements of large cardamom cultivation, have significantly influenced farmers' land-use decisions. The observed conversion reflects an ongoing process of agricultural diversification in the Himalayan region. Large cardamom cultivation offers important livelihood opportunities and contributes to household income, but continued reduction in rice cultivation may adversely affect local food security and accelerate the loss of indigenous rice germplasm. Therefore, strategies aimed at balancing cash-crop expansion with food-crop conservation are essential for sustainable agricultural development.

The study recommends strengthening irrigation infrastructure, promotion of water-harvesting technologies and implementation of conservation programmes for traditional rice varieties to reduce further decline in rice-growing areas. Policymakers should promote land-use planning and diversified farming systems that are both food secure and economically profitable. Future studies should emphasize long-term monitoring of land use dynamics using high-resolution remote sensing data and evaluate the socioeconomic and ecological impacts of crop diversification in the Himalayan region.

Acknowledgments

We gratefully acknowledge the support of Sikkim University, Samdur, Gangtok, East Sikkim, India and the State Council of Science and Technology, Deorali, Gangtok, East Sikkim, India.

References

Anand S, Mishra BP (2025). Impact of climate change on seasonality and rainfall pattern—recent Adv Earth Environ Sci 159:159.

Barcus HR, Brunn SD (2009). Towards a typology of mobility and place attachment in rural America. J Appalach Stud 15(1–2):26–48.

Belay A, Recha JW, Woldeamanuel T, Morton JF (2017). Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. Agric Food Secur 6:24. doi:10.1186/s40066-017-0100-1.

Belay T, Lebeza TM (2024). Livelihood vulnerability of rural households to climate variability and change: An agroecological system-based approach in northwestern Ethiopia. Heliyon 10(23)

Bhatt A, John J (2023). Including farmers' welfare in a government-led sector transition: The

Bhutia PH, Sharangi AB, Lepcha R, Yonzone R (2018). Post-harvest and value chain management of large cardamom in hills and uplands. Int J Chem Stud 6(1):505–511.

Boori M, Ferraro R (2015). Global land cover classification based on microwave polarization and gradient ratio (MPGR). In: Geoinformatics for Intelligent Transportation. Springer, pp 17–37.

Boori MS (2010). Coastal vulnerability, adaptation and risk assessment due to environmental change in Apodi-Mossoro estuary, Northeast Brazil. Int J Geomatics Geosci 1(3):620.

Borah D, Rout J, Nooruddin T (2025). Impacts of land use changes in Indian Himalayas: A socioeconomic and ecological perspective. In: People and Mountain Environments: Interconnectedness for Sustainable Development in the Himalayas. Springer Nature Switzerland, Cham, pp 115–147

Chettri D, Lepcha P, Sathyanarayana N (2026). Phenotypic and nutritional diversity of indigenous rice (*Oryza sativa* L.) cultivars from Sikkim, India. Discov Agric 4(1):75.

Choudhury B, Khan ML, Dayanandan S (2013). Genetic structure and diversity of indigenous rice (*Oryza sativa*) varieties in the Eastern Himalayan region of Northeast India. SpringerPlus

2(1):228.

Davis K, Nkonya E, Kato E, Mekonnen DA, Odendo M, Miiro R, Nkuba J (2010). Impact of farmer field schools on agricultural productivity and poverty in East Africa. IFPRI Discussion Paper No. 00992.

Dubey NK, Srivastava B, Kumar A (2008). Current status of plant products as botanical pesticides in storage pest management. J Biopestic 1(2):182–186.

Dubey RK, Kumar R, Jaya, Chansouria JPN, Dubey NK (2008). Evaluation of Amomum subulatum Roxb. oil as a source of botanical fungitoxicant for the protection of mango fruits from fungal rotting. J Food Saf 28(3):400–412.

Fukai S, Cooper M (1995). Development of drought-resistant cultivars using physiomorphological traits in rice. Field Crops Res 40(2):67–86.

Giannarakis G, Sariannidis N, Konteos G (2023). Climate-smart agriculture as a driver for sustainability and resilience. Sustainability 15(4):3202. doi:10.3390/su15043202.

Govindarajan V S, Narasimhan S, Raghuveer KG, Lewis YS, Stahl WH (1982).Cardamom production, technology, chemistry, and quality. Critical Reviews in Food Science & Nutrition, 16(3), 229-326.

Gurung A, Hannan A (2021). Dynamics of land use and trends of agriculture in Sikkim. J North East India Stud 11: 73-93

Jafri MA, Javed K, Singh S (2001). Evaluation of the gastric antiulcerogenic effect of large cardamom (fruits of Amomum subulatum Roxb). J Ethnopharmacol 75(2-3): 89–94

Jarvis DI, Hodgkin T, Sthapit BR, Fadda C, Lopez-Noriega I (2011). A heuristic framework for identifying multiple ways of supporting the conservation and use of traditional crop varieties within the agricultural production system. Crit Rev Plant Sci 30(1–2):125–176.

Jensen RR, Gatrell JD, McLean DD, Jensen JR, Hodgson ME, Tullis JA, Raber GT (2005). Remote sensing of impervious surfaces and building infrastructure. In: Geospatial Technologies in Urban Environments. Springer, pp 5–21.

