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Cropland abandonment and flood risks: Spatial analysis of a case in North Central Vietnam

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ABSTRACT

Agricultural land abandonment due to floods has become a significant global problem, causing multiple environmental issues, deteriorating rural landscapes, and impacting the socioeconomic conditions of farmers. Although research on agricultural abandonment has addressed different spatial scales, very few studies have focused on Southeast Asian countries, particularly Vietnam, where abandonment rates have significantly increased due to flooding and urbanization. This study assessed the drivers of land abandonment in a river valley in Central Vietnam. The analysis comprised: 1) quantifying changes in land use/cover using satellite data; 2) conducting socioeconomic field surveys; 3) simulating flooding using a 2013 dataset on flood occurrences; and 4) mapping community resilience. Results suggested that the tendency of farmers to abandon agricultural land in high-flood zones and community resilience were vital factors influencing agricultural land outcomes. From a planning perspective, findings of this study highlight the potential for spatial planning to limit the adverse effects of flood events. This approach provides a consistent framework for further research on landscape and agricultural management in similar regions around the world. It is also applicable for other economically developing countries.

1. Introduction

Agricultural land is the most common landuse type on Earth and plays an important role in sustaining human societies (Han and Song, 2019). Additionally, agricultural land covers approximately 40% of Earth's land surface (Levers et al., 2018) and is continually expanding. However, the abandonment of agricultural land (Van der Sluis et al., 2014; Zhang et al., 2014; Gabarrón-Galeote et al., 2015), which first began in the 20th century, is predicted to become more frequent, which will adversely impact societies in many rural areas. Therefore, a stronger understanding of the long-term relationships between the abandonment of agricultural land and its socioeconomic and environmental effects can contribute to the development of theoretical frameworks for supporting sustainable planning and rural development (San Roman Sanz et al., 2013). However, identifying the dominant drivers is complex due to several interrelated driving factors including location, culture, socioeconomics, and the frequency and intensity of natural hazards (Sroka et al., 2019).

Agricultural abandonment is the termination of agricultural activity, which modifies biodiversity and ecosystems (Terres et al., 2015). To

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reduce agricultural abandonment, it is necessary to assess the underlying causes and mechanisms, including socioeconomic and natural environmental challenges. Li and Li (2017) suggested that the root cause of agricultural abandonment was poor land quality, which led to lower production and economic output. Sroka et al. (2019) grouped agricultural-abandonment drivers into five “syndromes”: (1) the natural environment (Hinojosa et al., 2016); (2) socioeconomic factors (Justice et al., 2015); (3) location (Corbelle-Rico and Crecente-Maseda, 2014); (4) institutional framework (Abolina and Luzadis, 2015); and (5) farm characteristics (Van der Sluis et al., 2016). However, most of these drivers were based on abandonment in developed countries—especially in Europe—where this process is well understood. In these regions, because exogenous variables such as urbanization and industrial growth are emphasized, endogenous drivers such as a community’s resilience to floods are rarely considered or investigated (Galarza-Villamar et al., 2018). For example, Walker and Salt (2012) argued that assessing endogenous drivers was the most important approach for understanding sustainable rural development in the context of complex external drivers. In this regard, understanding such endogenous drivers can help increase community resilience to flooding / extreme climatic events (Saja et al., 2019) and significantly influence rural planning policies. Moreover, increasing community resilience can improve farmers’ adaptability to floods (Vallés-Planells et al., 2020).

Resilience is the capacity of an object to return to its initial state after a shock or continuous pressure (Taillet et al., 2018). It also represents the ability to predict, cope with, and recover from an initial shock or impact from a climate event at the individual or community level (Warner et al., 2010; Rubin, 2014). The resilience of communities has been assessed at different scales with different approaches related to different areas (Dauphiné and Provitolo, 2007; Folke, 2016; Quinlan et al., 2016; Vallés-Planells et al., 2020). The Intergovernmental Panel on Climate Change (IPCC) in 2014 has argued that the resilience capacity of a given community depends on three factors: the ability to access a given resource, self-organization, and perception capacity. Resilience also depends on the economic, political, and socio-demographic characteristics of society. Socioeconomics and politics play a key role in reducing vulnerability and increasing resilience. Differences in the level of vulnerability show that the level of exposure and the adaptation of populations vary in space and over time (Black et al., 2011; Rubin, 2014). Resilience is an integrative concept well suited for risk management in terms of physical and social aspects (Van der Leeuw and Aschan-Leygonie, 2005). It is seen as a useful tool for limiting flood damage (Dauphiné and Provitolo, 2007). The framework includes the flood risk combined with the ability of a society to limit agricultural abandonment, such as by identifying high-risk areas in need of flood control and increasing its resilience capacity. Therefore, community resilience and its interaction with agricultural abandonment should be assessed.

Floods are one of the most dangerous natural hazards, and the flood risk is defined using a combination of hydroclimatological hazards and population vulnerability (Burton et al., 1993). Recently, flood control strategies have been the subject of discussion among researchers worldwide. Faced with persistent flood risks, societies have two broad options: (1) adopt structural measures, containing or attenuating floods through various actions such as dam construction (Merz et al., 2010) or (2) reduce population vulnerability and increase community resilience (Disse et al., 2020). To reduce societal vulnerability to flooding, current risks, impacts, and local adaptation must be understood (Bastakoti et al., 2014). This knowledge provides an overview of relevant challenges or opportunities to improve the resilience of vulnerable communities. For example, the UK has revised agricultural policies and evaluated flood risk-management policies to reduce cropland abandonment (Posthumus et al., 2008).

In Vietnam and other countries, floods are a leading cause of agricultural land abandonment.Climatic factors play an essential role in agricultural land abandonment in the mountainous region of Vietnam. Extreme weather conditions such as heavy rainfall and flooding, which directly influence agriculture, have recently become increasingly frequent (Xie et al., 2014). Moreover, previous studies have identified the negative effects of floods on agricultural activities, causing farmers to abandon these activities. For example, according to Dun (2009), the number of Vietnamese migrating from agricultural/rural areas to cities has fluctuated considerably since the mid-1980 s. This is partly because of the effects of natural hazards, such as floods and typhoons and partly due to new economic opportunities. Likewise, Sakdapolrak et al. (2014) found that floods were the main cause of agricultural land abandonment in Northern Thailand. Therefore, we built a novel theoretical framework to analyze the relationship between flooding and agricultural land abandonment to manage agricultural land abandonment, which continues to increase. We hypothesized that farmers mainly decide to abandon agricultural land due to low resilience. The hypothesis was tested by assessing the contribution of community resilience to the overall impact of flooding events. The mountainous region of Vietnam is particularly interesting for studying the links between flood risk and agricultural land abandonment.

Thus, we evaluated the change in agriculture upstream of the Gianh River to answer two main questions: (1) How does agricultural land abandonment relate to flood risk? (2) How and why is community resilience related to agricultural land abandonment rates? Although previous studies have attempted to answer the first question, they have not addressed the causes of agricultural land abandonment. This study further elucidates the dominant links between agricultural land abandonment and environmental factors. This information can support decisionmakers in developing strategies to protect societies and provide robust agricultural land management recommendations. Moreover, although this study addresses changes in land-use in Vietnam, thefindings are also important for spatially planning and sustainably developing agricultural land in other countries that are often affected by floods.

2. Data and methodology

2.1. Study area

The Gianh River watershed is in Central Vietnam and covers an area of 4,680 km^2 (Fig. 1). The study area includes seven communes in the upper watershed covering an area of 28,671 ha, with a total population of 38,969 people (General Statistics Office of Vietnam, 2019). The topography ranges from 0 to 2,017 m above sea level. the area is divided into two distinct topographic regions: the mountains and plains. The study area’s climate is monsoonal and tropical. there are divided by two main seasons: the dry season (from December to July) and the rainy season (from August to November). The average precipitation is between 2,000 and 2,500 mm per year, and approximately 50% of the annual precipitation is concentrated in two months September and November.

This region is composed of agricultural land (> 10%), forest (75%), urban land (6%), and barren land (9%). Agricultural land is concentrated in the low slope area of the upper Gianh River. Rice is the predominant agricultural crop, and the paddy fields are located on the valley bottom, which is approximately 2 km wide. The regional fields mainly follow three crop patterns: (1) two rice crops and one dry crop per year, (2) two rice crops per year, and (3) Pennisetum purpureum only. Fields following crop patterns (1), (2), and (3) are situated 5–7, 7–10, and 3–5 m above sea level, respectively, and the lowest-lying fields are located in flood-prone areas.

