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Cropland abandonment threatens food security in rural Nepal: Understanding the role of long-term and seasonal migration☆

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A R T I C L E I N F O

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A B S T R A C T

Cropland abandonment is a growing concern in rural Nepal, with critical implications for food security, land management, and the future of community forestry. This study investigates how different forms of labor outmigration, including long-term and seasonal migration, along with remittances, are associated with household land-use decisions on cropland abandonment. Drawing on household survey data from community forest user groups in two watersheds in Pyuthan and Salyan districts, we apply statistical models to examine cropland abandonment decisions, area, and parcel numbers. Our findings reveal that long-term migrant counts are consistently associated with cropland abandonment, while remittances show weaker, less consistent associations. In contrast, seasonal migration tends to have limited or even countervailing effects. Among abandonment measures, the number of abandoned parcels shows the clearest association with long-term migrant count, suggesting that parcel-level outcomes may better capture management burdens in fragmented smallholder landscapes. Households report labor shortage due to migration, alongside other factors, as one of the leading reasons for cropland abandonment. These results highlight the need for integrated policy responses that consider migration patterns, reduce labor and management burdens in fragmented landscapes, and support context-specific strategies for maintaining cultivation where feasible. Addressing cropland abandonment is essential not only for enhancing rural food security but also for maintaining the ecological and social sustainability of Nepal's community forestry.

1. Introduction

1.1. Background

Food security is a fundamental component of household well-being and global sustainable development, particularly in the context of population growth, climate change, and constrained land resources (Ansari et al., 2022). The United Nations' Sustainable Development Goal #2 (SDG #2: Zero Hunger) seeks to eliminate hunger and ensure access to safe and nutritious food by 2030. However, progress to this goal remains a challenge (Sporchia et al., 2024). According to the latest State of Food Security and Nutrition in the World report, approximately 733 million people (~9.1% of the global population) were chronically undernourished in 2023, and nearly 2.3 billion people (~28.9% of the world population) experienced moderate or severe food insecurity (FAO, IFAD, UNICEF, WFP, WHO, 2024; Prosekov and Ivanova, 2018). In many low-income and mountainous regions, food security challenges are closely tied to changes in agricultural land use and the availability of productive cropland.

Cropland abandonment has emerged as a growing concern, with important implications for food production, rural livelihoods, and landscape governance. Although global cropland area has expanded in some regions through land conversion, many rural areas, particularly those characterized by smallholder farming and fragmented landholdings, have experienced cropland contraction. Agricultural land abandonment has been documented in many parts of the worlds, including China, Europe, Latin America, and South Asia, often attributed to a combination of environmental constraints, economic restructuring,

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policy interventions, and demographic shifts (Bista et al., 2021; Crawford et al., 2024; Dong et al., 2011; Subedi et al., 2021; Zhang et al., 2024b; Zheng et al., 2023). In mountainous regions, cropland located on steep slopes, distant from settlements, or exposed to wildlife incursions may be particularly vulnerable to abandonment due to high labor demands and low returns.

Existing studies commonly categorize the drivers of cropland abandonment into environmental, socioeconomic, and institutional factors (Van Vliet et al., 2015). Environmental constraints include slope, soil fertility, irrigation availability, and proximity to forested areas (Zhang et al., 2018). Socioeconomic drivers include labor shortages, off-farm employment, market integration, and income diversification (Subedi et al., 2021). Institutional contexts, such as land tenure arrangements and community forest governance, also shape land-use decisions (Bista et al., 2021). Among these drivers, labor outmigration has increasingly been recognized as an important socioeconomic factor that can influence cropland use in many rural contexts (Busso et al., 2021; Mazumdar, 1987). However, despite extensive documentation of migration-abandonment linkages, less attention has been given to how different forms of migration may exert distinct pressures on land-use decisions and how these pressures interact with fragmented landscapes and parcel-level management burdens.

1.2. Theoretical underpinning

The New Economics of Labor Migration (NELM) conceptualizes migration as a household-level strategy for income diversification and risk management (Stark and Bloom, 1985). From this perspective, migration reallocates labor from agricultural to non-agricultural activities and may reduce dependence on farming income, particularly when remittances provide financial stability (Carte et al., 2019, 2010; Radel et al., 2018). More recently, the aspirations-capabilities framework emphasizes that migration decisions depend not only on economic necessity but also on migrants' aspirations for improved livelihoods and their capability to pursue mobility opportunities (De Haas, 2021). These theoretical perspectives suggest that migration is not a uniform phenomenon, but its duration, stability, and income characteristics may shape whether migration results in temporary labor adjustment or structural livelihood transformation.

In many rural contexts, migration takes different forms. Some household members migrate for extended periods, often years, living away from the household and engaging in stable employment that can generate regular remittances. Others migrate seasonally, returning home during key agricultural periods. These distinct migration patterns may influence agricultural land use in different ways (Eklund et al., 2024; Han and Song, 2019; Li et al., 2018; Xu et al., 2019b, 2019a). Long-term migration may induce sustained labor shortages and facilitate structural disengagement from agriculture (Shrestha et al., 2022), while seasonal migration may function as an income-smoothing mechanism that remains compatible with continued cultivation (Gautam, 2017; Janzen and Noray, 2021; Sapkota, 2018) (Asefawu, 2022; Nienkerke et al., 2023). Yet, empirical studies often treat migration as a binary or aggregate measure, overlooking potential differences between long-term and seasonal migration in shaping cropland abandonment.

At the same time, most research measures cropland abandonment primarily in terms of total abandoned area or a binary incidence indicator. However, in smallholder systems characterized by fragmented landholdings, the number of abandoned parcels may provide additional insight into household land-use strategies (Latruffe and Piet, 2014; Tan et al., 2006). Managing multiple dispersed parcels increases transaction costs, travel time, and monitoring burdens that are not proportional to total land area. Abandonment decisions may therefore occur first at the parcel level, particularly for marginal or distant plots, before substantial reductions in total cultivated area become evident (Wang et al., 2020). Incorporating parcel-based indicators may thus offer a more insightful understanding of how migration reshapes land-use structures in fragmented agricultural landscapes.

1.3. Hypotheses, study cases, and research aim

Building on these theoretical considerations, we conceptualize cropland abandonment as a household decision shaped by labor availability, remittance-enabled livelihood diversification, and parcel-level management burden (Guo et al., 2023; Prishchepov et al., 2013; Subedi et al., 2022) (Fig. 1). Long-term migration is likely to reduce agricultural labor permanently and to signal a structural shift in livelihood style, thereby increasing the opportunity cost of cultivation and the likelihood of abandoning marginal parcels. Seasonal migration, by contrast, may temporarily reallocate labor without fundamentally reducing household engagement in farming (Latruffe and Piet, 2014). Environmental and institutional contexts, such as elevation, proximity to forests, crop raiding by wildlife, and community forest governance, condition these relationships by influencing the relative costs and benefits of maintaining cropland in cultivation. Based on this framework, we formulate the following hypotheses:

- **H1:** Long-term migration is positively associated with the likelihood and intensity of cropland abandonment due to the sustained loss of labor.
- **H2:** Seasonal migration has weaker or neutral associations with cropland abandonment due to its temporary and income-smoothing nature, and the temporary migrant labor is available in times of need for cropland cultivation.
- **H3:** Parcel-based measures of abandonment will show clearer associations with migration than area-based measures in fragmented smallholder systems.

Nepal provides a study case for examining these relationships. In recent years, rural out-migration from Nepal's Middle Hills region has intensified (Bista et al., 2023; Paudel et al., 2014; Tiwari, 2025). The 2021 census reported approximately 2.19 million Nepalis living abroad, up from 1.92 million in 2011, with the Hill ecological belt showing an emigration rate of 8.4%, higher than the national rate of 7.5%, and outmigration is also concentrated among young adults, as 75.8% of Nepal's absentee population departed between ages 15 and 34 (NSO, 2024). At the same time, Nepal's agricultural landscape is characterized by small, dispersed cropland parcels embedded within community forestry systems managed by Community Forest User Groups (CFUGs) (Bista et al., 2021). Wildlife crop-raiding, limited irrigation, and steep terrain further complicate cultivation decisions. These conditions make Nepal an ideal location to examine how heterogeneous migration patterns interact with fragmented landscape and environmental constraints to influence cropland abandonment.

This study investigates how labor out-migration is associated with cropland abandonment using detailed household survey data from two watersheds in the Middle Hills of Nepal. Specifically, we differentiate between long-term and seasonal migration and examine their associations with three complementary indicators of cropland abandonment: (1) abandonment incidence, (2) total abandoned area, and (3) number of abandoned parcels. By examining migration in fragmented landscapes, we contribute to the theory of human-environment interactions in three ways. First, we differentiate migration types to reveal its heterogeneous land-use consequences. Second, we demonstrate the analytical value of parcel-based abandonment measures in fragmented landscapes. Third, we provide empirical evidence from Nepal's community forestry context to inform discussions on rural transformation, land consolidation, and food security under conditions of sustained labor mobility. Although our analysis identifies associations rather than causal effects, we use year-cutoff sensitivity models to assess whether the observed associations are stable across alternative definitions of recent abandonment. Understanding these relationships is essential for designing policies that balance livelihood diversification, agricultural

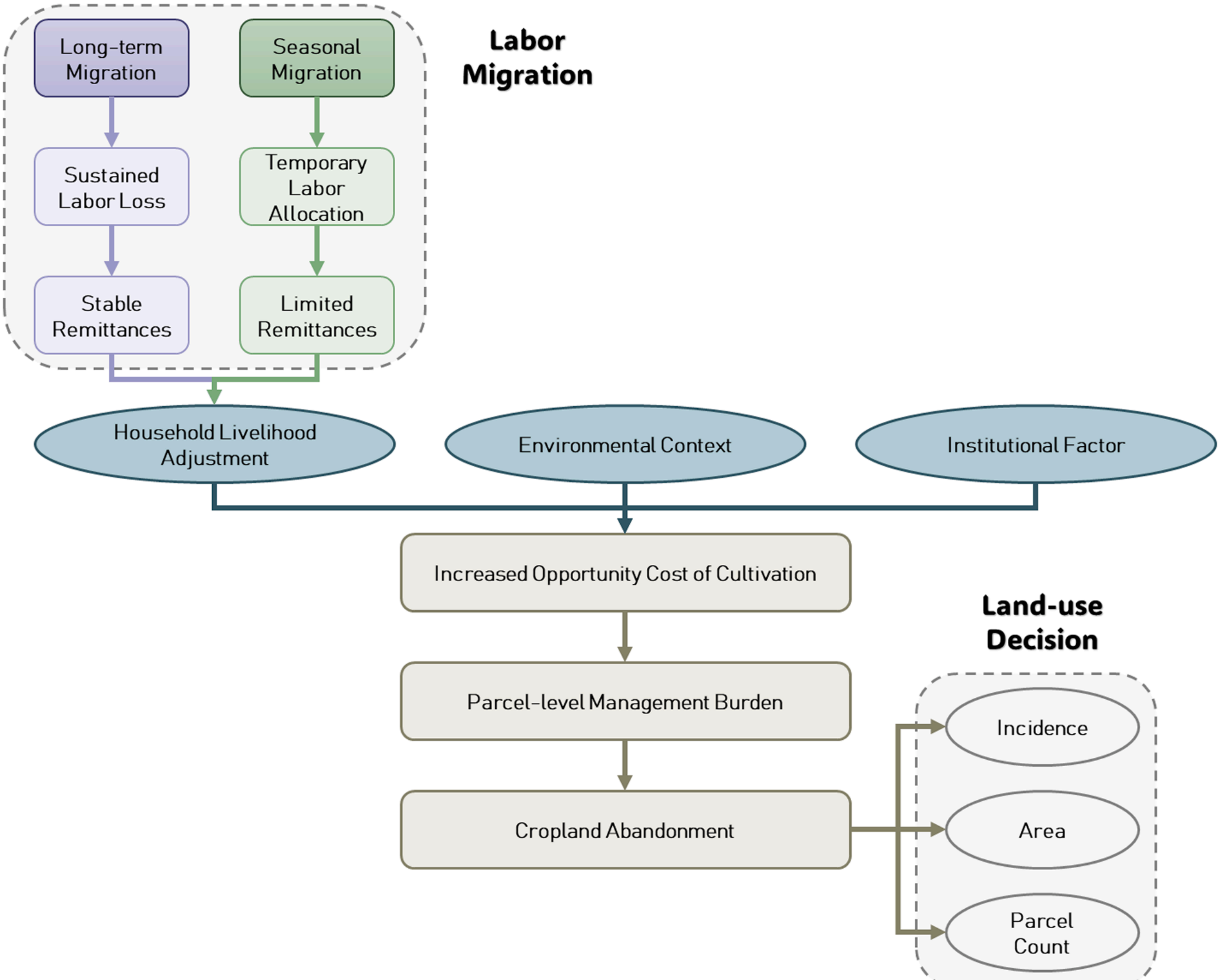

Fig. 1. Conceptual framework linking migration type to cropland abandonment. Long-term and seasonal migration are hypothesized to influence cropland abandonment through changes in labor availability, remittance flows, and household livelihood adjustment. Parcel-level management burden mediates these effects, while environmental and institutional contexts condition abandonment outcomes.

sustainability, and long-term food security.