Kapoor C, Avasthe RK, Chettri PK, Gopi R, Kalita H (2017). On-farm status and collection of rice (Oryza sativa L.) genetic resources of Sikkim Himalayas. Indian J Plant Genet Resour 30(1):48–54.

Karuppaiyan R, Rahman H (2007). Strategies for increasing organic rice productivity in the mid-hills of Sikkim with special reference to varietal choice. In: Rice and Food Security Workshop, Nagaland Rice Festival 2007, Dimapur, Nagaland, 12–13 December 2007: 57–58

Lepcha P, Gaira KS, Pandey A, Chettri SK, Lepcha J, Lepcha J, Chettri N (2023). Elevation determines the productivity of large cardamom (Amomum subulatum Roxb.) cultivars in Sikkim Himalaya. Sci Rep 13(1): 21673

Lepcha PT, Pandey PK, Ranjan P (2021). Hydrological significance of Himalayan surface water and its management considering anthropogenic and climate change aspects. In: IOP Conf Ser Mater Sci Eng 1020(1):012013.

Leul Y, Assen M, Damene S, Legass A (2023). Effects of land use types on soil qualitydynamics in a tropical sub-humid ecosystem, western Ethiopia. Ecological Indicators. Mar 1;147:110024.

Lhamo T, Lucantoni D, van den Berg S, Jeanneaux P, Barjolle D (2026). Assessing agroecological performance in yak pastoral systems: A holistic case study using TAPE in Merak and Sakteng, Bhutan. Front Agron 8:1715816.

Mackill DJ, Ismail AM, Pamplona AM, Sanchez DL, Carandang JJ, Septiningsih EM (2010). Stress tolerant rice varieties for adaptation to a changing climate. Crop Environ Bioinform 7:250–259.

Makate C, Wang R, Makate M (2016). Crop diversification and livelihoods of smallholder farmers in Zimbabwe: Adaptive management for environmental change. SpringerPlus 5(1):1135. doi:10.1186/s40064-016-2802-4.

Morrell RW, Mayhorn CB, Bennett J (2000). A survey of World Wide Web use in middle-aged and older adults. Hum Factors 42(2):175–182.

Negi BK, Joshi RK, Pandey A (2018). Status of large cardamom (Amomum subulatum Roxb.) farming system in the changing scenario of modern economics of Sikkim, Himalaya. Glob J Bio-Sci Biotechnol 7(1):189–199.

Parikh A (2023). Sikkim: Making of the first 100% organic state of the world. Indian J Sustain Dev 9(1): 22–28

Partap U, Sharma G, Gurung MB, Chettri N, Sharma E (2014). Large cardamom farming in changing climatic and socioeconomic conditions in the Sikkim Himalayas. ICIMOD Working Paper 2014/2. International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal Gudade BA, Sharma G, Rai LK (2012). Traditional cropping systems in Sikkim Himalayas. Indian J Tradit Knowl 11(3):529–532.

Pingali PL, Rosegrant MW (1995). Agricultural commercialization and diversification: Processes and policies. Food Policy 20(3):171–185.

Prakash KD, Kumar B, Arshad H, Shikhar V, Mala M (2012). Evaluation of antioxidant activity of large cardamom (leaves of Amomum subulatum). Int J Drug Dev Res 4(1):175–179.

Pundibari P (2020). [Title of the dissertation]. Doctoral dissertation, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India.

Rai SC (2023). Food and Livelihood Securities in Changing Climate of the Himalaya. Springer, Cham, Switzerland.

Romeo R, Manuelli S, Abear S (2022). The International Year of Sustainable Mountain Development 2022: an opportunity to promote action for mountains. Front Sustain Food Syst 6:933080. doi:10.3389/fsufs.2022.933080

Saxena KG, Maikhuri RK, Rao KS (2005). Changes in agricultural biodiversity: Implications for sustainable livelihood in the Himalaya. J Mt Sci 2(1):23–31

Sharma E, Sharma R, Sharma G, Rai SC, Sharma P, Chettri N (2008). Values and services of nitrogen-fixing alder based cardamom agroforestry systems in the eastern Himalayas. In: Snelder DJ, Lasco RD (eds) Smallholder Tree Growing for Rural Development and Environmental Services: Lessons from Asia. Springer, Dordrecht, The Netherlands, pp 393–409.

Sharma G (2001). Productivity and Nutrient Cycling in an Age Series of Alnus–Cardamom Agroforestry in the Sikkim Himalaya. Doctoral dissertation, University of North Bengal, Siliguri, India.

Sharma G, Sharma R, Sharma E (2009). Traditional knowledge systems in large cardamom farming: biophysical and management diversity in Indian mountainous regions. Indian J Tradit Knowl 8(1): 17–22

Singh R, Babu S, Avasthe RK, Yadav GS (2018). Crop Diversification and Intensification for Enhancing Livelihood Security in Sikkim. ICAR-National Organic Farming Research Institute, Gangtok, India

Vaidya RA, Shrestha A, Shrestha S (2019). Water scarcity and climate change in the Hindu Kush Himalayas. Environ Dev 31:43–52.

Vasily L, Thomas S, Chettri R, Maharjan SK (2020). International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal.

Wangchu L, Angami T, Jini D, Bam J, Singh R, Tasung A, Suryawanshi A (2024). Natural Farming: Scope and Prospective in Arunachal Pradesh. ICAR Research Complex for North Eastern Hill Region, Umiam, Meghalaya, India