The crop patterns are related to the fields’ locations relative to the irrigation infrastructure, land topography, and flood risk. The distinct land use categories in the study area are similar to those in the region surrounding the Red River Delta in Northern Vietnam (Erout and Castella, 2002). However, depending on the flood risk, other landuses are possible in the study area. Cultivated rice paddies decreased by

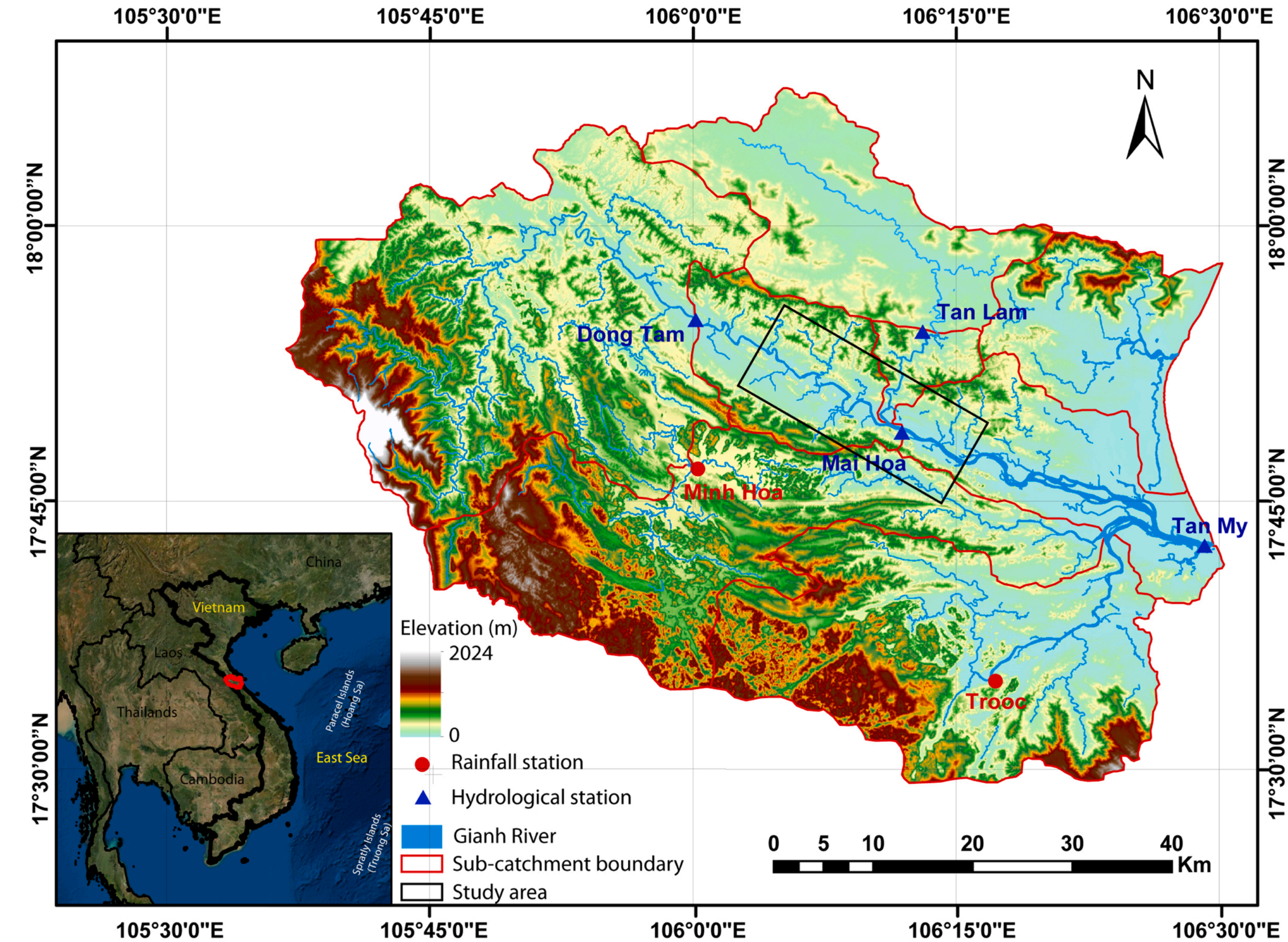

Fig. 1. Study area in North Central Vietnam.

approximately 50% from 1989 to 2019; this was strongly correlated to urban growth (Haemmerli et al., 2017). Agricultural land abandonment due to natural hazards was also a significant driving factor (Nguyen et al., 2018). In particular, the agricultural land in the study area experiences several hydrographical disturbances such as floods.

The Gianh River watershed has a narrow topography and short and steep rivers, and altitude tends to decrease from west to east (Fig. 1); as a result, during periods of heavy rainfall, the water quickly flows to the river and causes severe floods. In addition, the rainy season is concentrated in the months of August and November. This is also the period when many types of extreme weather conditions, such as storms and tropical depressions, occur. These phenomena often occur independently; sometimes the combined effect causes very heavy rains on a large scale, producing major floods in the study area. Fifty-eight typhoons and tropical disturbances inundated the region between 2000 and 2014, resulting in significant flooding at least twice per year. According the data from the Ministry of Natural Resources and Environment of Vietnam (MONRE) in 2019, these events have intensified and have occurred more frequently since 2005 (Nguyen et al., 2018), causing significant human losses and massive economic damage.

2.2. *Methodology*

The study workflow consisted of four main steps, as illustrated in Fig. 2. First, we analyzed the change in land sse and land cover (LULC), land cover maps for 1989, 2003, and 2019 were constructed from Landsat 5, Landsat 7, and Sentinel 2A data, respectively. The satellite images were classified using at supervised classification method and eCognition Developer software. In parallel, we conducted flood simulations in October 2013 using a spatial geodatabase, which included hydrological, climatic, topographical, and human activity data to develop 1D and 2D hydrodynamic flood simulation models. The final depth and velocity maps were built from this model. Next, we overlapped the flood and landcover maps to identify the relationship between agriculture land abandonment and flooding. Finally, we assessed community resilience using socioeconomic data obtained from field surveys carried out in 2020 to understand the links between community resilience and farmers' decisions to abandon their agricultural land.

2.2.1. *Analysis of changes in landuse/cover*

We obtained historical maps of the study region to determine the change in the agricultural area. These maps included LULC maps for 2005, 2010, and 2020. The landcover was also analyzed using aerial photographs taken in 1990 and satellite images (Landsat 5, Landsat 7, and Sentinel 2A) taken in 1989, 2003, and 2019 (Supplementary 1). These years were selected due to important policy changes in 1986 (doi moi or "renovation"). Data were projected onto the WGS84/UTM Zone 48 N coordinate system. Geographic information system (GIS) data on land use in 2005, 2010 and 2020, administrative boundaries, and town locations were obtained from the Natural Resources and Environment Department of the province of Quang Binh (https://stnmt.quangbinh.gov.vn/3cms/). All spatial analyses were performed using eCognition Developer software and QGIS. The data were resampled and normalized to assure that all data had the same resolution before analysis.