2. Data and methods

2.1. Study areas

We selected two watersheds in the Middle Hills of Nepal (Fig. 2). The first is the Jhimruk Watershed in Pyuthan District of Lumbini Province, and the second is the Sharada Watershed in Salyan District of Karnali Province. Both watersheds fall within the subtropical climate zone (Paudel et al., 2021) and feature a mosaic of croplands and forests across steep terrain, with elevations ranging from 600 to 3,000 m above mean sea level. These watersheds capture several features common across Middle Hills CFUG communities, including mixed forest-cropland mosaics, steep terrain, fragmented landholdings, and widespread reliance on remittances from outmigrants. At the same time, Nepal is highly heterogeneous in market access, agroecology, and livelihood portfolios (Joshi et al., 2019). Thus, our study sites should not be interpreted as statistically representative of all rural Nepal but rather as informative cases for CFUG-based Middle Hills smallholder systems. The extent to which our findings transfer to other regions (e.g., the Tarai plains or high-mountain areas) remains an empirical question for future multi-site research. Nepal's community forestry program originated in the Middle Hills and currently manages over a third of Nepal's forests through more than 23,000 Community Forest User Groups (CFUGs) (DFSC, 2024). About 75% of the CFUGs are located in the Middle Hills of Nepal. Within our study districts, there are 340 CFUGs in the Sharada Watershed (Salyan) and 188 CFUGs in the Jhimruk Watershed (Pyuthan). CFUGs consist of households located near forests that have been handed over for community management by the District Forest Office. CFUGs have authority to manage forests under an approved Operation Plan. Member households have regulated access to timber, fuelwood, fodder, and other non-timber forest products. Livelihoods in these communities remain closely tied to smallholder agriculture (subsistence crops and sometimes livestock). A large number of households increasingly combine farming with domestic and overseas off-farm employment as livelihood options (Bista et al., 2021). Both long-term (more than six consecutive months away) and seasonal migrants are common in the study areas, making these watersheds well-suited for examining how different forms of labor mobility relate to cropland abandonment in a community forestry context.

2.2. Household surveys

In spring 2023, we conducted household surveys in the two study watersheds. To obtain reliable estimates, we aimed to interview 500 households in each watershed. We used a two-stage, stratified random sampling design, first selecting CFUGs and then sampling households in

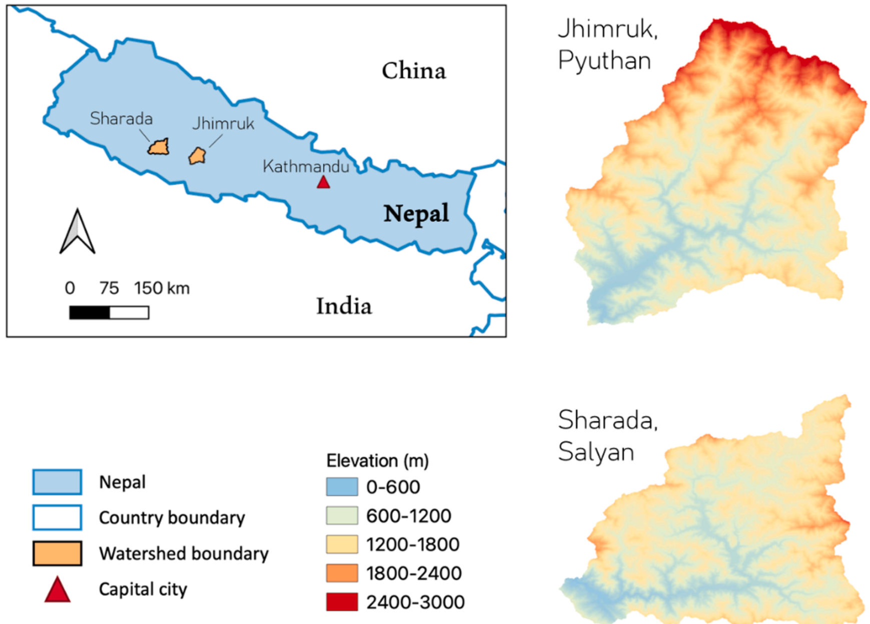

Fig. 2. Study areas: Jhimruk Watershed in Pyuthan and Sharada Watershed in Salyan, Nepal.

each selected CFUG. We first selected 35 CFUGs in each watershed and 24 households within selected CFUGs. At the design stage, we planned to select 35 CFUGs per watershed and 24 households per CFUG. Given the rugged terrain and the likelihood that some households would be unavailable due to outmigration, we anticipated completing surveys in ∼25 CFUGs and ∼20 households per CFUG. An overview of the sampling procedure for household surveys is provided in Appendix (Fig. A1).

Selection of CFUGs: In the first stage, CFUG selection was stratified by municipality to maintain spatial coverage across the watershed, and within municipalities we further considered CFUG membership size so that both smaller and larger CFUGs were represented. Because road access and travel time vary greatly, we allocated a larger share of the CFUG sample to more accessible municipalities for field feasibility. Thus, the sampling was designed to achieve broad spatial coverage within logistical constraints rather than strict proportional representation of all municipalities. Within each municipality, we then randomly selected CFUGs within size strata (based on number of member households). For example, if three CFUGs were allocated to a municipality, we created three size-based strata and randomly selected one CFUG from each stratum.

Selection of households: In the second stage, we selected 24 households within each sample CFUG identified in the first stage. From the District Forest Office administering each study area, we obtained the Operation Plan and the Constitution for each selected CFUG, with household rosters and their well-being status classified as rich, medium, poor, or ultra-poor. To simplify sampling, we merged the "rich" and "medium" households to become the "rich" stratum and the "poor" and "ultra-poor" households to become the "poor" stratum, yielding two sampling strata, because some CFUGs had very small number of households in the rich or ultra-poor category, making four-stratum sampling impractical. This consolidation was used solely for field stratification to maintain representation of relatively better-off and worse-off households within each CFUG. Households were still randomly selected within each merged stratum. Importantly, the merged strata were not used as a primary explanatory variable in the regression analysis. Instead, household socioeconomic status is captured through our survey-based continuous Wellness measure (and other covariates), which reduces concern that the operational merging could distort substantive inferences. From each stratum, 12 households were randomly selected, resulting in 24 sampled households per CFUG.

Data collection: We trained 12 graduates from the Institute of Forestry at Tribhuvan University, Pokhara, Nepal, a postdoctoral researcher, and doctoral students from the University of North Carolina at Chapel Hill (UNC) and North Carolina State University, to conduct the household survey in spring 2023. The team collected data from 873 households, including 427 in Pyuthan from 28 CFUGs and 446 in Salyan from 27 CFUGs. The questionnaire contained 13 sections, including a detailed household roster that covered household socio-economic activities, natural resource use, land use, migration, etc. The questionnaire was pretested in CFUG communities not included in the main sample (about 10–20 households), where interviewers administered with tablets programed with ODK to assess question clarity, skip logic, and survey length, and feedback was used to refine wording and response options. The questionnaire was approved by the Institutional Review Board at UNC-Chapel Hill. We obtained informed consent from each respondent before the interview. Completed surveys were reviewed by supervisors in the field. Once the field supervisor approved the survey, it was securely transmitted to a server in the Carolina Population Center at UNC-Chapel Hill.

Definitions of cropland abandonment: For consistency during data collection, we provided standardized definitions of cropland abandonment (and labor outmigration as described below) to household interviewers during training and pretesting. A cropland parcel was classified as abandoned if it is currently not under cultivation with no plan to re-cultivate it in the foreseeable future. To distinguish abandonment from other land-use states, we explicitly treated parcels that were temporarily fallow, rented out, sold, or had their use-rights transferred as not abandoned. Intention-based classification can involve subjectivity. Therefore, we used a uniform survey script and probing questions during interviews to promote consistency across interviewers. In the household survey, we recorded the total number of abandoned cropland parcels and the stated reason for each reported abandonment.

Definitions of labor migration: We distinguish two types of migration, long-term and seasonal, using duration away from the household as the criterion, while acknowledging that migration is a multidimensional and continuous process and that any binary typology is a simplification. Long-term migrants were individuals who left their household at age 16 or above, lived away for at least six consecutive months, and were still living away at the time of the survey. Seasonal migrants were those who left home for work and returned within less than six consecutive months and they were still living at home or away at the time of the survey. To help interpret these duration-based categories, we also recorded contextual information on migration, including the main reason for migration (e.g., wage employment, education), the occupation/primary income source while away, and remittance sent back over the past 12 months. These supplementary measures help interpret long-term vs. seasonal migration not only as a duration difference, but also in terms of likely implications for household labor allocation and agricultural decision-making (McHugh, 1990; Zhang et al., 2020).

2.3. Statistical modeling of land-use decisions on cropland abandonment

2.3.1. Core variables

To understand factors influencing household land-use decisions on cropland abandonment, we constructed five sets of statistical modeling analyses. The first set explores whether a household has abandoned cropland (binary: 0 =No, 1 =Yes) using logistic regression. The second and third sets assess the total abandoned cropland area and its proportion, respectively, by a household using ordinary least squares (OLS) regression. The fourth and fifth evaluate the total abandoned parcel number using Zero-Inflated Poisson (ZIP) regression, and the percentage of abandoned parcel numbers using OLS regression. For parcel-based outcomes, the dependent variables are measured at the household level by aggregating reported abandonment across all cropland parcels owned/managed by the household. Specifically, the "abandoned parcel number" is the count of parcels that the household reported as abandoned under our abandonment definition, and the proportion of abandoned parcels is this count divided by the household's total number of cropland parcels. In each set, we fitted three models, each including one of the three pairs of core explanatory variables regarding long-term and seasonal migration: 1) whether a household has any outmigrants (Model 1), 2) the number of outmigrants (Model 2), and 3) the amount of remittances received from migrants (Model 3). Remittance variables measure the total amount of money received from long-term and seasonal migrants during the 12 months prior to the survey. The questionnaire also included a household-level multiple-response question on the reported uses of remittances. However, the remittance use was not collected separately for remittances from long-term versus seasonal migrants, and the survey did not record the timing or regularity of remittance receipt in sufficient detail to construct measures such as regular receipt or coefficient of variation. Therefore, our regression models focus on remittance amount, while remittance use is examined descriptively.

2.3.2. Covariates

In addition, models controlled for household-level covariates that prior land-use and migration studies identify as relevant to cropland abandonment decisions. Household demographics, including household size and the gender and age of the household head, capture labor availability, household life-cycle effects, and decision-making capacity, which can influence cultivation under labor scarcity (Eklund et al., 2024; Shrestha et al., 2022). Socioeconomic status, measured by the well-being score, accounts for differences in livelihood capacity, dependence on farming, and access to alternative income sources (Bhandari, 2013; Subedi et al., 2021). Biophysical and accessibility variables, including elevation, slope, cropland area, and walking distance to the nearest community forest, represent terrain constraints, farm scale, and exposure to forest-edge risks such as crop raiding. These factors are widely recognized as drivers of agricultural land-use change and abandonment in mountain and smallholder systems (Bista et al., 2021; Li et al., 2018; Van Vliet et al., 2015; Zhang et al., 2018). We also include district fixed effects to account for broader differences in market access, institutional context, and agroecological conditions across the two watersheds. Finally, we control for ethnic group because it is a salient dimension of social stratification in rural Nepal that may shape both migration opportunities and cropland abandonment decisions through differences in land access, land quality, livelihood opportunities, labor-sharing networks, and access to agricultural services and local institutions (Bhandari, 2013; Fisher, 2007).

2.3.3. Checking collinearity and group-level variations

We conducted Pearson correlation and variance inflation factor analyses for the hypothesized factors and retained those with less collinearity, with full results presented in *Appendix* (Table A1). Covariates to be controlled include ethnicity group, age of household head, household size and well-being score, elevation and slope at house location, and distance to nearest community forest (walking time measured in hour).

Households within the same CFUG may share contextual conditions that can influence land-use decisions at the group level. To assess these potential higher-level impacts, we tallied the number of households and estimated the mean values of core variables relating to cropland abandonment (abandonment rate, abandoned area, abandoned area percentage, abandoned parcel number, and proportion of abandoned parcel number) by CFUG, and tested between- versus within-group variation, with full results presented in the Appendix (**Fig. A2**; **Fig. A3**). Although there is some variation in these variables among CFUGs, between-group variation accounts for a relatively small share of total variation, while within-group variation dominates. The intra-class correlation (ICC), an indicator of the relative importance of group-level clustering, is below 6.0% for all key variables. Low ICC suggests outcomes vary mainly within CFUGs in our sample. However, CFUG institutions may still matter through specific governance mechanisms (e.g., rules, enforcement, collective labor arrangements) that are not directly measured here.

2.3.4. Model specification

The logistic regression model is:

$$\log\frac{\Pr(y_b=1)}{1-\Pr(y_b=1)} = \alpha+\beta x_l+\gamma x_s+\delta z \tag{1}$$

.

The OLS regression model is:

$$y_c = \alpha+\beta x_l+\gamma x_s+\delta z+\varepsilon \tag{2}$$

.

The probability distribution for the ZIP regression is:

$$\Pr(Y_i=0) = \pi_i+(1-\pi_i)e^{-\lambda_i} \tag{3}$$

$$\Pr(Y_i=y_i) = (1-\pi_i)\frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!}, \quad y_i>0 \tag{4}$$

.

In Eq. (1), y_b represents the binary outcome variable of whether a household abandoned cropland (0 =No, 1 =Yes) with *Pr()* denoting the probability of reporting abandonment. Similarly, y_c in Eq. (2) represents the continuous variable of the total abandoned cropland area; x_l and x_s in Eqs. (1) and (2) represent the focal migration variable regarding long-term and seasonal migrants, respectively, including the three pairs of alternative measures of the variable mentioned above (i.e., migration incidence, number of migrants, and the amount of remittances received); and z in Eqs. (1) and (2) represents other covariates. Among the parameters, α is the intercept; β, γ, and δ are fixed effects corresponding to long-term migration, seasonal migration, and covariates, respectively; ε is the error term. In the ZIP model, πi is the probability that household i belongs to the structural-zero component; λi is the Poisson parameter for household i. The explanatory variables used in the logistic and OLS models enter the Poisson count component of the ZIP model; the inflation component contains only an intercept. Because the inflation model was specified with an intercept only, the structural-zero probability is constant across households within each model.

2.4. Year-specific sensitivity analysis of recent cropland abandonment

Cropland abandonment and long-term migration may influence each other in complex and potentially bidirectional ways. Sustained out-migration may reduce household labor availability and increase the likelihood of abandonment. Conversely, households that have already abandoned marginal cropland may subsequently pursue migration opportunities. In addition, unobserved household characteristics, such as risk preferences, social networks, land quality, or prior livelihood shocks, may simultaneously affect both migration and land-use decisions. Because our data are cross-sectional and include retrospective timing only for abandonment events, our models cannot establish causal and effect direction between migration and abandonment.

To assess whether the observed associations are sensitive to alternative definitions of recent abandonment, we implemented a series of year-specific regression models using retrospective information on the most recent year of cropland abandonment. Specifically, households reported the year in which their most recent abandonment event occurred. Using this information, we constructed a set of binary outcome variables $y_{b,t}$, each indicating whether cropland abandonment occurred in or after a given cutoff year t. For example, under a 2020 cutoff, households that abandoned cropland in 2020 or later are coded as 1, while all others are coded as 0. We repeated this procedure for cutoff years from 2020 back to 2010. For each cutoff year t, we estimate the following model:

$$\log\frac{\Pr(y_{b,t}=1)}{1-\Pr(y_{b,t}=1)} = \alpha_t+\beta_t x_l+\gamma_t x_s+\delta_t z$$

.

This approach should be interpreted as a temporal sensitivity analysis rather than a causal identification strategy. It allows us to examine whether migration-abandonment associations remain stable when abandonment is defined over different recent time windows. Therefore, estimates from these models are interpreted as conditional associations. Detailed methods and full results are presented in the Appendix (Fig. A4; Fig. A5; Table A2).

3. Results

3.1. Cropland abandonment at parcel and household levels: descriptive statistics

Among 873 sampled households in the two study areas, 200 (22.9%) reported cropland abandonment. Thus, we derived relevant statistics (e.g., abandoned cropland area) from these 200 households. The mean total abandoned area per abandoning household is 3.66 ropani (1 ropani = 508.72 m^2) or ~1862 m^2. Comparing the two study areas, the mean areas of abandoned parcels are 3.36 and 4.04 ropani (1709 m^2 and ~2055 m^2) in Pyuthan and Salyan, respectively. Among households that have abandoned cropland, the majority abandoned three or fewer parcels, with total abandoned areas of less than 7 ropani (~3561 m^2) (Fig. 3). Among the 200 households, 70.5% abandoned only one parcel, followed by two (17.5%) and three (7.0%) parcels, while about 5% abandoned four or more parcels. Regarding the total abandoned area, two-thirds (66%) of the 200 households abandoned less than 3.0 ropani (~1526 m^2) of cropland on average, while about 27% abandoned 3.1–7.0 ropani (from ~1577 m^2 to ~ 3561 m^2), and the remaining 7% abandoned 7.0 ropani or more.

We recorded 384 responses for reasons that led to abandoning cropland from the 200 households. Note that one household may

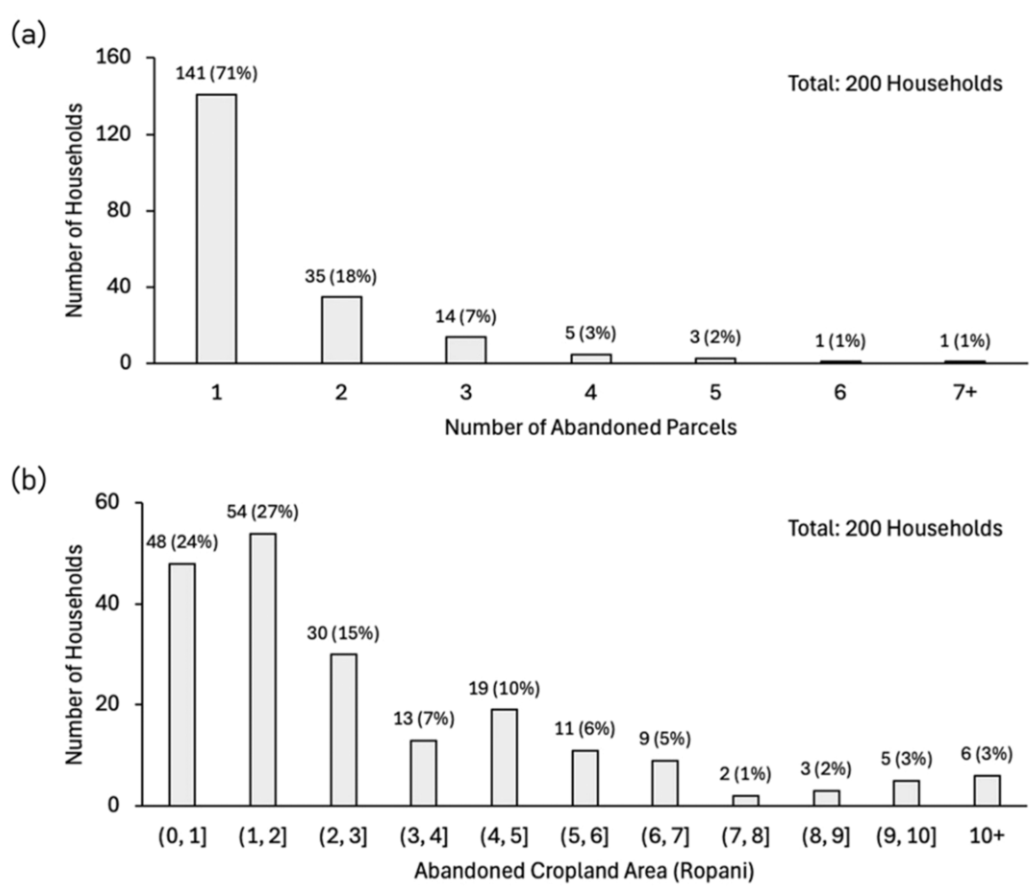

Fig. 3. Frequency distribution of households with abandoned cropland by (a) number of abandoned parcels and (b) abandoned cropland area category.

provide more than one reason, thus the percentages were calculated based on the 384 reported reasons. The top-ranked five reasons were: 1) crop-raiding by wild animals (25%), 2) lack of household labor (21%), 3) low soil fertility (10%), 4) parcels far from the house (10%), and 5) lack of water for irrigation (Fig. 4). Other reasons include shading from nearby trees, including trees on private land or in community forests (8%), and climate variability (5%), such as flooding or unpredictable precipitation, followed by seven other reasons provided rarely.

3.2. Long-term and seasonal migration

There were more long-term migrants than seasonal migrants in the study areas, with over half (55%) of the households reporting having at least one long-term migrant living away at the time of the survey. In comparison, only 17% have at least one seasonal migrant.

Regarding remittances, more long-term migrants than seasonal migrants sent remittances back to their households during the 12 months prior to the interview, which met expectations as the latter usually brought their savings with them upon returning home (Fig. 5). Among the 477 households with *long-term migrants*, 74% received remittances from one or more long-term migrants, while 26% received none. The majority (58%) have one long-term migrant sending remittances, and one in seven has two remittance-sending migrants. Among the 151 households with *seasonal migrants*, 37% received no remittances, and 51% had one remittance-sending migrant. Only 11% and less than 1% of households received remittances from two and three seasonal migrants, respectively.

The mean amount of remittances sent by long-term migrants was 249,000 NPR (~1900.8 USD, 1 USD = 131 NPR in 2023), about 2.5 times that of seasonal migrants (98,000 NPR, or ~748.1 USD), both for households that received remittances (Fig. 6). From long-term migrants, 56% of households received remittances under 150,000 NPR (~1145.0 USD). Meanwhile, a substantial share of households received higher amounts, e.g., 21% received more than 300,000 NPR (~2290.1 USD), including 9% more than 500,000 NPR (~3816.8 USD). From seasonal migrants, most households (78%) received 100,000 NPR (~763.4 USD) or less, 16% received 100,000–300,000 NPR, while only 6% received more than 300,000 NPR (~2290.1 USD). These statistics suggest that long-term migration contributes more to remittance-based household support than seasonal migration in the study areas.

Reported remittance uses further suggest that remittances were directed primarily toward household maintenance rather than direct

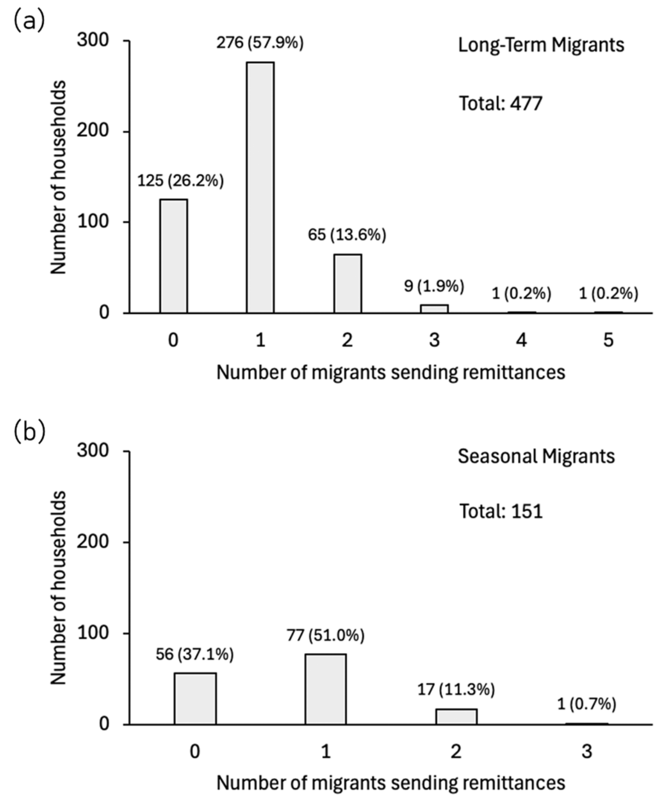

Fig. 5. Frequency distribution of surveyed households by total number of (a) long-term migrants and (b) seasonal migrants.

agricultural reinvestment. Among the 428 households that received remittances from either long-term or seasonal migrants, 43 households (10.0%) reported using remittances to purchase agricultural equipment or irrigation. Because households could report multiple uses, we also counted all reported remittance-use mentions. Across 887 total mentions, the most frequently reported uses were living expenses (41.1%), healthcare (17.8%), education of household members (16.9%), and debt repayment (16.3%). In contrast, agricultural equipment or irrigation accounted for only 43 mentions (4.8%) (Fig. A6).

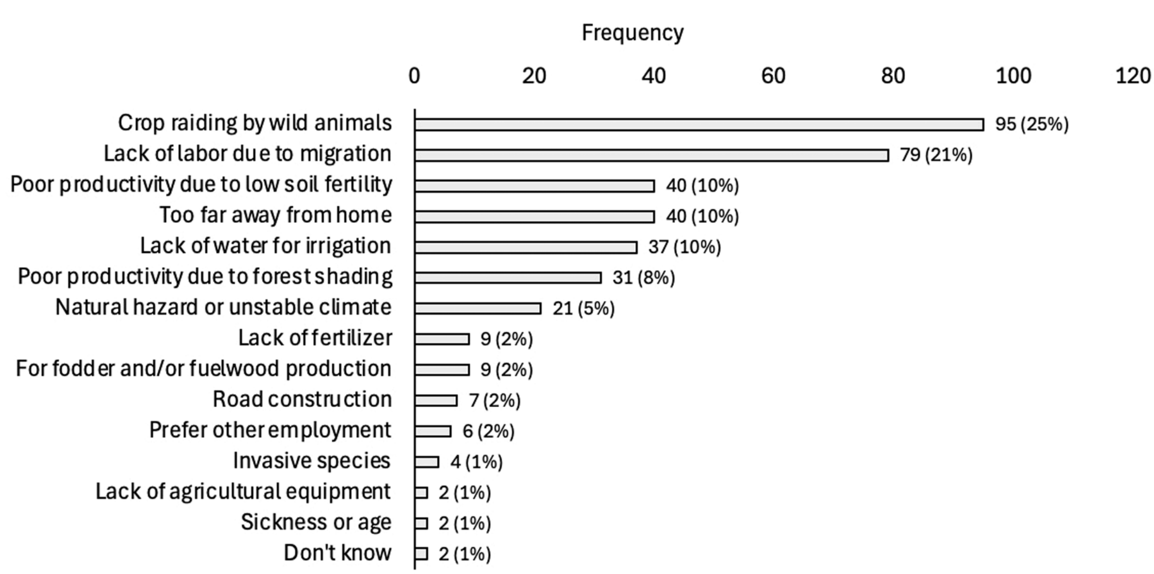

Fig. 4. Reported reasons for abandoning cropland parcels by surveyed households. Percentages are based on 384 reported reasons because one household could report multiple reasons.