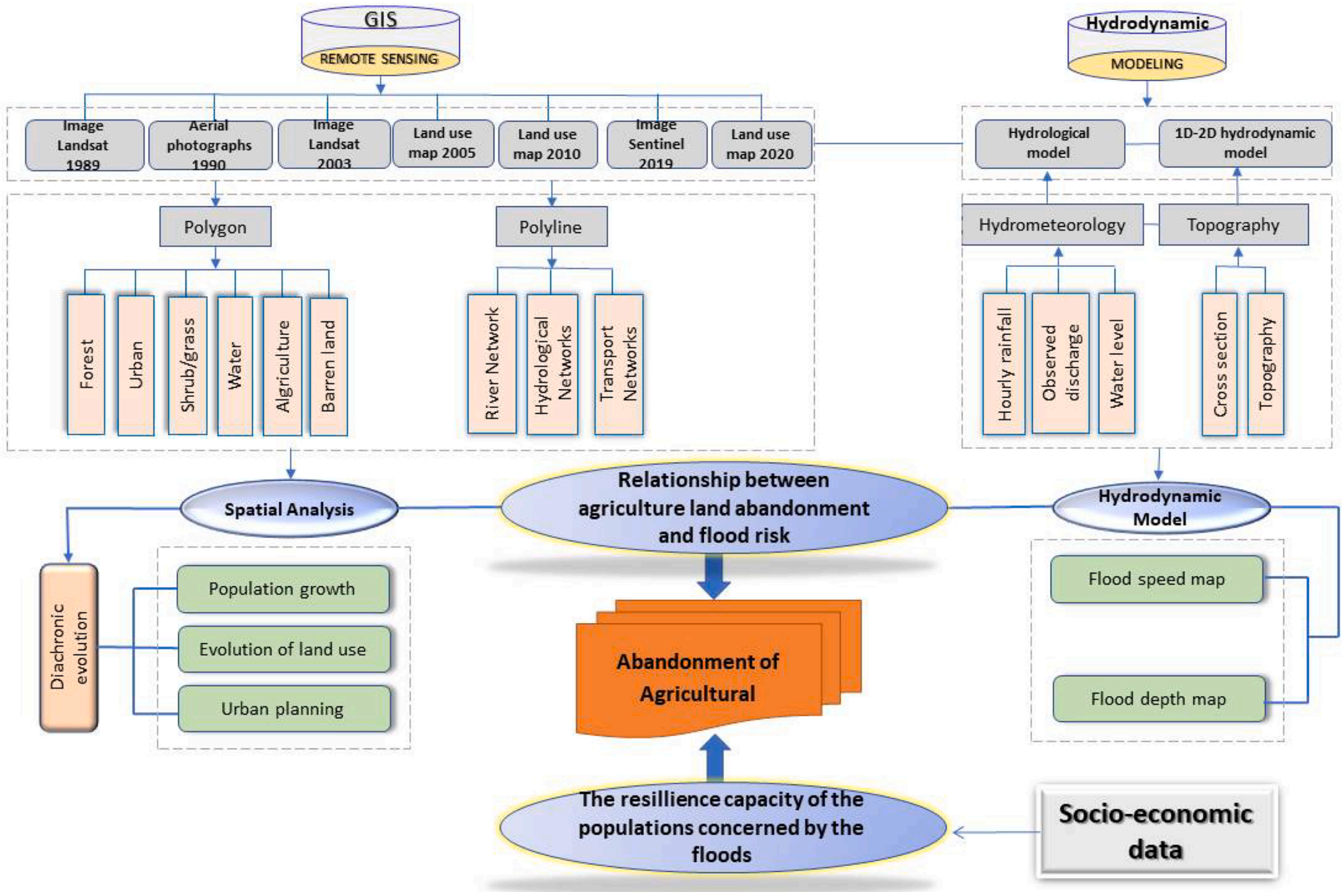

Fig. 2. Diagram of model setup.

In recent years, due to the increasing spatial resolution and availability of remote sensing data, the method of object-based image analysis has received the attention of researchers interested in monitoring land use changes. However, this method requires a preliminary step: image segmentation. The purpose of image segmentation is to create image segments with maximum homogeneity. The principle consists of aggregating pixels according to adjacency criteria and similar spectral characteristics and/or shapes that are determined by the user (Phiri et al., 2020). This process was performed using eCognition Developer software and can be adjusted using shape, scale, and compactness parameters (Pham et al., 2019). Several methods have been integrated into object-based image analysis, including the decision tree, support vector machine, and random forest methods (Nguyen et al., 2019; de Oliveira Cordeiro and Rossetti, 2015; Xu et al., 2019). However, in this study, the support vector machine (SVM) was used to classify 1,486 ground truth samples selected from historical survey data to train and validate the model (Table 1). The samples included the forest, urban, shrub / sparse forest, water, agricultural, and barren land use classes.

The classification accuracy was assessed by comparing high-resolution remote sensing and landuse maps (Pontius and Millones, 2011). The accuracy of the 1989 land cover map was assessed by comparing it with aerial photographs, and the accuracis of the 2003 and 2019 land cover maps were assessed by comparing them with land use maps generated in 2005 and 2020, respectively.

In order to analyze the land cover changes over the three periods, the change trajectories were classified into six groups: (1) deforestation (the transformation of forest into a non-forest area), (2) reforestation (the transformation of a non-forest area into a forest area), (3) the abandonment of agricultural land (the transformation of an agricultural area into a shrubs area, forest or barren land), (4) other changes, and (5) no change. One of the major challenges in analyzing land cover changes was detecting areas affected by permanent agricultural abandonment and areas affected by temporary agricultural abandonment. In this study, agricultural abandonment was defined as the transformation of an agricultural area (observed in 1989) into natural shrub regrowth (observed in 2003) provided that these areas are not put back into production in 2019. Changes like AAS, AAF, etc., which are not definitively abandonned, are part of the "other change" group (Table 2).

Table 1
Class Name and Number of Samples.

Class Name	Number of Samples
Forest	312
Urban	251
Shrub/Sparse forest	153
Water	214
Agricultural	375
Barren Land	181

2.2.2. *Flood simulation*

For hydrodynamic modeling, we collected meteorological and hydrological data from 2010 to 2014, including (1) hourly rainfall timeseries data at four hydrological and two meteorological gauges collected by the National Centre for Hydrometeorological Forecasting (NCHMF; http://nchmf.gov.vn/); (2) discharge time series data at Dong Tam hydrological gauge; (3) water-level time series data at Mai Hoa and Tan My gauges; (4) 53 river cross-sections measured in the main streams of Gianh and Son rivers, which were used for 1D hydraulic model MIKE 11 simulations; and (5) a topographical map at 1:10,000 scale published in 2010 by the Ministry of Natural Resources and Environment, which was

Table 2
Land cover change trajectories and their descriptions (1989–2019) (F: Forest; B: Barren land; A: Agricultural; S: Shrub).

Group	Land Cover Change	Category	Change Trajectory		
			1989	2003	2019
1	Deforestation	F-F-A	Forest	Forest	Agricultural
		F-F-B	Forest	Forest	Barren land
		F-B-B	Forest	Barren land	Barren land
		F-B-A	Forest	Barren land	Agriculture
		F-S-B	Forest	Shrub	Barren land
		F-S-A	Forest	Shrub	Agriculture
		F-A-A	Forest	Agricultural	Agricultural
		F-A-S	Forest	Agricultural	Shrub
2	Reforestation	A-F-F	Agricultural	Forest	Forest
		S-F-F	Shrub	Forest	Forest
		S-S-F	Shrub	Shrub	Forest
		B-F-F	Barren land	Forest	Forest
		B-S-F	Barren land	Shrub	Forest
3	Agricultural abandonment	A-S-F	Agricultural	Shrub	Forest
		A-S-B	Agricultural	Shrub	Barren land
		A-B-B	Agricultural	Barren land	Barren land
		A-B-F	Agricultural	Barren land	Forest
4	Other change	A-A-S, A-F-S, A-F-A, S-A-S, A-S-A, S-F-S, F-A-F, F-S-F, S-A-F, A-A-F, B-B-F, B-B-S, B-B-A, B-S-A, B-S-S.			
5	No change	F-F-F, A-A-A, S-S-S, B-B-B			

used to generate bathymetric data to be input into MIKE-21. The station locations are shown in Fig. 1.

We applied the MIKE FLOOD model to simulate flood events in the study area (Ahmad and Simonovic, 1999). This model incorporates the dynamic and automatic interactions of the one-dimensional (1D) MIKE 11 and two-dimensional (2D) MIKE 21 models to capture a flood's dynamics. To accurately capture lateral flows and flood-wave propagation, the 2D MIKE 21 model uses the incompressible Reynolds-averaged Navier–Stokes equations based on Boussinesq and hydrostatic pressure assumptions (Sarker, 2019). Unlike in 1D modeling, in which results can only be obtained at points where cross-sectional information is available, results from the 2D model are calculated at each point of a 2D (15 m) model grid in the solution domain.

The entire watershed was divided into eight subbasins (Fig. 1). A hydraulic network was generated in MIKE 11 using 42 cross-sections along the main stream of the Gianh River from Dong Tam to the Gianh River Estuary (56.5 km long), and 11 cross-sections along the Son River from the Trooc gauge station to the river's confluence with the Gianh River (a total distance of 21.5 km). The discharge timeseries observed at the Dong Tam gauge and the water level at the Tan My gauge were used as the upper and lower boundaries of the study area. The inflow and discharge boundaries for the Son River were simulated using the MIKE NAM model.

The 2D computational domain was bounded by the Dong Tam gauge and Gianh River outlet; it had a total area of 281 km^2. A mesh was generated by discretizing the computational domain into 30,644 mesh nodes and 60,362 cells ranging from 70 to 100 m. The model system was calibrated and validated using data measured during flood events in October 2010 and 2013, respectively. We applied the discharge time series observed for the Dong Tam gauge to calibrate and validate the MIKE NAM model.

2.2.3. Socioeconomic field survey

Socioeconomic data were obtained from historical flood damage reports and field surveys. The flood damage reports listing the damages to goods, people, and agricultural activities were obtained from the Vietnam Disaster Management Authority. Field surveys were conducted to assess the impacts of the flooding, residents' perception of flood protection, the resilience of communities, and socioeconomic status (Supplementary 2). The perception of residents is essential because physical flood protection and the perception of the flood risk both influence land abandonment decisions. In 2020, we conducted a field survey across seven municipalities experiencing the highest flood-risk exposure and agriculture land abandonment. The survey consisted of structured questionnaires aimed at understanding different particularities of the study area. Although the selected survey sites were not representative of the entire population, we focused on the causes of changes in the agricultural region to assess the resilience of farmers and their vulnerability to flood risks. Structured interviews were conducted with adult residents (with ages from 18 to 60 years) working in the agricultural sector. The structured questionnaire collected relevant information from 380 households that were randomly selected from the survey area. The study methodology is shown in Fig. 3.

3. Results

3.1. Land cover analysis

The kappa indexes for the LULC classifications were 0.78, 0.82, and 0.84 for 1989, 2003, and 2019, respectively. Fig. 4 and Table 3 show that from 1989 to 2019, agricultural areas and forest areas slightly decreased. The study area has experienced a general trend of increasing shrub / sparse forest areas and urban growth. Table 4 shows the area of abandoned agricultural land in each municipality from 1989 to 2019. It can be seen that agricultural abandonment in the study area increased from 1989 to 2019. This type of land cover increased by about 116% in the commune of Tien Hoa, followed by Dong Hoa (80%), Phong Hoa (59%), Thach Hoa (26%), Chau Hoa (18%), and Mai Hoa (1.5%); meanwhile, the area affected by agricultural abandonment decreased in the municipality of Duc Hoa by around 6% from 1989 to 2019.

3.2. Flood impacts

In this study, the Nash–Sutcliffe indices (Nash and Sutcliffe, 1970) and flood peak error were used to evaluate the results of the calibration and verification of the hydrological and hydrodynamic models. The results showed that the hydrological model performed well, with at Nash-Sutcliffe value of over 90% at the Dong Tam gauge (Fig. 5). Thus, this model has sufficient reliability to be used to compute inputs for the hydrodynamic model. The hydrodynamic model was calibrated and validated using water-level data obtained from the Mai Hoa gauge. The results showed that the hydrodynamic model performed well, with Nash–Sutcliffe values of 0.87 and 0.85 and flood peak errors in the range from 0.03 to 0.04 m for the calibration and validation timeseries, respectively (Table 5).

Rainfall was recorded on the morning of October 15, 2013. The rainfall intensity was 250 mm per day and increased to > 400 mm per day upstream at the Dong Tam gauge, where flooding peaked at

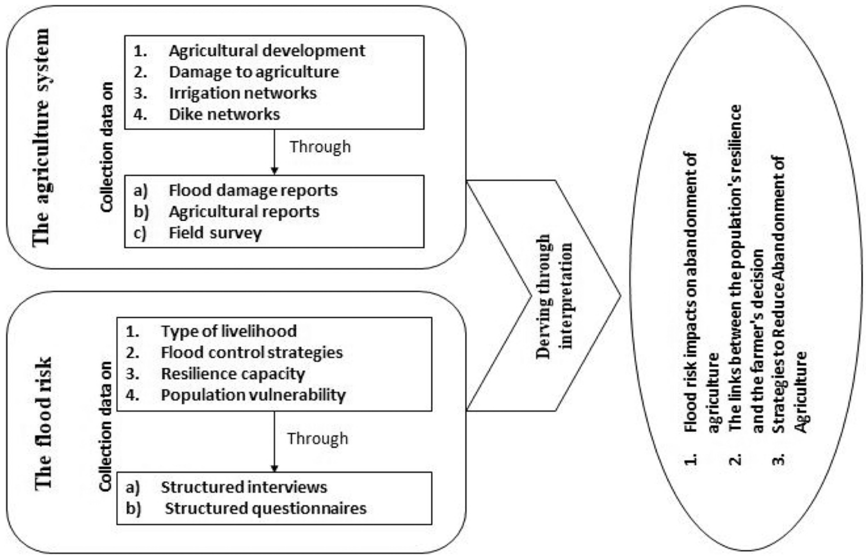

Fig. 3. Methods used for socio-economic survey.

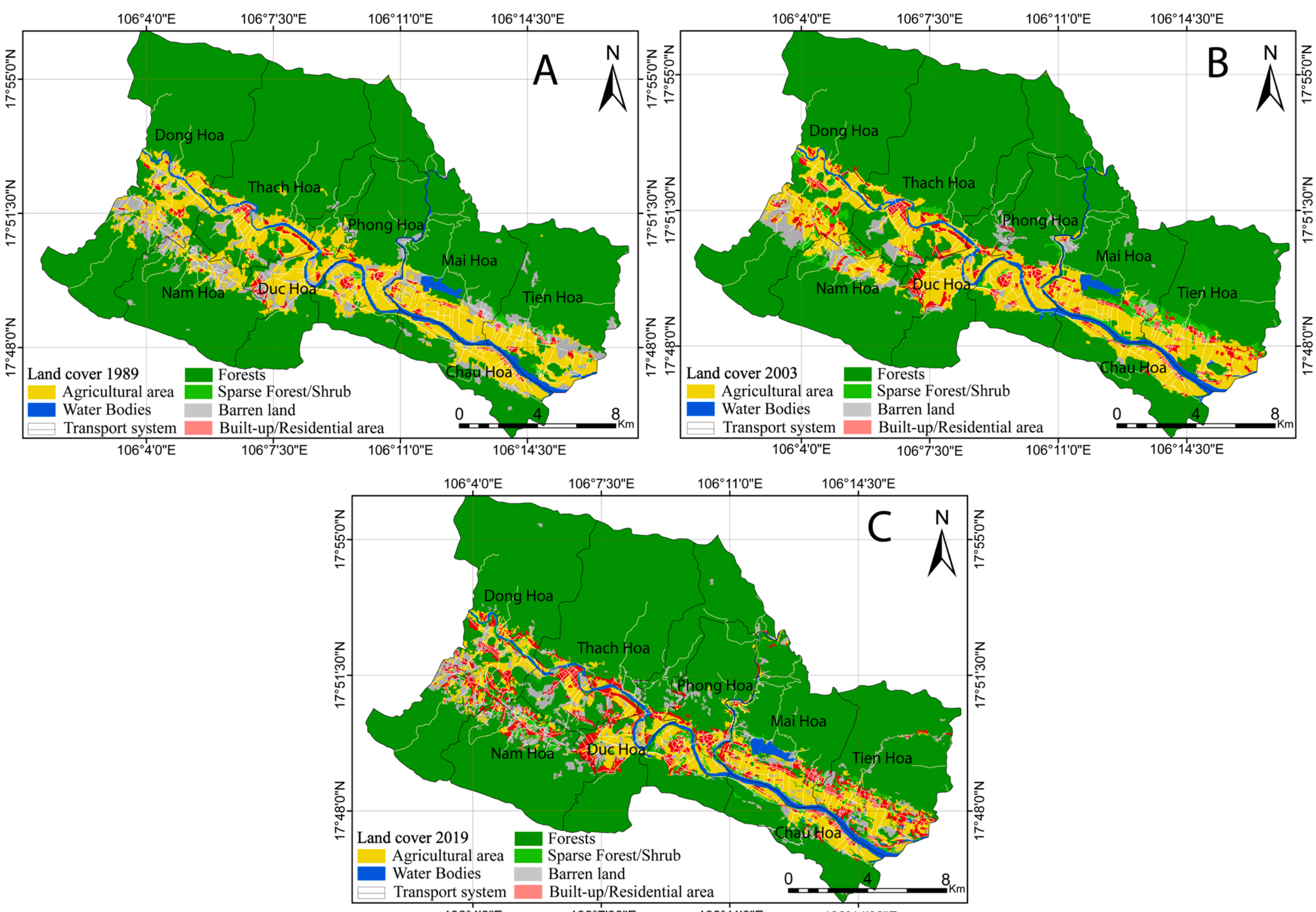

Fig. 4. Land cover in the study area in (A) 1989, (B) 2003, and (C) 2019.

approximately 8.9 m. Fig. 6 shows the water depth and flooding extent based on the hydrodynamic modeling results. According to the flood map, approximately 14.5% of the area was flooded, 1.72% was flooded by less than 1 m, 3.0% was flooded by 1–2 m, 3.1% was flooded by 2–3 m, 2.5% was flooded by 3–4 m, 1.8% was flooded by 4–5 m, 1.4% was flooded by 5–6 m, and 1.0% was flooded by more than 6 m of water.

The communes of Thach Hoa, Duc Hoa, and Phong Hoa were the most severely affected by upstream floods of the Gianh River. Based on the analysis of the flood and land cover maps (Tables 6), 66.4% of the agricultural area (6% of the study area) was located in the flood zone in 2019 compared to 61.4% in 2003 (8.7% of the study area) and 61.2% in 1989 (9% of the study area).