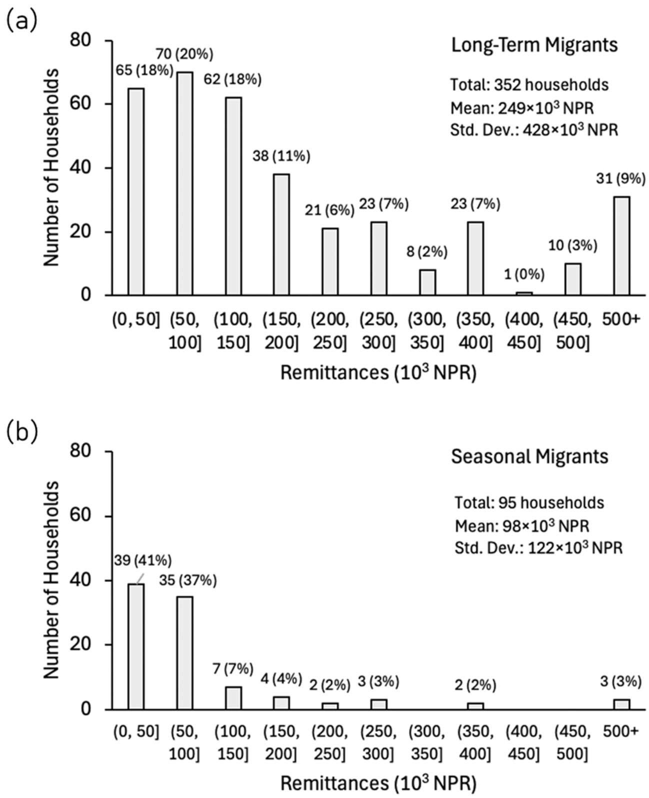

Fig. 6. Frequency distribution of remittance-receiving households by total remittance amount received from (a) long-term migrants and (b) seasonal migrants.

3.3. Comparing households with and without abandoned cropland

Based on our understanding from literature on food security, labor migration, cropland use, cropland abandonment, and the data collected in our 2023 household survey in Nepal, we have data on a host of variables that may influence cropland abandonment. The first step in examining the relevance of these potentially important factors is to compare the characteristics of households with and without abandoned cropland. We therefore developed tabulations showing mean values of these factors, for which we use *t*-tests of the difference in means to identify factors with statistically significant differences between the two household groups (Table 1). Most household and physical variables do not differ significantly between households with and without abandoned cropland, with two exceptions. First, households with abandoned cropland have 1.32 more ropani (~671.5 more m^2) of cropland (about 25%) than households without abandoned cropland. Second, the mean number of long-term migrants of all the households with abandoned cropland is 0.61, significantly higher than the mean number (0.48) of long-term migrants in households without cropland abandonment. In addition, because of this, households with abandoned cropland tend to receive more remittances, but the difference is not statistically significant. Also, households with abandoned land have fewer seasonal migrants than their counterparts. On average, households with abandoned cropland received 32,000 NPR (~244.3 USD) more remittances from long-term migrants but received 5000 NPR (~38.2 USD) less from seasonal migrants, compared to households without abandoned cropland. The key question is, do these differences hold up when all the potentially relevant factors are included in a multivariate model, to which we now turn, focusing on migration.

Table 1
Comparison of independent variables between households with and without abandoned cropland. The *t*-test is used to test the difference in means between households with and without abandoned cropland for continuous variables. For some variables, the observations are fewer due to missing data. ** $p < 0.05$.

Household variable	No abandonment [0]			Has abandonment [1]		
	Count/ Mean	% /SD	Obs.	Count/ Mean	%/SD	Obs.
Has Long-term migrant	653	N/A	N/A	200	N/A	N/A
0: No	296	45.3%	N/A	87	43.5%	N/A
1: Yes	357	54.7%	N/A	113	56.5%	N/A
Has Seasonal migrant	653	N/A	N/A	200	N/A	N/A
0: No	535	81.9%	N/A	169	84.5%	N/A
1: Yes	118	18.1%	N/A	31	15.5%	N/A
Number of long-term migrants **	0.48	0.68	653	0.61	0.79	200
Number of seasonal migrants	0.14	0.41	653	0.11	0.39	200
Remittances from long-term migrants (10^6 NPR)	0.09	0.31	653	0.13	0.28	200
Remittances from seasonal migrants (10^6 NPR)	0.01	0.06	653	0.01	0.03	200
Ethnicity group	653	N/A	N/A	200	N/A	N/A
0: Brahman/Chhetri	387	59.3%	N/A	120	60.0%	N/A
1: Other	266	40.7%	N/A	80	40.0%	N/A
Gender of household head	596	N/A	N/A	184	N/A	N/A
0: Male	410	68.8%	N/A	129	70.1%	N/A
1: Female	186	31.2%	N/A	55	29.9%	N/A
Age of household head	54.06	13.60	596	55.56	13.44	184
Education of the household head	4.39	4.75	592	4.77	4.70	184
Household size (persons excluding migrants)	4.05	1.76	653	4.25	1.83	200
Well-being score	49.47	7.14	653	49.93	7.47	200
Elevation at house location (1000 m)	1.38	0.30	632	1.36	0.29	194
Slope at house location (degree)	17.53	7.69	632	16.40	8.32	194
Area of cropland (ropani) **	7.49	6.83	636	8.81	6.80	194
Distance to nearest community forest (hours)	0.57	0.52	649	0.52	0.49	200

3.4. Associations of long-term and seasonal migration with cropland abandonment

We present results from five sets of models. The first set models factors associated with the cropland abandonment incidence, i.e., whether a household has any abandoned cropland, using logistic regression. The second and third sets model factors associated with the total abandoned cropland areas and percentage of abandoned cropland area, respectively, by a household using ordinary least squares regression. The fourth and fifth sets model factors associated with abandoned parcel numbers and proportion of abandoned parcel numbers in total parcel number. Some coefficients are statistically significant at the 10% level, which we interpret as suggestive rather than conclusive evidence, given the heterogeneity of mountain farming systems and measurement noise inherent in household survey outcomes. We pay particular attention to the core explanatory variables of long-term and seasonal migration by comparing their marginal effects on the outcome variables.

3.4.1. Model results of the incidence of cropland abandonment

Based on the results of the logistic regression models (Table 2), the number of long-term migrants is positively associated with the likelihood of reporting cropland abandonment. In contrast, seasonal migration is not significantly associated with abandonment, although the coefficient is negative. Holding all the covariates constant, every additional long-term migrant is associated with an increase in the log odds of cropland abandonment incidence by 0.23. Similarly, every additional 10^6 NPR (~7633.6 USD) in remittances is associated with an increase of log odds by 0.27. For other household characteristics, walking distance to the nearest community forest has a negative relationship with cropland abandonment, with a shorter distance associated with a higher risk of cropland abandonment incidence. The likelihood of cropland abandonment is less in the Salyan district, compared with Pyuthan.

3.4.2. Model results of the total area and area proportion of abandoned cropland

Based on the OLS regression models (Table 3), the relationships of migration with the total abandoned area remain generally consistent with the results on the abandonment incidence. However, there exist several notable changes. Remittances from long-term migrants (Model 3) show a weakly positive relationship, with every additional 10^6 NPR in remittances associated with 0.53 more ropani (~269.6 more m^2) abandonment (significant at the 10% level). Seasonal migration continues to exhibit negative but insignificant coefficients across models. Regarding other household characteristics, older household heads are significantly more likely to abandon more cropland. Larger cropland holdings are positively associated with a greater area abandoned, possibly indicating households abandoning marginal plots while retaining core farmland. Distance to community forests is negatively associated, suggesting that croplands closer to forests are more likely to be abandoned.

For the proportion of cropland area abandoned, long-term migration measured by both number (Model 2) and remittances (Model 3) shows positive coefficients, but only the number of migrants reaches marginal significance. Specifically, each additional long-term migrant is associated with a 1.6 %age point increase in abandoned cropland (significance at 10%). The association of cropland abandonment with seasonal migration remains insignificant. Among other covariates, a larger cropland base is again significantly associated with a lower proportion of land abandoned, suggesting that although households with more land

Table 2
Results of logistic regression models on whether a household has abandoned cropland. Numbers shown are regression coefficients, with standard errors in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Explanatory variable	Model 1	Model 2	Model 3
If has long-term migrants (0 =no, 1 =yes)	−0.05 (0.19)		
If has seasonal migrants (0 =no, 1 =yes)	−0.36 (0.25)		
Number of long-term migrants		0.23 (0.12) *	
Number of seasonal migrants		−0.18 (0.23)	
Remittance by long-term migrants (10^6 NPR)			0.27 (0.25)
Remittance by seasonal migrants (10^6 NPR)			−2.83 (2.37)
Ethnicity Group (0 =Brahman/ Chhetri, 1 =other)	−0.05 (0.19)	−0.07 (0.19)	−0.06 (0.19)
Gender of household head (0 =male, 1 =female)	0.15 (0.2)	0.09 (0.2)	0.13 (0.20)
Age of household head	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
Well-being score	0.06 (0.05)	0.05 (0.05)	0.06 (0.05)
Household size	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
Elevation at house location (1,000 m)	0.41 (0.34)	0.43 (0.34)	0.42 (0.34)
Slope at house location (degree)	−0.01 (0.01)	−0.01 (0.01)	−0.01 (0.01)
Area of cropland (ropani)	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
Distance to nearest community forest (hr)	−0.35 (0.20) *	−0.35 (0.20) *	−0.37 (0.20) *
District (0 =Pyuthan, 1 =Salyan)	−0.7 (0.20) ***	−0.63 (0.20) ***	−0.66 (0.20) ***
Constant	−2.32 (1.02) **	−2.48 (1.02) **	−2.38 (1.02) **

Table 3
Results of ordinary least squares regression models for abandoned cropland area and proportion of abandoned cropland. Numbers outside parentheses are coefficients, while numbers inside are standard errors. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Explanatory variable	Model 1	Model 2	Model 3
Total area of abandoned cropland (ropani)			
If has long-term migrants (0 =no, 1 =yes)	−0.11 (0.19)		
If has seasonal migrants (0 =no, 1 =yes)	−0.13 (0.24)		
Number of long-term migrants		0.16 (0.13)	
Number of seasonal migrants		−0.14 (0.22)	
Remittance by long-term migrants (10^6 NPR)			0.53 (0.29) *
Remittance by seasonal migrants (10^6 NPR)			−0.36 (1.79)
Ethnicity Group (0 =Brahman/ Chhetri, 1 =other)	0.11 (0.19)	0.10 (0.19)	0.11 (0.19)
Gender of household head (0 =male, 1 =female)	0.08 (0.2)	0.04 (0.2)	0.03 (0.2)
Age of household head	0.02 (0.01) **	0.02 (0.01) **	0.02 (0.01) **
Well-being score	−0.02 (0.05)	−0.02 (0.05)	−0.02 (0.05)
Household size	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
Elevation at house location (1000 m)	0.24 (0.34)	0.25 (0.34)	0.26 (0.34)
Slope at house location (degree)	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)
Area of cropland (ropani)	0.03 (0.01) **	0.03 (0.01) **	0.03 (0.01) **
Distance to nearest community forest (hr)	−0.41 (0.19) **	−0.42 (0.18) **	−0.46 (0.19) **
District (0 =Pyuthan, 1 =Salyan)	−0.32 (0.2)	−0.27 (0.19)	−0.25 (0.19)
Constant	−1.2 (1.02)	−1.29 (1.01)	−1.22 (1.01)
Proportion of abandoned cropland area			
If has long-term migrants (0 =no, 1 =yes)	−0.01 (0.013)		
If has seasonal migrants (0 =no, 1 =yes)	−0.024 (0.016)		
Number of long-term migrants		0.016 (0.009) *	
Number of seasonal migrants		−0.009 (0.015)	
Remittance by long-term migrants (10^6 NPR)			0.021 (0.02)
Remittance by seasonal migrants (10^6 NPR)			−0.101 (0.122)
Ethnicity Group (0 =Brahman/ Chhetri, 1 =other)	0.003 (0.013)	0.002 (0.013)	0.003 (0.013)
Gender of household head (0 =male, 1 =female)	0.015 (0.014)	0.01 (0.014)	0.012 (0.014)
Age of household head	0.001 (0)	0.001 (0)	0.001 (0) *
Well-being score	0.001 (0.004)	0.001 (0.004)	0.001 (0.004)
Household size	0.002 (0.001) *	0.002 (0.001)	0.001 (0.001)
Elevation at house location (1000 m)	0.037 (0.023)	0.038 (0.023) *	0.038 (0.023)
Slope at house location (degree)	0 (0.001)	0 (0.001)	0 (0.001)
Area of cropland (ropani)	−0.002 (0.001) **	−0.002 (0.001) **	−0.002 (0.001) **
Distance to nearest community forest (hr)	−0.026 (0.013) **	−0.026 (0.013) **	−0.028 (0.013) **
District (0 =Pyuthan, 1 =Salyan)	−0.044 (0.013) ***	−0.039 (0.013) ***	−0.04 (0.013) ***
Constant	−0.041 (0.069)	−0.052 (0.069)	−0.047 (0.069)

abandon more area in absolute terms, they tend to abandon a smaller share relative to their total holdings. Additionally, households in proximity to community forests tend to abandon a larger share of their cropland.

3.4.3. Model results of the total number and proportion of cropland parcels abandoned

Compared with area-based outcomes, the number of abandoned parcels shows the clearest association with long-term migrant count (Table 4). The ZIP count-component coefficient is 0.222. Exponentiating this coefficient gives an expected-count ratio of 1.25. Thus, holding the other covariates constant, each additional long-term migrant is associated with an approximately 25% higher expected number of abandoned parcels in the Poisson count component. While the presence of long-term migrants (Model 1) and remittances (Model 3) also show positive associations, they are not statistically significant. This pattern is consistent with the idea that parcel-level measures may capture management burdens in fragmented agricultural systems. However, this result should be interpreted cautiously because most control variables are not consistently significant across outcomes, and the estimates identify associations rather than causal effects. Seasonal migration coefficients are small and inconsistent in sign, and never statistically significant. For other variables, older household heads, higher household well-being scores, greater cropland holdings, and higher elevations show positive associations in some model specifications with more abandoned parcels. Ethnicity is also significantly associated with parcel abandonment. Specifically, households categorized as non-Brahman/Chhetri show a higher expected number of abandoned parcels across all three models. This result suggests that parcel-level abandonment may also reflect broader social and livelihood differences beyond migration alone.