Table 3
Total area (ha) of different land cover types from 1989 to 2019.

	1989	2003	2019
Forest	21,614.8	21,521.1	21,478.9
Barren land	1666.7	773.7	1658.1
Agriculture	4176.1	4105	2622.4
Shrub/Sparse forest	105.9	597.3	611.2
Residential area	434.7	989.2	1609.5
Water	673.3	685.2	691.4

Table 4
Area (ha) of abandoned agricultural land in in each municipality from 1989 to 2019.

	1989–2003	2003–2019
Dong Hoa	190.3	343.7
Thach Hoa	164.8	207.1
Duc Hoa	166.7	159.7
Phong Hoa	113.2	180.3
Mai Hoa	129.5	131.9
Tien Hoa	80.8	210.9
Chau Hoa	94.8	111.1
Total	**940.1**	**1344.7**

Flooding negatively impacts agricultural areas in the short term by modifying the land's topography, damaging infrastructure, and destroying crops. According to the Department of Natural Resources and Environment in the province of Quang Binh, typhoon and flood intensity and frequency have both increased since 2005, causing high rates of agricultural land abandonment in Quang Binh. Approximately 940 (54%), 1342 (53.2%), and 1412 ha (54.7%) of agricultural land within the flood zone were flooded by less than 3 m of water in 2019, 2003, and 1989, respectively. In contrast, approximately 800 (46%), 1180 (46.8%), and 1169 ha (45.3%) of agricultural land within the flood zone were flooded by more than 3 m of water in 2019, 2003, and 1989, respectively (Table 6). Our analysis showed that agriculture is one of the economic sectors that is most affected by flood events, especially due to crop loss and the drowning of livestock.

Approximately 340.3 (13%) and 716.5 ha (28%) of the agricultural land in the flood zone were abandoned from 1989 to 2003 and 2003–2019, respectively. Of the total abandoned agricultural land, approximately 210.7 (61%) and 129.5 ha (39%) were in areas flooded by 0–3 and more than 3 m of water, respectively, from 1989 to 2003. In comparison, 367.4 (52%) and 349.1 ha (48%) were in zones flooded by 0–3 m and more than 3 m of water, respectively, from 2003 to 2019. Table 7 shows the amount of agricultural land abandoned at different floodwater depths in each municipality.

3.3. Agricultural land abandonment and flood risk: Survey results

The ability to access resources plays an important role in improving the resilience of communities. At the scale of the study region, 25% of interviewed households (n = 97) were in poverty. The number of households whose main source of income was dependent on agriculture decreased from 92% (n = 353) in 2003–44% (n = 169) in 2020. Of those households that declared a change in source of income, the majority associated it with factors related to flooding or socioeconomic change. However, 77.5% of the households interviewed indicated that agriculture experiences much of the damage caused by floods.

In reaction to the different impacts of floods on agricultural production and life, households have self-organization strategies to improve resilience. Well-organized civil security minimizes flood risks. Almost 70% of respondents (n = 269) said that they received a flood warning one week in advance through the television, radio or other media. Nine percent said that they were not alerted about the occurrence of a flood. Some are still marked by these past events. Almost 35% of households (n = 133) did not feel safe at all despite the containments made since the floods happened, and 55.7% (n = 212) did not feel safe at all. Fifty-eight percent of the victims (n = 221) declared that they had a very difficult life during the 2–4 days of flooding. Fifteen percent of the respondents (n = 58) had to take refuge on a roof, and food stored in attics was lost. Furthermore, 19% of respondents (n = 74) were forced to leave their houses and take refuge in elevated mountain areas or at neighbor's house. We found that only 7% of the respondents (n = 27) experienced a lower impact during floods either due to their higher-altitude locations or because their houses were built using more durable construction materials. These figures indicate the strong effects of recent flooding, but also underline the low level of resilience of those living in the study area: they live in poverty and in low houses, without built floors, made of relatively fragile materials.

After the occurrence of a flood, 62% of interviewed households (n = 235) stated that they took a week to return to a normal situation; 24.4% of households (n = 93) took two weeks, while 13.6% of households (n = 52) responded that they needed more than a month to return to normal. Support from the government, NGOs, and volunteer groups is particularly important, directly affecting the resilience of these communities. This support includes: support for plant and animal varieties; financial aid; food, such as instant noodles and rice; and loan support.

Table 5
Error evaluation indices.

Index	Dong Tam Gauge	Mai Hoa Gauge
Nash	94% (Calibration) 96% (Verification)	87% (Calibration) 85% (Verification)
Peak error of flood event	1.3% (Calibration) 1.7% (Verification)	0.38% (Calibration) 0.50% (Verification)

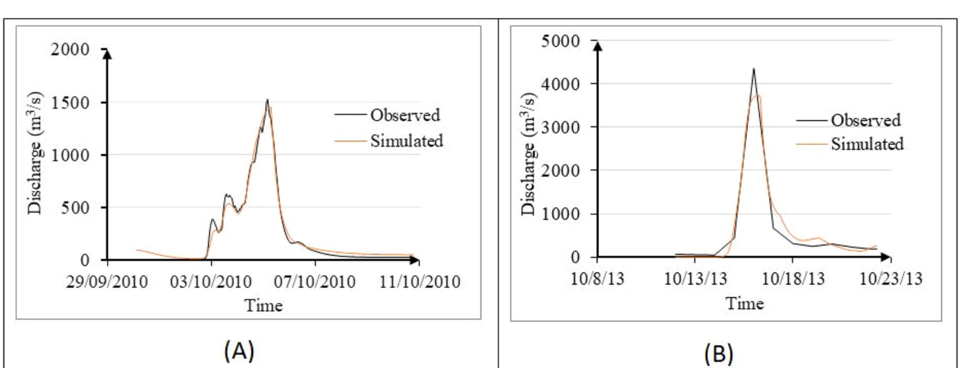

Fig. 5. (A) Calibration and (B) verification results of MIKE NAM at Dong Tam Gauge using data from flood events in October 2010 and 2013.

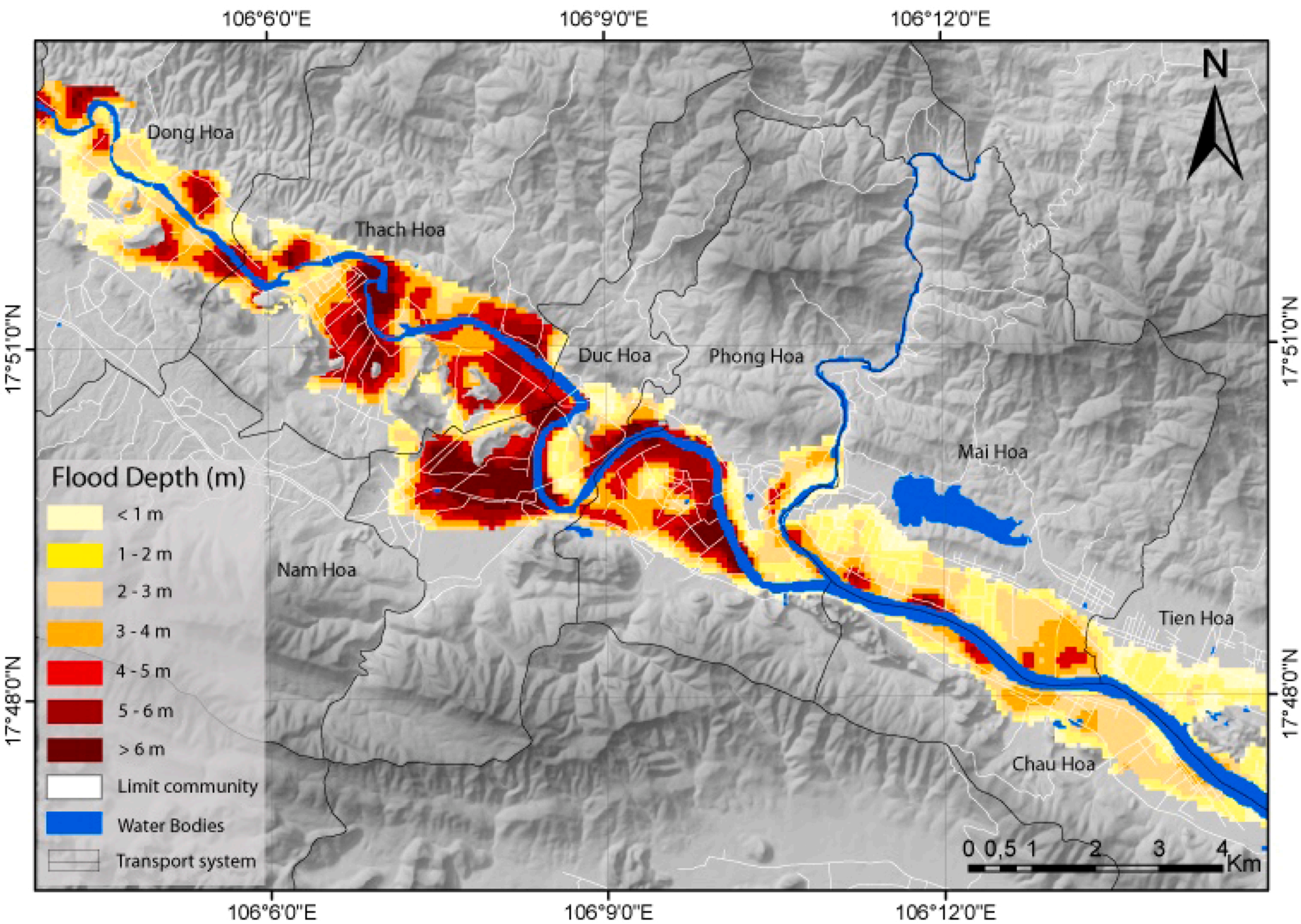

Fig. 6. Simulated floodwater depths for a flood in October 2013.

Table 6
Agricultural area flooded under different water depths.

Flood Depth (m)	Agricultural Land in 2019 Flood Zone		Agricultural Land in 2003 Flood Zone		Agricultural Land in 1989 Flood Zone	
	ha	%	ha	%	ha	%
< 1	171.9	9.9	274	10.9	287.1	11.1
1–2	369.3	21.2	517.4	20.5	541.4	21.0
2–3	399.2	22.9	550.8	21.8	584.1	22.6
3–4	270.6	15.5	407.4	16.2	419.1	16.2
4–5	205.8	11.8	305.8	12.1	316.7	12.3
5–6	176.7	10.2	264.6	10.5	258.7	10.0
> 6	147.6	8.5	202.4	8.0	175.0	6.8

Only 8.9% of the surveyed households (n = 34) felt very satisfied with the level of government support; 44.7% of households (n = 170) felt satisfied, 31.3% (n = 119) felt normal, 11% (n = 42) felt dissatisfied, and 4.1% (n = 15) felt very unsatisfied. For NGOs, 24.7% of households (n = 94) felt very satisfied, 48.4% (n = 184) felt satisfied, 20.2% (n = 77) felt normal and 6.5% (n = 25) felt dissatisfied and very dissatisfied. However the surveyed community members expressed concerns about the way aid is distributed and the ability of local governments to distribute aid; for example, food and clean water distribution was slow and uneven, and most of the surveyed household ditno't have an alternative plan. Sixty-two percent of surveyed households (n = 237) said that they do not have the financial resources to recover from flood damage without this external support.

Besides support from local governments, loans were also mentioned

Table 7
Agricultural land area abandoned at different floodwater depths in each municipality.

Floodwater depth (m)	Agricultural Land Abandoned from 1989 to 2003 (ha)							Agricultural Land Abandoned from 2003 to 2019 (ha)						
	Dong Hoa	Thach Hoa	Duc Hoa	Phong Hoa	Mai Hoa	Tien Hoa	Chau Hoa	Dong Hoa	Thach Hoa	Duc Hoa	Phong Hoa	Mai Hoa	Tien Hoa	Chau Hoa
< 1	13.6	7.1	5.6	7.0	10.9	8.7	4.2	19.7	7.3	2.8	16.2	8.4	38.8	7.7
1–2	22.8	17.3	3.4	8.6	16.7	5.8	12.5	23.5	13.6	11.7	18.0	12.5	34.9	12.5
2–3	18.7	19.3	8.3	7.8	16.2	1.3	9.5	31.0	24.6	11.8	17.7	17.7	12.6	23.4
3–4	11.8	12.8	5	7.2	12.9	1.2	7.0	25.5	25.3	12.1	27.1	20.2	10.5	8.3
4–5	6.3	19.7	11	5.3	4.5	0	0.9	10.0	34.0	22.9	14.1	7.9	0	2.1
5–6	3.3	18.5	7.3	2.8	1.7	0	< 0.1	6.1	30.2	18.2	22.8	0.9	0	0.4
> 6	0.4	3.8	3	1.3	1.2	0	0	0.7	17.5	24.5	6.9	0	0	0
Total	**77.2**	**98.9**	**43.9**	**40.3**	**64.2**	**17**	**34.2**	**116.7**	**153**	**104**	**123**	**67.8**	**97**	**54.6**

as a strategy to improve resilience. This strategy is mentioned by most households: 31.8% of households (n = 121) borrowed money from banks, 20.7% (n = 79) borrowed money from relatives, 8.1% (n = 31) borrowed money from friends and neighbors, 6.5% (n = 25) households borrowed money from local associations and 13.4% (n = 51) did not borrow money. Households also refer to mutual support among community members, including emotional support, help with cleaning, and provision of food and household appliances. The survey showed that 57.3% of households (n = 218) felt very satisfied and satisfied, 23.9% (n = 91) felt normal and 18.6% (n = 71) felt dissatisfied and very dissatisfied.

The perception capacity of communities plays an important role in improving resilience. Two hundred and ninety-seven households (78%) reported that the amount of forest was sharply reduced from 2003 to 2019. This is one of the causes of increased floods in the study area. From a planning perspective, when the respondents were asked what type of development should be performed on the Gianh River, more than 171 respondents (45%) wanted dikes, 127 (33.4%) wanted a dam, and 54 (14.2%) advocated for planting forests. The remainder of the respondents preferred the construction of an industrial center to create jobs outside the agricultural sector.

Among the 380 households that were affected by the floods, 79% (n = 301) changed agricultural activities; of these, 184 households abandoned their farmland, while 117 households converted their farmland to Pennisetum purpureum. Most respondents (n = 137) indicated that flood events alone were the main drivers of cropland abandonment; n = 99 respondents suggested that floods and socio-economic issue were the main drivers of cropland abandonment; and 65 respondents indicated socio-economic issues alone as the main drivers of cropland abandonment.

Based on statistical data from the Department of Agriculture and Rural Development, the number of households engaged in agriculture fell sharply between 2003 and 2018 (Fig. 7). This trend was most notable in the municipalities of Chau Hoa and Phong Hoa, where the number of farmers decreased by about 50% (i.e., from 2,000 and 2,500 farmers to 1,000 and 1,500 farmers, respectively) between 2003 and 2018.

Agricultural land abandonment significantly impacted food security and local livelihoods in areas already affected by poverty and food scarcity.

Fig. 8 shows the total agricultural production of the seven communes upstream of the Gianh River. Clearly, the total agricultural production decreased from 2003 to 2018, due to reduced cropland and persistent flood risks, resulting in diminished food production. Notably, 2008 was an exception because no significant floods occurred that year. Decreased agricultural production increased poverty in the study region, which further increased the population's vulnerability to flood risks.

4. Discussion

4.1. *Significance of the results*

Several challenges exist in policy development to steer agricultural abandonment. It is necessary and urgent to create a well structured, coherent management policy that can adapt to all cases. The theoretical framework for assessing the abandonment of agricultural land due to floods and the resilience of societies proposed in this study is considered important for sustainable rural development and relevant to all subsequent policy decisions. However, it is not covered well by the existing literature. This theoretical framework has allowed the examination of several aspects of the farmers' decisions to abandon their land, which is considered a prerequisite for understanding agricultural abandonment. This is the first effort to facilitate research on the future abandonment of agricultural land, and to propose policies for sustainable rural development. Our results indicate that there are relationships between flood risks, community resilience, and agricultural land abandonment; these relationship are the basis for understanding the mechanisms of agricultural land abandonment in Vietnam and worldwide.