When considering the proportion of abandoned parcels among total holdings, results are generally weaker in magnitude and statistical significance. Still, the number of long-term migrants remains positively associated with the proportion of cropland parcels abandoned (Model 2), with a modest but significant relationship (significant at 5%). Other variables, including household characteristics and location factors, mostly exhibit small and insignificant coefficients. Importantly, households in Salyan show significantly lower proportions of parcel abandonment compared to those in Pyuthan across all models, consistent with patterns observed in area-based models. This suggests that although absolute abandonment behavior may be similar, relative abandonment tendencies differ more systematically between the two districts.

3.5. Modeling cropland abandonment using different year cutoff thresholds

Migration and cropland abandonment may influence each other in both directions, thus we implemented year-specific cutoff models to examine the temporal stability of the observed associations. Positive associations emerge and remain relatively consistent once broader windows include sufficient abandonment cases, whereas estimates for the narrowest recent windows are imprecise and sometimes opposite in sign. However, because migration timing is not observed relative to each abandonment event, these results should be interpreted only as sensitivity checks, not as evidence of temporal ordering or reduced reverse causality (Fig. 7; Table A2).

Data retained under alternative cutoff years: To check for model sensitivity to cropland abandonment years, we re-estimated our models using a series of year-based thresholds to define "recent" abandonment, ranging from 2020 back to 2010. For each cutoff year *t*, households that abandoned cropland in or after year *t* were coded as 1 (abandoned). Moving the cutoff backward in time increases the number of abandonment cases, as expected (Fig. 7**a**), but also progressively incorporates earlier abandonment events that may be more temporally distant from current migration status.

Table 4
Results of zero-inflated Poisson (ZIP) regression models for the number of abandoned cropland parcels and ordinary least squares (OLS) regression models for the proportion of abandoned parcel numbers. For the ZIP models, explanatory-variable coefficients are from the Poisson count component and are expressed on the log-count scale; exponentiating a coefficient gives the corresponding expected-count ratio. The inflation component is an intercept-only logit model. Numbers outside parentheses are coefficients, while numbers inside parentheses are standard errors. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Explanatory variable	Model 1	Model 2	Model 3
Number of abandoned parcels			
If has long-term migrants (0 = no, 1 = yes)	0.251 (0.153)		
If has seasonal migrants (0 = no, 1 = yes)	−0.319 (0.22)		
Number of long-term migrants		0.222 (0.097) **	
Number of seasonal migrants		0.086 (0.228)	
Remittance by long-term migrants (10^6 NPR)			0.343 (0.274)
Remittance by seasonal migrants (10^6 NPR)			−0.56 (1.772)
Ethnicity Group (0 = Brahman/Chhetri, 1 = other)	0.43 (0.146) ***	0.456 (0.147) ***	0.43 (0.148) ***
Gender of household head (0 = male, 1 = female)	0.075 (0.163)	0.012 (0.164)	0.083 (0.162)
Age of household head	0.02 (0.006) ***	0.019 (0.006) ***	0.02 (0.006) ***
Household size	−0.026 (0.039)	−0.032 (0.038)	−0.038 (0.038)
Well-being score	0.034 (0.01) ***	0.038 (0.01) ***	0.039 (0.01) ***
Elevation at house location (1000 m)	0.529 (0.291) *	0.484 (0.294)	0.603 (0.299) **
Slope at house location (degree)	−0.018 (0.009) *	−0.017 (0.009) *	−0.017 (0.009) *
Area of cropland (ropani)	0.049 (0.01) ***	0.051 (0.01) ***	0.047 (0.01) ***
Distance to nearest community forest (hr)	−0.093 (0.162)	−0.035 (0.161)	−0.054 (0.167)
District (0 = Pyuthan, 1 = Salyan)	0.18 (0.161)	0.219 (0.162)	0.221 (0.161)
Count component: Constant	−4.122 (0.856) ***	−4.272 (0.86) ***	−4.406 (0.872) ***
Proportion of abandoned parcels			
If has long-term migrants (0 = no, 1 = yes)	0.004 (0.013)		
If has seasonal migrants (0 = no, 1 = yes)	−0.012 (0.017)		
Number of long-term migrants		0.021 (0.009) **	
Number of seasonal migrants		−0.004 (0.015)	
Remittance by long-term migrants (10^6 NPR)			0.016 (0.02)
Remittance by seasonal migrants (10^6 NPR)			−0.085 (0.123)
Ethnicity Group (0 = Brahman/Chhetri, 1 = other)	0.002 (0.013)	0.001 (0.013)	0.002 (0.013)
Gender of household head (0 = male, 1 = female)	0.012 (0.014)	0.008 (0.014)	0.011 (0.014)
Age of household head	0.001 (0)	0.001 (0)	0.001 (0)
Well-being score	0.001 (0.004)	0.001 (0.004)	0.001 (0.004)
Household size	0 (0.001)	0 (0.001)	0 (0.001)
Elevation at house location (1000 m)	0.036 (0.023)	0.038 (0.023) *	0.037 (0.023)
Slope at house location (degree)	−0.001 (0.001) *	−0.001 (0.001) *	−0.001 (0.001) *
Area of cropland (ropani)	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)
Distance to nearest community forest (hr)	−0.016 (0.013)	−0.017 (0.013)	−0.017 (0.013)
District (0 = Pyuthan, 1 = Salyan)	−0.039 (0.013) ***	−0.035 (0.013) ***	−0.038 (0.013) ***
Constant	0.014 (0.07)	0.008 (0.069)	0.015 (0.069)

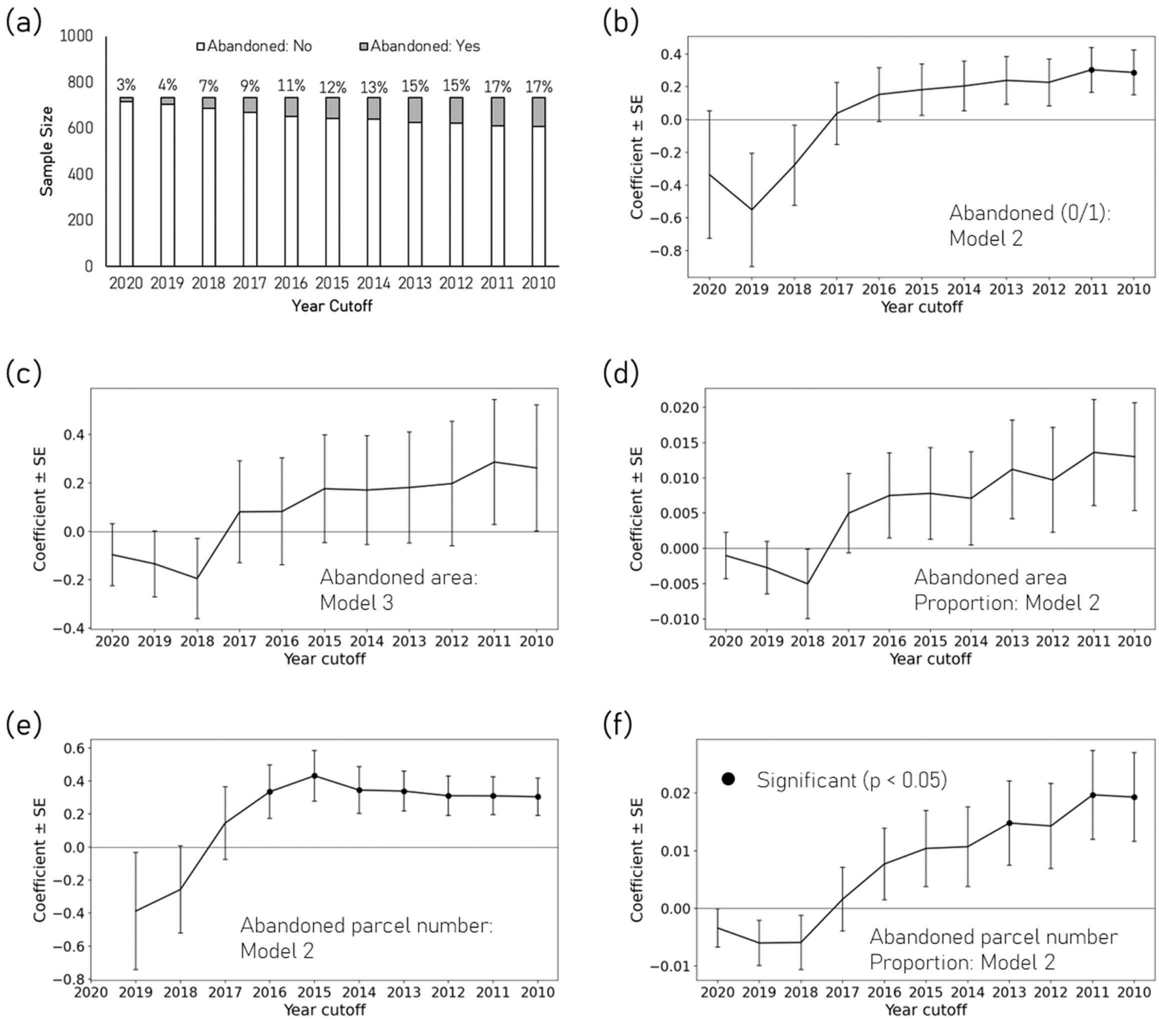

Fig. 7. Modeling results of cropland abandonment and migration with different year cutoff thresholds. The sample size shows the proportion of households with cropland abandonment in the data. Model 2 includes key variables of the numbers of long-term and seasonal migrants; Model 3 includes remittances received from long-term and seasonal migrants.

Abandonment incidence: The results reveal distinct temporal patterns across outcome measures. For abandonment incidence (Model 2), the coefficient for the number of long-term migrants becomes positive and statistically significant beginning with the 2011 cutoff and remains stable through the 2010 threshold (Fig. 7**b**). Notably, the association strengthens as the cutoff year moves backward, suggesting that the migration-abandonment relationship is not confined to a narrow period. The estimates vary across cutoff years partly because sample size and the number of abandonment cases change across thresholds. However, the direction and magnitude remain stable once sufficient cases are included.

Abandoned area and area proportion: In contrast, models using total abandoned area (Model 3 with remittances) and abandoned area proportion (Model 2 with migrant counts) show generally weak and statistically insignificant associations across cutoff years (Fig. 7**c,d**). These patterns reinforce our earlier finding that area-based measures are less sensitive to migration dynamics in fragmented smallholder systems.

Parcel numbers: The most consistent temporal patterns emerge in parcel-based models. The number of long-term migrants is significantly associated with a higher number of abandoned parcels beginning with the 2016 cutoff and continuing through 2010 (Fig. 7**e**). Similarly, parcel abandonment proportion becomes significant for most cutoff years between 2013 and 2010 (Fig. 7**f**). Importantly, these effects persist across multiple adjacent temporal windows rather than appearing sporadically in isolated years. This stability suggests that the parcel-level association is not driven only by a single cutoff definition, although it cannot rule out post-abandonment migration responses.

Overall, the year-specific models show that the association between long-term migration and parcel-level abandonment is not highly sensitive to a single cutoff definition. However, because migration timing is not observed relative to each abandonment event, these results should be interpreted only as sensitivity checks. They do not establish cause and effect direction, reduce endogeneity, or rule out post-abandonment migration responses. The consistency of parcel-based associations across multiple cutoff thresholds is consistent with the interpretation that sustained labor outmigration is linked to structural adjustments in cropland management.

4. Discussion

4.1. Implications of cropland abandonment for food security

Our findings contribute directly to the ongoing discussion about food security in developing countries (Prosekov and Ivanova, 2018), particularly in mountainous regions where arable land is scarce and rural out-migration is widespread (Bista et al., 2021; Li et al., 2018). In the Nepal study sites, 22.9% of surveyed households reported cropland abandonment. This level of contraction is consistent with broader evidence that abandonment often emerges where environmental constraints intersect with socioeconomic pressures. In mountain regions, these constraints include steep terrain, limited accessibility, labor loss, and changing livelihood strategies (Zheng et al., 2023). In such settings, smallholders face rising production and marketing costs. They also face greater difficulty maintaining distant parcels, especially when household labor is limited and fields require monitoring or protection from crop raiding by wildlife (Bista and Song, 2022). Similar tensions have been documented in other mountainous and marginal farming regions in Asia and Latin America. In these regions, outmigration can reduce on-farm labor availability and weaken incentives to continue cultivation (Aide and Grau, 2004; Crawford et al., 2024; Paudel et al., 2014).

Cropland abandonment can have implications beyond individual households because local production shortfalls may accumulate and increase dependence on external food sources. Nepal's agriculture sector has declined in relative economic importance over recent decades. Agriculture's share of GDP was reported at 27% in 2019, down from 40% in 1995 (National Planning Commission, 2019), while agricultural imports have increased (Bista et al., 2021). To convey the possible food-security relevance of household-level abandonment in a more interpretable way, we present a simplified illustrative scenario using Nepal's Community Forestry (CF) program as a reference frame. Approximately 2.91 million households participate in CF, organized into more than 23,000 CFUGs (Dhungana et al., 2024). If the abandonment prevalence observed in our study households were applied to CF-participating households nationally, the implied abandoned area over the decade prior to the 2023 survey would be approximately 2.44 million ropani (~124,000 ha). Using average unit-area productivity observed in our surveys, this illustrative abandoned area would correspond to approximately 78,000 tons of rice, 59,000 tons of wheat, or 61,000 tons of maize in staple-equivalent terms. These quantities are intended only as an order-of-magnitude translation of potential production relevance, not as nationally representative estimates of abandonment or crop loss. This scenario relies on strong simplifying assumptions. It assumes comparable abandonment prevalence and productivity beyond the study sites and does not account for spatial heterogeneity in yields, cropping systems, market access, or agroecological conditions. It should not be interpreted as a causal estimate of food-production loss attributable to migration. Rather, it helps connect observed household-level land-use changes to food-security-relevant quantities and highlights the need for more studies to estimate the national scale of abandonment and its production implications.

Households' perceived reasons for abandonment reinforce that food-security risks emerge from multiple, interacting constraints rather than a single driver. The top-cited reasons were wildlife crop raiding, labor shortages due to outmigration, and low soil fertility. Together, they point to a coupled socio-ecological process in which farming becomes riskier and more costly while the local labor base erodes. Wildlife crop raiding was the most frequently reported reason for abandoning parcels, consistent with growing concerns that human-wildlife conflict can make cultivation economically unattractive, particularly near forested areas (Zhang et al., 2024a). In line with this, we found proximity to community forests, measured by walking distance, is significantly associated with cropland abandonment. This suggests that households closer to forests may face greater pressure to disengage from farming. This finding aligns with studies arguing that forest recovery and conservation efforts can unintentionally intensify crop-raiding risks and contribute to cropland losses in some contexts (Bista et al., 2023; Zhang et al., 2024b), underscoring trade-offs between ecosystem restoration and agricultural land retention (Li et al., 2018). Meanwhile, labor shortage due to outmigration, which ranked second, highlights that migration is not only a livelihood strategy but also a structural force reshaping land use. These patterns suggest that food-security policy in mountain regions should address both ecological and socioeconomic constraints, including crop raiding near forests, labor availability, farm profitability, and parcel accessibility.

4.2. Divergent associations of long-term and seasonal migration with cropland abandonment

Our results suggest that long-term and seasonal migration are linked to cropland abandonment through different livelihood pathways. Long-term migrant count shows a consistently positive association with abandonment, while seasonal migration shows weak or inconsistent relationships. Across model specifications and abandonment indicators, households with more long-term migrants are more likely to report abandonment, and they tend to abandon more parcels (and, in some specifications, larger areas). These patterns are consistent with the New Economics of Labor Migration (NELM) perspective, which conceptualizes migration as a household strategy to manage risk and reallocate labor and capital across activities (Stark and Bloom, 1985). In this framing, sustained outmigration can reduce household reliance on farming in two ways. It removes labor from day-to-day cultivation and may increase access to remittance income. Together, these changes can lower the economic necessity of maintaining marginal or low-return plots. Similar dynamics have been reported in other agrarian transition contexts. In these settings, longer-duration migration is associated with durable shifts away from agriculture and greater abandonment of distant or less productive land (Dong et al., 2011; Eklund et al., 2024; Ellis, 2010; Xu et al., 2019a).

A key empirical insight is that the parcel-based abandonment measure shows the clearest association with long-term migration. This association is also comparatively stable across alternative year-cutoff definitions of "recent" abandonment. This pattern suggests that parcel counts can be informative in fragmented smallholder landscapes. However, the parcel-number results should be interpreted as suggestive rather than definitive evidence. Each additional parcel typically implies separate travel time, monitoring, and management effort. When labor is reduced by long-term migration, households may respond first by consolidating cultivation into fewer, easier-to-manage parcels rather than immediately exiting farming altogether (Koirala and Bashyal, 2025). In that sense, parcel abandonment may detect early-stage disengagement that is not fully captured by binary (any abandonment) or area-based indicators. This interpretation aligns with research linking fragmentation to higher management burdens and reduced efficiency, especially where labor is scarce and parcels are dispersed (Blarel et al., 1992; Latruffe and Piet, 2014; Tan et al., 2006). It also helps explain why area-based measures can appear less responsive. Households may stop cultivating multiple small or distant parcels without a large immediate change in total area, particularly when abandoned parcels are relatively small.

In contrast, seasonal migration exhibits limited and statistically weak associations with abandonment outcomes in our data. One plausible explanation is that seasonal migration functions more as a temporary income-smoothing strategy than a driver of long-term livelihood restructure. Seasonal migrants may time their departure around periods of lower on-farm labor demand and return during planting or harvesting windows. This timing can reduce the extent to which migration creates sustained labor shortages (Gautam, 2017; Shrestha et al., 2022). Seasonal migration may also generate smaller or less predictable remittance flows than long-term migration, making it less likely to relax subsistence constraints enough to justify abandoning cropland. These patterns imply that the migration–abandonment relationship is not simply about "migration" per se. It also depends on duration, timing, and whether migration changes households' longer-run labor allocation and income dependence on farming.

Several control variables also show significant associations with cropland abandonment and help contextualize migration-related results. In particular, the significant association between ethnicity and abandoned parcel number should be interpreted cautiously. Ethnic group in rural Nepal may serve as a proxy for historically shaped differences in land access, land quality, livelihood opportunities, social networks, and access to institutions, rather than representing a direct causal mechanism itself (Bhandari, 2013; Fisher, 2007). These factors can affect whether households maintain or abandon marginal parcels under labor constraints. Thus, ethnicity should be understood as a marker of broader social and institutional differences that may shape parcel-level abandonment.

4.3. Role of remittances in cropland abandonment

Our results also point to remittances, especially those linked to long-term migration, as an important mechanism connecting migration to land-use change. Remittance coefficients are generally smaller and less consistently significant than those for migrant counts. Still, the overall pattern suggests that sustained remittance inflows from long-term migrants are associated with more abandoned cropland parcels and, in some cases, larger abandoned areas. This is consistent with the idea that remittances can relax income and labor constraints (Rozelle et al., 1999). They may buffer households against income volatility, reduce reliance on agricultural production, and allow household effort to shift toward off-farm work, education, or small enterprises. Over time, these shifts can make continued cultivation of low-return or difficult-to-manage plots less attractive (Guo et al., 2023; Subedi et al., 2022). In mountain environments, farming already entails high labor demands and transaction costs. Under these conditions, even moderate remittance support may shift the cost–benefit balance toward withdrawing from marginal parcels.

Importantly, remittances can be a double-edged sword for food security. On one hand, remittances can enhance household resilience by stabilizing consumption and providing resources to cope with climate shocks and market fluctuations. On the other hand, remittances may reduce dependence on farming income. This can weaken incentives to maintain fragmented or distant land and may reinforce deagrarianization in the most constrained parts of the landscape (Robson and Berkes, 2011), potentially reducing local food production or production-based food security. This pattern parallels evidence from other regions in the Global South. In these settings, migration-derived income can gradually shift livelihood portfolios away from subsistence agriculture and contribute to land-use transitions, including abandonment (Aide and Grau, 2004; Majumdar, 2020).

In contrast, remittances from seasonal migration show no clear relationship with cropland abandonment in our study. One plausible explanation is that seasonal remittances are often smaller and more irregular. They may also be closely tied to short-term household needs, such as food purchases, debt repayment, agricultural inputs, or hired labor. In this setting, seasonal migration may function more as an income-smoothing strategy that supports continued cultivation, rather than enabling a durable exit from farming. Prior research similarly shows that seasonal or circular migration can complement agricultural livelihoods rather than replace them. This is especially likely where farming remains central to subsistence and risk management (Gartaula et al., 2012; Rapoport and Docquier, 2006).

The weak and inconsistent associations between remittance amount from seasonal migrants and cropland abandonment should also be interpreted in light of how remittances are used. Only 10.0% of remittance-receiving households reported using remittances to purchase agricultural equipment or irrigation, and this use accounted for only 4.8% of all reported remittance uses. In contrast, living expenses, healthcare, education, and debt repayment were much more common. This pattern suggests that remittances in the study area are used primarily for household maintenance and human-capital needs rather than direct agricultural investment. This is consistent with prior evidence from Nepal that remittances often support consumption and education expenditures, while agricultural effects depend on how remittance income is allocated (Kapri and Ghimire, 2020; Mishra et al., 2022). Future research should collect more detailed information on remittance use, timing, and regularity to test these mechanisms more directly.

4.4. Limitations and future directions

Although our year-specific models assess whether results are sensitive to alternative definitions of recent abandonment, several limitations remain. First, migration status is measured at the time of survey rather than through a full longitudinal migration history. This limits our ability to establish strict temporal precedence. Unobserved household characteristics may also influence both migration and abandonment decisions. These include long-term livelihood preferences and inherited land quality. For instance, households with stronger aspirations for non-agricultural livelihoods may be more likely to send migrants and gradually withdraw from farming (De Haas, 2021). Similar patterns may occur among households with higher tolerance for occupational mobility. Meanwhile, inherited land conditions may shape both farming and migration decisions. Parcels with poor soil fertility or high wildlife exposure may reduce agricultural profitability and make out-migration more attractive as an alternative income strategy. Our models control for several observable factors, such as slope. However, unmeasured attributes, such as long-term risk preferences or social networks abroad, may still bias estimated associations. Finally, bidirectional dynamics between migration and land-use change cannot be fully disentangled with a cross-sectional design. The year-specific models help assess whether results are sensitive to alternative definitions of recent abandonment. They should not be interpreted as addressing endogeneity. The survey does not observe the exact timing of migration decisions relative to each abandonment event. Therefore, we cannot determine whether migration preceded abandonment or whether abandonment encouraged subsequent migration. Unobserved household characteristics may also shape both processes. Such feedbacks could be examined in future research using more sophisticated designs, such as panel studies or bottom-up agent-based simulations with feedback loops (Zhang et al., 2023). Future research using panel data, detailed migration histories, or credible quasi-experimental variation would be needed to estimate causal effects more directly.

Measurement limitations also apply to key variables. Cropland abandonment is identified from respondents' reports rather than repeated field observation, and the intention component ("no plan to re-cultivate in the foreseeable future") is inherently subjective. Interviewer training and a standardized interview protocol were used to promote consistency. Even so, households may differ in how they interpret "abandonment" versus extended fallow, and recall error may affect reported timing. We also explicitly excluded parcels that were temporarily fallow or transferred (e.g., rented/sold) from abandonment, but some misclassification may remain. Future work could strengthen measurement by combining survey responses with systematic plot verification or remote-sensing indicators of cultivation status.

Our migration measures are also simplified. Long-term and seasonal migration are defined by duration thresholds, which discretize a continuous and multidimensional process. As a result, migrants near the cutoff or with heterogeneous purposes/roles may be imperfectly classified, potentially attenuating estimated associations. In this study, seasonal migration shows limited direct association with cropland abandonment in our models, but it may still influence land-use decisions through indirect, timing-sensitive mechanisms. Seasonal migrants can alter the intra-annual allocation of household labor by leaving during slack periods and returning for planting or harvest. This timing may affect cultivation intensity, the timeliness of farm operations, and reliance on hired labor or labor-sharing arrangements (Nienkerke et al., 2023). Future work could combine detailed agricultural calendars, seasonal migration histories, and parcel-level management data. Such data would help test whether seasonal migration affects abandonment indirectly through labor bottlenecks, production outcomes, or risk-management strategies.

Furthermore, our models do not fully account for CFUG-level confounding factors. These factors may influence household land-use decisions and contribute to residual heterogeneity in abandonment outcomes. Future CFUG-level data collection and multilevel analysis could better capture the institutional context of cropland abandonment. This may be especially useful where CFUG strategies, such as wildlife deterrence, patrolling, or benefit-sharing arrangements, shape cultivation risks and incentives. More broadly, the relatively weak statistical significance of some predictors likely reflects contextual heterogeneity and unobserved drivers. These may include parcel-level land quality, sudden shocks, and social-network effects, which are difficult to measure in a cross-sectional survey.

5. Conclusions and policy implications

This study shows that rural outmigration, especially long-term migration, is associated with cropland abandonment patterns in the Middle Hills of Nepal, with implications for local agricultural production, food security, and land management. We find that long-term and seasonal migration have different associations with cropland use decisions, particularly on abandonment. Long-term migration is consistently associated with abandonment incidence and parcel-level abandonment, while seasonal migration shows limited or even countervailing associations. These patterns may reflect the more sustained labor reallocation associated with long-term migration, while remittances appear to play a weaker and more ambivalent role. These findings echo broader trends of agrarian transition in many parts of the Global South. Importantly, our findings suggest that the number of abandoned parcels shows the clearest association with long-term migrant count among the abandonment indicators. This points to the role of land fragmentation. Households managing multiple small, dispersed plots may face greater barriers to continued cultivation, including higher labor costs, time burdens, and logistical challenges. Voluntary land coordination and terrace-compatible service models may help reduce management burdens in some contexts.

For policy intervention, statistical significance should be distinguished from practical importance. The estimated migration-related effects are generally modest at the household level, especially for area-based outcomes, and should not be interpreted as implying large immediate land-use changes for every household. Their practical relevance lies mainly in the possibility that small parcel-level changes may accumulate across many households in steep and highly fragmented landscapes. Policy responses should therefore be guided not only by statistical significance, but also by local terrain, landholding structure, labor availability, forest proximity, and households' reported reasons for abandonment.