4.2. *Inner validation of the results*

We examined the effects of flooding on the abandonment of agricultural land and indicated that farmers tended to abandon agricultural land the high-flood zones. This land has traditionally been zoned for residential or agricultural use. Traditional villages stretch along road levees, and interstitial lowlands are primarily used for cultivating rice. Rural populations living along the riverbanks in the study area know how to effectively utilize the banks every day, and recurrent floods are the main natural hazard significantly damaging people and agricultural activity. The statistical analysis indicates that more than 13% of the flood-zone agricultural land was abandoned from 1989 to 2003, and 28% from 2003 to 2019. In particular, 20% of the agricultural land abandoned in the Dong Hoa and Thach Hoa communes had been flooded with > 1 m of water from 1989 to 2003. This figure increased to 38% from 2003 to 2019 and is expected to continue increasing. In addition to abandoning rice cultivation, some households have shifted from

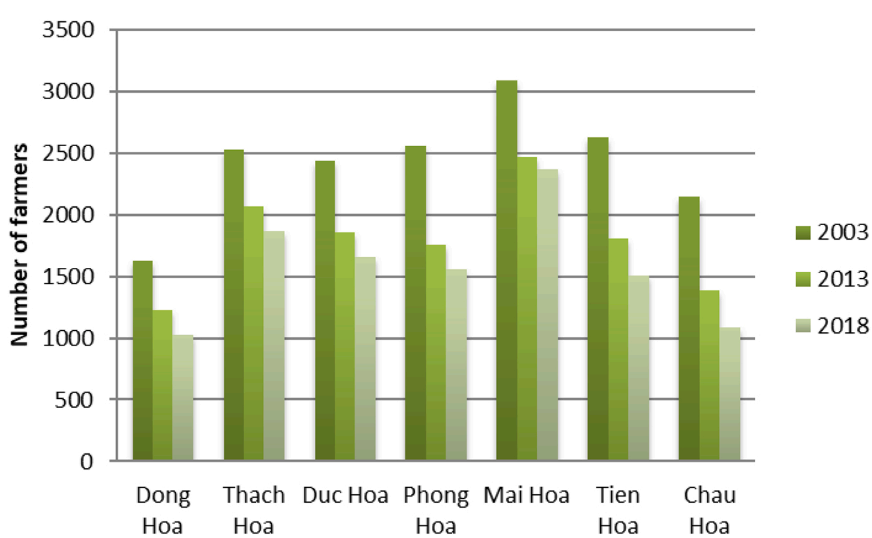

Fig. 7. Change in the number of farmers from 2003 to 2018.
(source: Department of Agriculture and Rural Development).

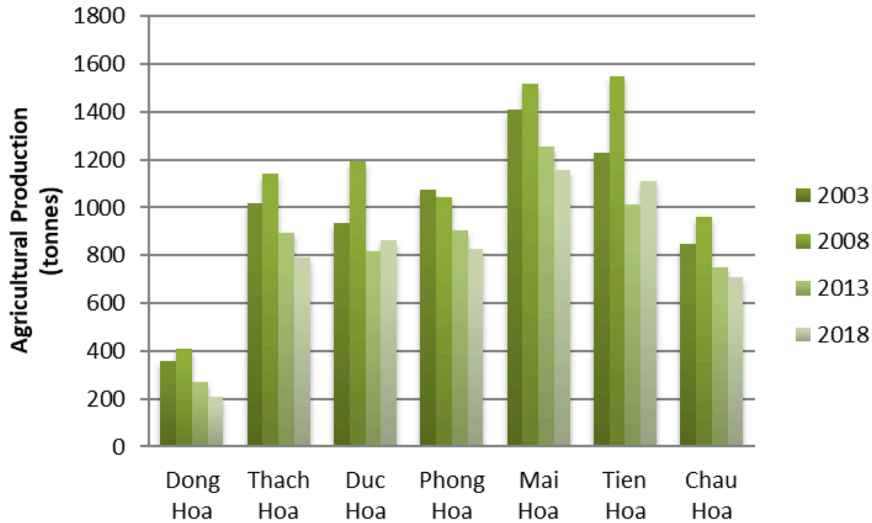

Fig. 8. Total agricultural production of seven communities in the study area. (source: Department of Agriculture and Rural Development).

growing rice to growing Pennisetum purpureum and looked for economic activities that are less dependent on natural resources, such as construction or trading. The abandoned land surfaces will regenerate into shrubs and secondary forests.

The results of this study highlighted that the resilience capacity of communities depends on three main factors: the capacity to access resources, self-organization strategies and the perception capacity. The results of the interviews indicated that the resilience of the population in the study area was relatively low; this is one of the main causes of agricultural land abandonment.

The capacity for resilience depends on the capacity of communities for accessing the resources. The low access to material resources in the study area has increased the effects of floods on residents. Since agriculture is the primary source of income for the population in the study area, the agricultural sector is also one of the economic sectors that is most harmed by flood events. Floods usually destroy agricultural amenities, thereby halting production and increasing poverty and suffering. Moreover, restoring agricultural production to preflood levels is a difficult task. This is why approximately 48% of households changed their main source of income from 2003 to 2019. However, socioeconomic status also plays a significant role, as confirmed by the analysis of the relationship between socioeconomic status and agricultural land abandonment. The communes exhibiting good or average socioeconomic status also exhibited a high rate of agricultural land abandonment. For example, the commune of Phong Hoa exhibited a poverty rate of 2.3%, while the rate of abandoned agricultural land reached 29.5%. Among the poorer communes, Thach Hoa and Dong Hoa exhibited poverty rates of 41.6% and 34%, respectively, and their corresponding rates of agricultural land abandonment were 36.1% and 38.4%, respectively.

Second, systemic resilience is directly proportional to the self-organization of the system. In the study area, most of the population had feelings of insecurity when recounting vivid memories of each flood disaster. Low-quality houses lacked suitable flooring and were built using relatively fragile materials in dangerous areas, i.e., near rivers. Moreover, the results highlighted the difficulties people encountered during flood events. In this respect, residents believe that local government involvement and access to loans will improve resilience. However, such crises usually expose shortcomings in civil protection and the associated logistical problems including weak and unreliable communication systems, immobility, a lack of resilient roads for easy and rapid escape, and insufficient or no means of intervention. Moreover, after flood events, the supply of essential resources, such as food and water, is usually delayed and unevenly distributed among victims, not only in Vietnam, but also in other flood-prone economically developing countries (Zaninetti et al., 2015). Community organization and mutual aid are needed to improve resilience. In this study, mutual support manifested itself in both material and spiritual aspects. However, mutual aid among community members is declining. All these factors weaken community resilience when combined.

4.3. External validation of the results

The analysis of the correlation between flooding and the abandonment of agricultural land in this study is consistent with previous research. Gautam and Andersen (2016) showed that environmental factors negatively impacted agricultural productivity, forcing farmers to leave agricultural land in rural Nepal. Thogmartin, Gallagher et al. (2009) also identified increasing farmland abandonment in the Missouri River floodplain in the United States due to repeated flooding. Moreover, Le Dang et al. (2014) found that recent climate change impacts negatively affected the livelihoods of Vietnamese living in the Mekong Delta, where approximately 10% of the households have abandoned farming as their main source of income due to floods. Different studies have also shown that floods more negatively impacted low-income populations because of their dependence on natural resources and the lack of alternative economic opportunities in their communities (Warner et al., 2010; Haemmerli et al., 2017). Consequently, people living in poverty often look for other jobs that depend less on natural resources and emigrate seasonally (i.e., six months or more per year) to work in growing urban and industrial centers that provide economic opportunities with more-stable incomes. This trend has been found in many rural areas worldwide. Haemmerli et al. (2017) found that although flooding indirectly influenced the migration of farmers to Central Vietnam, socioeconomic status was the dominant factor influencing emigration. Additionally, Nguyen et al. (2018) concluded that floods were not the only cause of changing landuse along the coast of the province of Quang Binh in Vietnam: increased urbanization and industrial growth were also major drivers. Moreover, Khanal and Watanabe (2006) identified socioeconomic conditions and flood impacts as major factors driving agricultural land abandonment in the Nepalese mountains. Therefore, our study is not an exceptional case; 43% of households stated that they decided to abandon farming due to both: flooding and socioeconomic conditions. Previous studies have highlighted that agricultural abandonment leads to the ability to recover vegetative cover and soil organic matter. The lack of irrigation also generates soils that contain a lower amount of water. Therefore, after agricultural abandonment, the surface runoff can decrease significantly due to improvements in the water infiltration capacity of the soil. This can lead to a reduction in the magnitude of floods (Nunes et al., 2010; Cerdà et al., 2019).

Land abandonment is often seen as part of modernization and development (Boersma, 2021), and for improving the livelihoods of remote rural populations, such as those surrounding the Giang River. From an ecomodernist perspective, sustainability can be achieved through a process involving three steps. The first step consists of clustering agricultural activities on a region's prime agricultural land, which is not affected by natural hazards. This contributes to improved productivity, which in a second stage allows populations to enhance their competitiveness in the market; as a result, people stop subsistence farming, which can become a poverty trap. The consequence of this change is represented, in a third stage, by rural-urban migrations and forest transitions, allowing for an increase in natural areas and a consequent decrease of natural hazards.