Policy interventions should recognize the heterogeneity of migration-related associations and align strategies with distinct household migration profiles and landscape constraints. For households with existing long-term migrants, the goal should not be to "reverse" migration, but to reduce the transaction costs and risks of continued cultivation under labor scarcity. Practical entry points may include voluntary land leasing, joint cultivation, service-based land coordination, and wildlife-risk mitigation near forest margins. For households at risk of future migration-related abandonment, policy support may need to focus on improving agricultural returns and reducing cultivation risks before abandonment occurs. This could include terrace-compatible irrigation, crop-protection measures, extension support for higher-value or lower-labor crops, improved market access, and community labor-sharing during peak agricultural periods. Because large-scale land consolidation and conventional mechanization may be difficult in steep and highly fragmented Middle Hills terrains, policy efforts should prioritize small-scale, locally adaptable options such as mini-tillers, shared tool banks, small irrigation systems, terrace-maintenance support, and machinery services designed for terrace farming. For households relying more on seasonal migration, policies may need to focus on timing and flexibility. Seasonal employment programs and public works could be scheduled to avoid peak labor bottlenecks during planting and harvest periods, while local labor-sharing or hiring mechanisms could help smooth short-term constraints. Overall, reducing cropland abandonment in migration-prone mountainous regions likely requires an integrated package that lowers cultivation risk, reduces labor and coordination costs, and treats migration and remittances as enduring features of rural livelihoods.

CRediT authorship contribution statement

Sophia A. Graybill: Writing – review & editing, Data curation. **Conghe Song:** Writing – review & editing, Writing – original draft, Supervision, Investigation, Funding acquisition, Conceptualization. **Erin O. Sills:** Writing – review & editing, Investigation. **Qi Zhang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Conceptualization. **Richard E. Bilsborrow:** Writing – review & editing, Investigation. **Rajan Parajuli:** Writing – review & editing, Investigation.

Declaration of Competing Interest

The first author, Qi Zhang, serving as a Managing Editor, had no involvement in the editorial decision. The other authors declare no competing interests.

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Appendix

Table A1
Correlation matrix and Variance Inflation Factor (VIF) values

Variable	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	VIF
x1	1																1.917
x2	−0.18	1															2.085
x3	0.65	−0.11	1														1.994
x4	−0.19	0.72	−0.09	1													2.593
x5	0.31	0.00	0.39	−0.05	1												1.252
x6	−0.13	0.46	−0.07	0.60	−0.01	1											1.648
x7	0.02	−0.01	0.02	−0.03	−0.01	−0.05	1										1.104

(*continued on next page*)

Table A1 (*continued*)

Variable	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	VIF
x8	0.10	0.05	0.14	0.06	0.11	0.08	−0.06	1									1.328
x9	−0.02	−0.04	0.04	−0.01	−0.03	−0.04	0.02	−0.10	1								1.256
x10	−0.02	0.01	−0.10	−0.01	0.01	0.05	−0.15	−0.35	−0.33	1							1.644
x11	−0.12	0.03	−0.01	0.03	0.00	0.02	0.05	−0.18	0.06	0	1						1.107
x12	0.05	0.03	0.00	0.02	0.08	0.01	−0.15	−0.12	−0.10	0.37	0.14	1					1.309
x13	−0.08	−0.01	−0.08	−0.01	−0.07	−0.01	0.14	0.03	−0.04	−0.22	0.07	−0.23	1				1.196
x14	0.01	0.01	0.00	0.04	−0.04	0.02	0.10	0.02	−0.02	−0.13	0.04	−0.18	0.19	1			1.080
x15	−0.06	−0.04	−0.05	−0.01	0.00	0.00	−0.08	−0.15	0.12	0.13	0.13	0.17	0.03	0.02	1		1.103
x16	0.04	−0.06	0.04	−0.04	0.11	−0.02	0.13	0.06	0.06	−0.13	0.00	−0.18	0.19	0.02	−0.11	1	1.127

Notes: x1 - If has long-term migrants (0 =no, 1 =yes); x2 - If has seasonal migrants (0 =no, 1 =yes); x3 - Number of long-term migrants; x4 - Number of seasonal migrants; x5 - Remittance by long-term migrants (10^6 NPR); x6 - Remittance by seasonal migrants (10^6 NPR); x7 - Ethnicity group (0 =Brahman/Chhetri, 1 =other); x8 - Gender of household head (0 =male, 1 =female); x9 - Age of household head; x10 - Education of household head; x11 - Household size; x12 - Well-being score indicating household overall socioeconomic status; x13 - Elevation at house location (1000 m); x14 - Slope at house location (degree); x15 - Area of cropland (ropani); x16 - Distance to nearest community forest (hour). According to the correlation analysis, we will separate the models into three pairs of migration variables and exclude the education of the household head.

Table A2
Modeling results with different year cutoff thresholds

Year Cutoff	Abandoned: No	Abandoned: Yes	Model 1	Model 2	Model 3
Abandoned (0/1)					
2020	715	19	−0.459 (0.4916)	−0.336 (0.3898)	−1.032 (1.5267)
2019	704	30	−0.703 (0.4029)	−0.551 (0.3463)	−2.354 (1.8287)
2018	685	49	−0.351 (0.3112)	−0.279 (0.2451)	−1.219 (1.0515)
2017	668	66	0 (0.2718)	0.037 (0.1892)	−0.025 (0.4079)
2016	652	82	−0.014 (0.2458)	0.153 (0.1645)	−0.053 (0.4048)
2015	644	90	−0.021 (0.2362)	0.182 (0.1577)	0.102 (0.3544)
2014	639	95	−0.014 (0.2305)	0.205 (0.1526)	0.099 (0.3388)
2013	625	109	−0.051 (0.2188)	0.239 (0.1445)	0.039 (0.3363)
2012	621	113	−0.069 (0.2157)	0.227 (0.143)	0.039 (0.3375)
2011	610	124	0.061 (0.2089)	0.304 (0.1367) **	0.192 (0.2911)
2010	609	125	0.032 (0.2084)	0.288 (0.137) **	0.169 (0.2937)
Abandoned area					
2020	715	19	−0.089 (0.0824)	−0.047 (0.058)	−0.096 (0.1285)
2019	704	30	−0.133 (0.0873)	−0.069 (0.0613)	−0.134 (0.1359)
2018	685	49	−0.148 (0.1061)	−0.107 (0.0745)	−0.195 (0.1651)
2017	668	66	−0.039 (0.1355)	0.034 (0.0951)	0.081 (0.2105)
2016	652	82	−0.069 (0.1421)	0.066 (0.0996)	0.082 (0.2206)
2015	644	90	−0.049 (0.1438)	0.098 (0.1008)	0.176 (0.2232)
2014	639	95	−0.056 (0.1449)	0.104 (0.1015)	0.171 (0.2249)
2013	625	109	−0.056 (0.1481)	0.131 (0.1037)	0.181 (0.2299)
2012	621	113	−0.131 (0.1659)	0.093 (0.1163)	0.198 (0.2575)
2011	610	124	−0.077 (0.1669)	0.133 (0.1169)	0.287 (0.2589)
2010	609	125	−0.105 (0.1677)	0.117 (0.1174)	0.262 (0.2602)
Abandoned area %					
2020	715	19	−0.004 (0.0046)	−0.001 (0.0033)	−0.004 (0.0072)
2019	704	30	−0.007 (0.0053)	−0.003 (0.0037)	−0.007 (0.0082)
2018	685	49	−0.012 (0.007)	−0.005 (0.0049)	−0.013 (0.0108)
2017	668	66	−0.004 (0.0081)	0.005 (0.0056)	0.004 (0.0125)
2016	652	82	−0.006 (0.0086)	0.008 (0.006)	0.003 (0.0134)
2015	644	90	−0.008 (0.0092)	0.008 (0.0065)	0.008 (0.0143)
2014	639	95	−0.009 (0.0094)	0.007 (0.0066)	0.007 (0.0147)
2013	625	109	−0.008 (0.01)	0.011 (0.007)	0.005 (0.0155)
2012	621	113	−0.009 (0.0105)	0.01 (0.0074)	0.004 (0.0164)
2011	610	124	−0.003 (0.0108)	0.014 (0.0075)	0.009 (0.0167)
2010	609	125	−0.004 (0.0108)	0.013 (0.0076)	0.008 (0.0168)
Abandoned parcel number					
2020	715	19	−0.786 (0.5384)	N/A	−0.943 (1.6081)
2019	704	30	−0.617 (0.4335)	−0.388 (0.3539)	−1.113 (1.4009)
2018	685	49	−0.461 (0.3228)	−0.257 (0.2636)	−0.977 (1.0027)
2017	668	66	−0.056 (0.27)	0.145 (0.2213)	1.056 (0.9184)
2016	652	82	0.065 (0.2358)	0.335 (0.1619) **	N/A
2015	644	90	0.117 (0.2234)	0.431 (0.1536) ***	N/A
2014	639	95	0.082 (0.2205)	0.345 (0.1413) **	N/A
2013	625	109	0.111 (0.2)	0.338 (0.1214) ***	N/A
2012	621	113	0.117 (0.1982)	0.31 (0.1186) ***	N/A
2011	610	124	0.116 (0.1886)	0.31 (0.1141) ***	N/A
2010	609	125	0.11 (0.1873)	0.304 (0.1131) ***	N/A
Abandoned parcel number %					
2020	715	19	−0.006 (0.0046)	−0.003 (0.0033)	−0.006 (0.0072)
2019	704	30	−0.01 (0.0056)	−0.006 (0.0039)	−0.011 (0.0087)

(*continued on next page*)

Table A2 (*continued*)

Year Cutoff	Abandoned: No	Abandoned: Yes	Model 1	Model 2	Model 3
2018	685	49	−0.009 (0.0068)	−0.006 (0.0047)	−0.014 (0.0105)
2017	668	66	−0.002 (0.0078)	0.002 (0.0055)	−0.001 (0.0121)
2016	652	82	−0.002 (0.0088)	0.008 (0.0062)	−0.001 (0.0136)
2015	644	90	−0.001 (0.0094)	0.01 (0.0066)	0.008 (0.0146)
2014	639	95	−0.001 (0.0098)	0.011 (0.0069)	0.007 (0.0153)
2013	625	109	−0.002 (0.0105)	0.015 (0.0073) **	0.006 (0.0162)
2012	621	113	−0.002 (0.0106)	0.014 (0.0074)	0.005 (0.0165)
2011	610	124	0.004 (0.011)	0.02 (0.0077) **	0.01 (0.0171)
2010	609	125	0.003 (0.011)	0.019 (0.0077) **	0.009 (0.0171)

Notes: Model 1 includes whether a household has any long-term and seasonal outmigrants, Model 2 includes the number of long-term and seasonal migrants, and Model 3 includes the amount of remittances received from long-term and seasonal migrants. ** $p < 0.05$; *** $p < 0.01$.

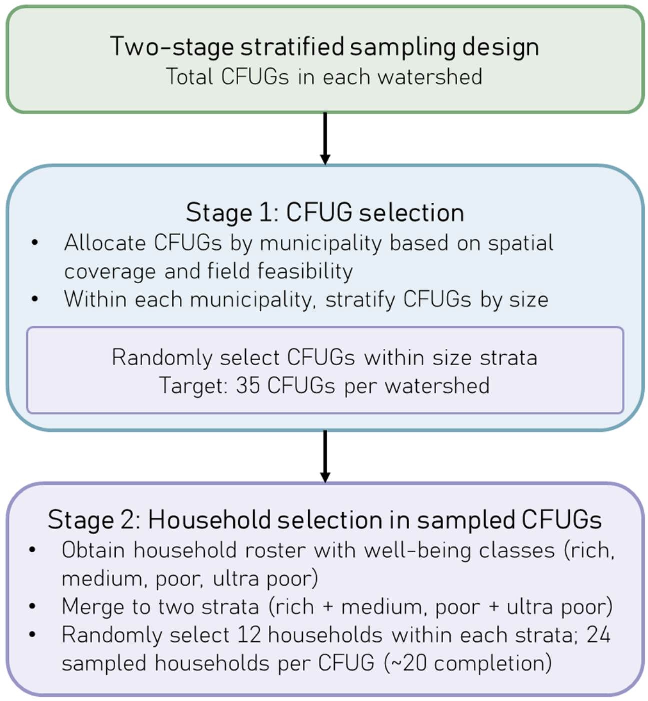

Fig. A1. Overview of the sampling procedure for household surveys in the two watersheds in rural Nepal

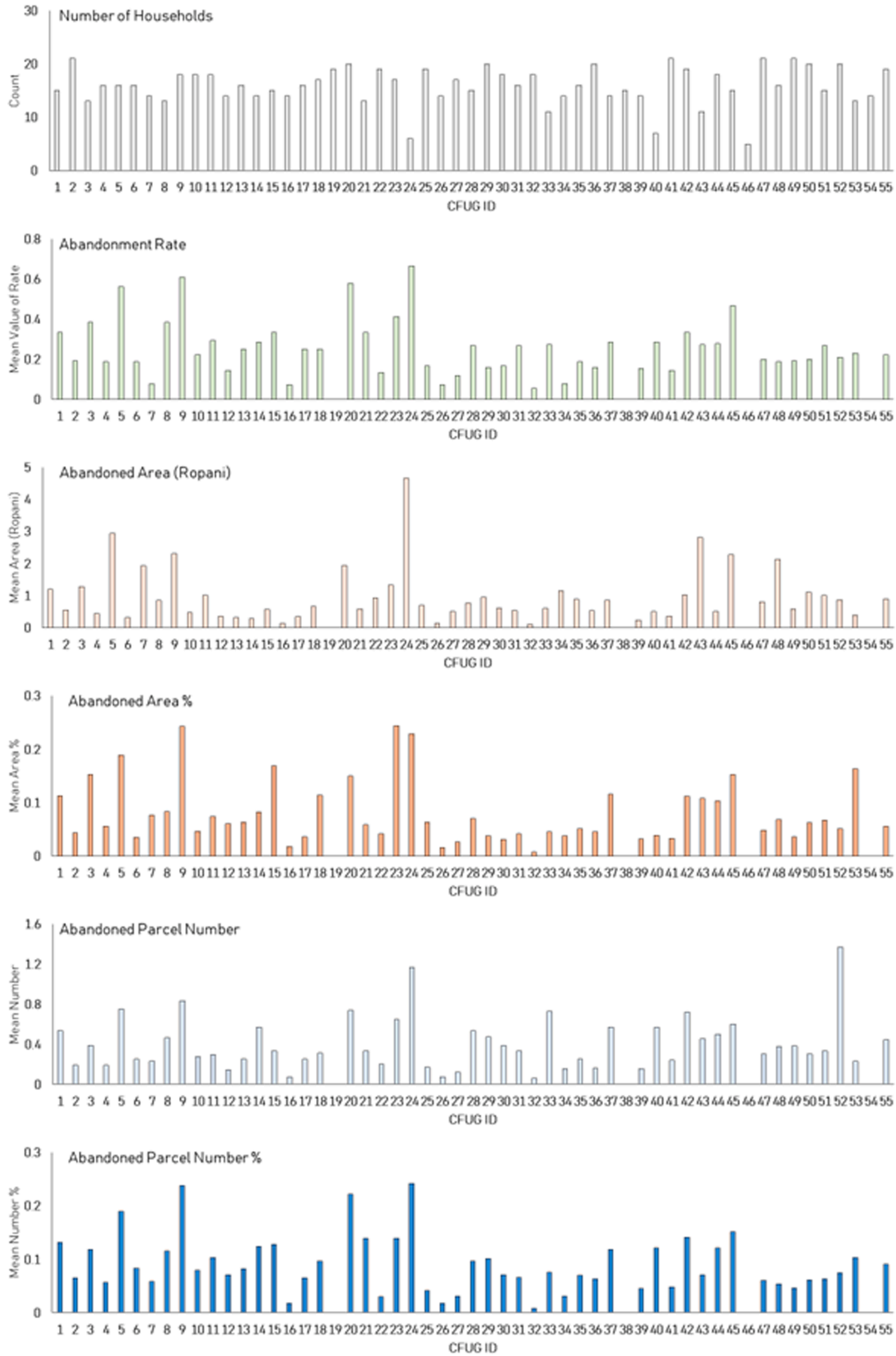

Fig. A2. Descriptive statistics at the CFUG level. From top to bottom, the variables are number of households, rate of cropland abandonment, abandoned area, percentage of abandoned area, abandoned parcel number, and proportion of abandoned parcel number in total parcel number

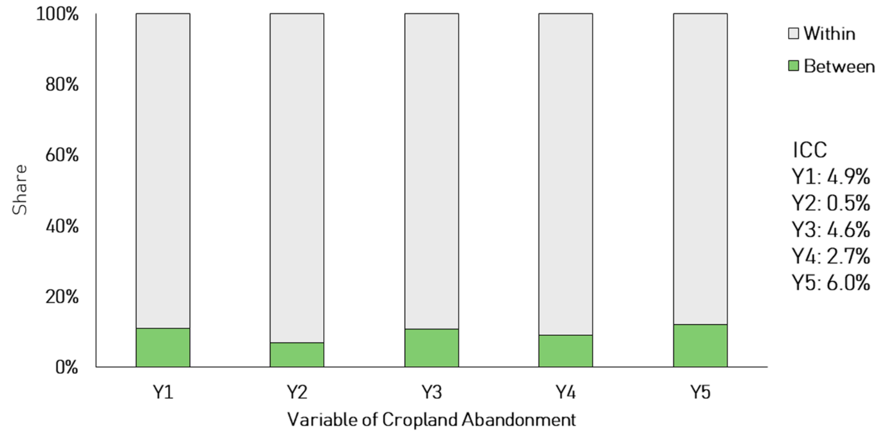

Fig. A3. Statistical summary of between vs. within CFUG for variables related to cropland abandonment. Y1: Has abandoned cropland; Y2: Abandoned area; Y3 Abandoned area %; Y4: Abandoned parcel number; Y5: Abandoned parcel number %

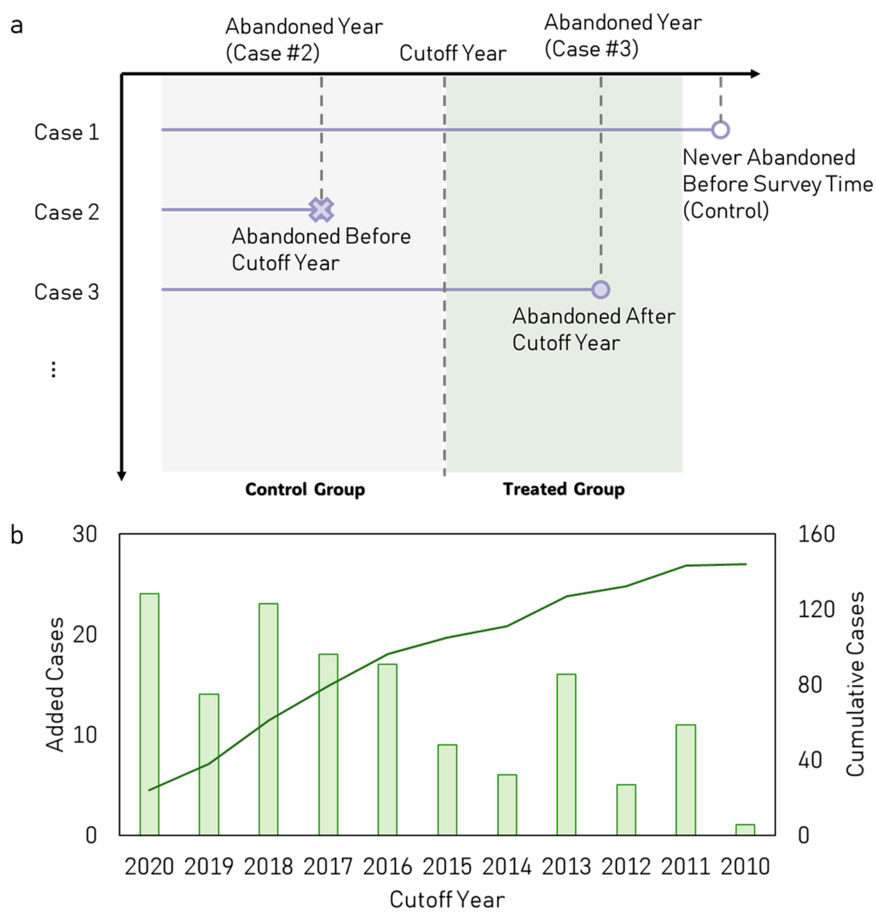

Fig. A4. Design for testing sensitivity of associations between cropland abandonment and labor migration with different year cutoff thresholds. (a) Schematic illustration of analytical design with cutoff years. The cutoff year is a dynamic variable ranging from 2020 back to 2010. Cases represent households regarding three types: (1) no abandoned cropland at the survey time, which would remain to be in the cultivated group; (2) abandoned cropland before the cutoff year, which would be added to the cultivated group; and (3) abandoned cropland after the cutoff year, which would be the abandonment group. (b) Bar plots of added cases and cumulative cases with different cutoff years

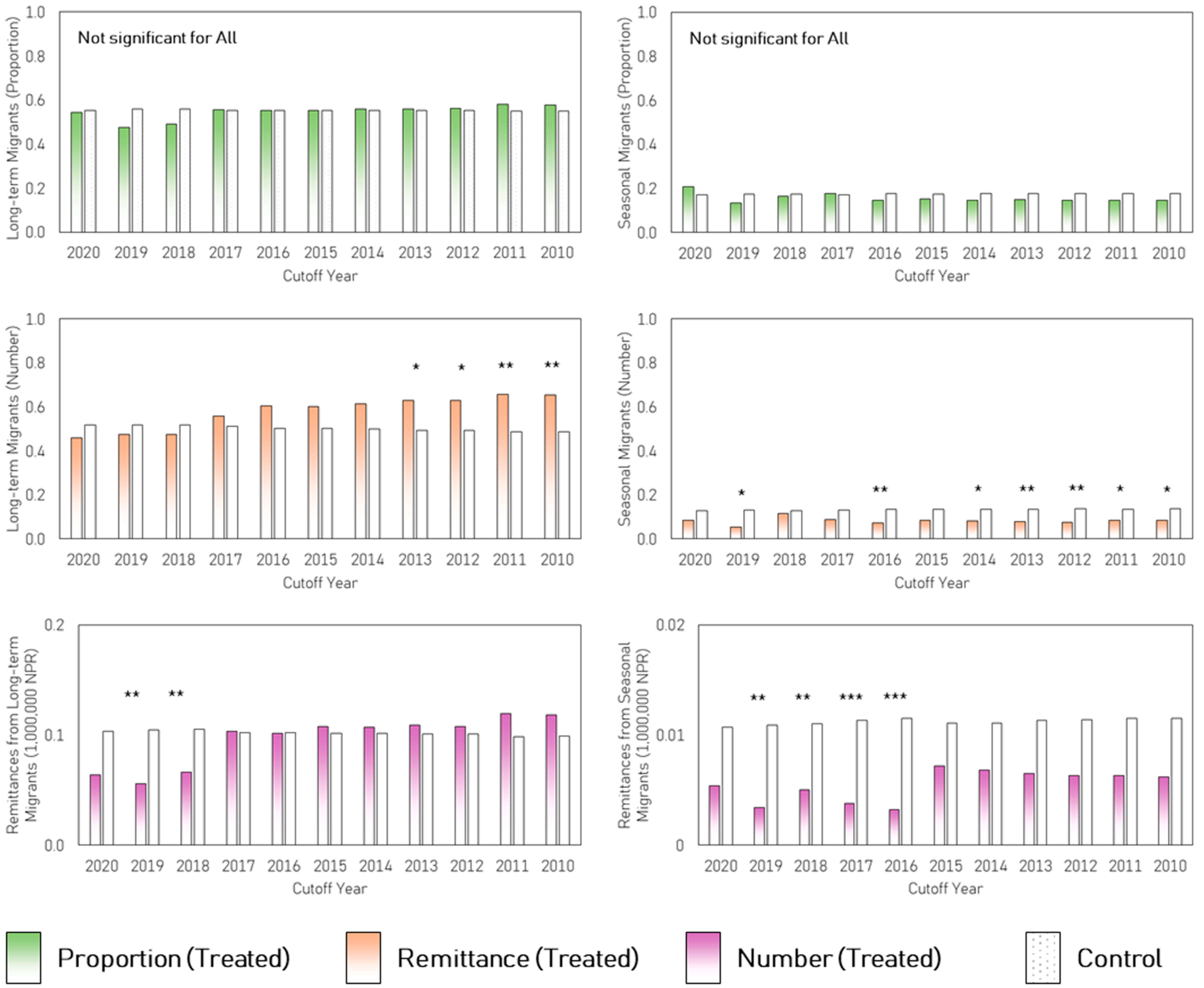

Fig. A5. Statistical summary of comparisons between abandoned and control non-abandoned groups by cutoff years, regarding whether a household has migrants (upper panel), number of migrants (middle panel), and remittances from migrants (lower panel)

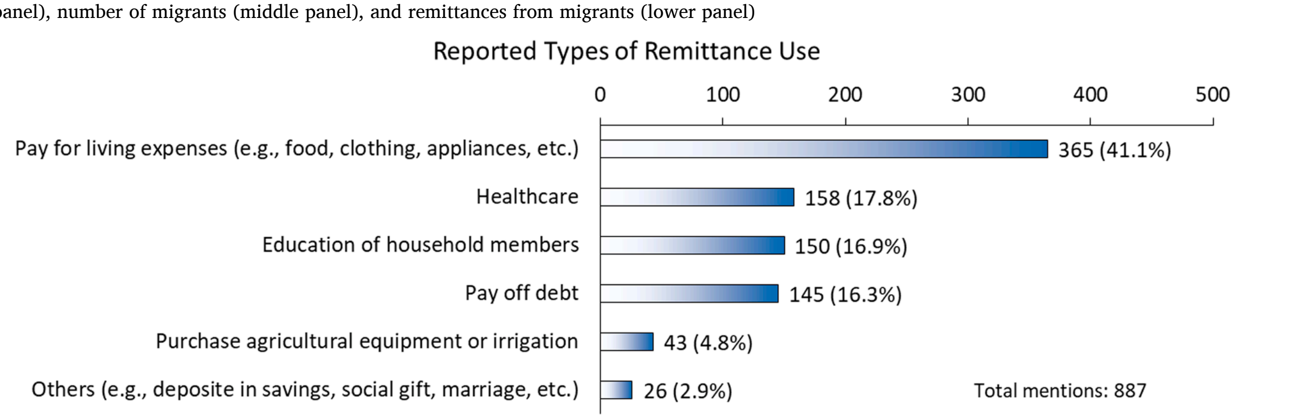

Fig. A6. Reported types of remittance use among surveyed households. Households could report multiple uses of remittances. Thus, percentages shown in the figure are based on 887 total remittance-use mentions, not the number of households. Among the 428 households that received remittances from either long-term or seasonal migrants, 43 households (10.0%) reported using remittances to purchase agricultural equipment or irrigation

Data Availability

Data will be made available on request.

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