4.4. Importance of the results

The theoretical framework represents a tool that is able to study the problem of agricultural land abandonment by focusing on hazards and community resilience. Focusing on improving the response strategies implemented after a flooding event, including support from family and neighbors and government and NGO assistance, can improve the resilience of communities and reduce agricultural abandonment. This framework can support the governments of Vietnam and other tropical-monsoon countries, and contribute to improving land use planning and sustainable rural development. Recent case studies have highlighted the severity of agricultural land abandonment by families that are highly vulnerable and less resilient to flood risks. However, interventions implemented by local authorities are ineffective and cannot prevent agricultural land abandonment. Increasing urbanization combined with industrial growth further drive the decision to abandon farming. The importance of this research lies in the creation of a framework for studying agricultural land abandonment in mountainous regions frequently damaged by flooding. This study provides a basis for analyzing the policies necessary to reduce landscape abandonment, specificallyagricultural land abandonment. The theoretical framework proposed in this study provides an initial point of reference for discussing agricultural land abandonment and its causes. We believe that this framework can be developed further and applied to different socioeconomic systems at different scales. The case-study results elucidate the critical aspects of this theoretical framework and emphasize the potential of spatial planning to limit and mitigate flood damage.

4.5. Lessons for planning and governance from the case studies

Faced with inherent flood risks (Fig. 9), residents can retreat, resist, or adapt. Residents only retreat when the risk reaches an unacceptably high level. As discussed in previous studies, personal planned retreats are rare, expensive, and contentious. Resistance strategies and defensive arrangements such as embankments allow, in most situations, the use of exposed territory (Zaninetti et al., 2015). Adapting land use to flood hazards is a third option. In the study area, although local authorities

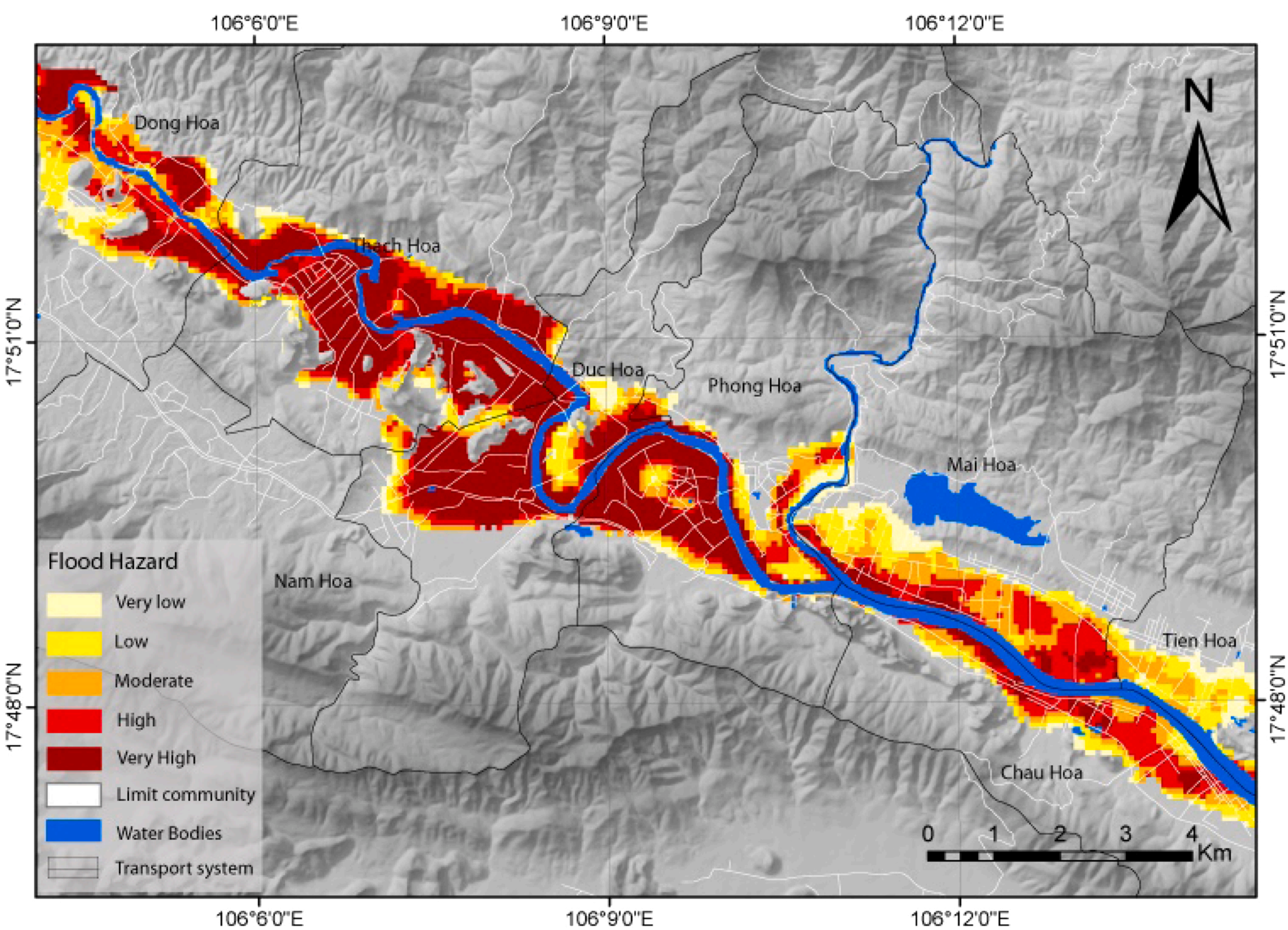

Fig. 9. Flood hazard map of the study area.

have developed a communal flood-crisis-management unit, the unit focuses on emergency response and not on decreasing flood risks. The authorities have also developed educational and outreach programs concerning the risks of settling in flood-hazard areas. However, such efforts do not influence land use in the absence of strong planning regulations.

Fig. 9 shows a flood hazard map of the study area. This map can be used in writing risk prevention policies to help decision-makers carry out land use and agriculture planning and reduce vulnerability. Based on this flood hazard map, we can propose several ideas for development and limiting the flood risk. Potential adaptive actions include prohibiting new construction in the high hazard areas and moving residents or creating incentives to stimulate development in low- and medium-hazard areas. Shifting the crops being raised to more flood-tolerant crops (for example Pennisetum purpureum) can also help with adaptation in flood-prone areas.

Actions that can be taken to minimize hazards have become increasingly visible, concrete, and scientifically substantiated. Ideally, participatory planning should be used in conjunction with a data-driven approach. Experience-driven feedback has improved our understanding of the areas that were flooded during different flood events. Different methods could influence development projects upstream and along the river, especially those aimed at water conservation, which could improve the resilience of populations to flooding hazards. For example, the Minh Cam Reservoir in the study area was built to store 5.2 million m^3 of water; it is an important structure designed to significantly reduce the volume of floodwater flowing into inhabited areas. However, although the flood alert system effectively identifies the flood-hazard intensity, its capacity to transmit information and increase community resilience to flood risks must be improved. This may be an effective solution to the problem of farmland abandonment.

4.6. Limitations

An important limitation of this study was the use of data with a resolution of 30 m; this resulted in classification errors (Jansen, 2006). In 1989 and 2003, the interpretation accuracies of remote sensing data were 78% and 82%, respectively, when compared with aerial photographs taken in 1990 and 2005 by the Department of Natural Resources and Environment. Nonetheless, our results still show that these methods reliably extracted information about agricultural land abandonment in the study area.

In addition, because constructing a theoretical framework for social resilience predominantly depends on politics and economics, further research on socioeconomic issues is required to ensure a sustainable rural development policy. Given that obtaining socioeconomic data for Vietnam is difficult, the causes of agricultural land abandonment cannot be accurately determined. Therefore, the availability of such data could support future research on the role of socioeconomic factors in farmers' decisions to abandon their agricultural land.

5. Conclusions

This study analyzed the background of and links between flooding, community resilience, and agricultural land abandonment in the Gianh River Valley in the mountains of Vietnam. We carried out an analysis of changes in land use between 1989 and 2019 and created a flood risk map. First, the results show that a relationship exists between agricultural land abandonment and flood risk: the agricultural abandonment rate is higher in communes more affected by floods such as Dong Hoa, Thach Hoa, Duc Hoa and Thanh Hoa, than in communes less affected by floods such as Mai Hoa, Tien Hoa, and Chau Hoa.

Second, the resilience of communities has a strong impact on the agricultural abandonment rate. The resilience of communities in the study area was relatively low; this is one of the main causes of agricultural land abandonment. The analysis of the features of communes within the study area showed that a lack of economic resources limits the resilience capacity. Moreover, it stressed the importance of the capacity for self-organization, including support from government organizations and NGOs and mutual assistance during floods. Feelings of insecurity about this support also highlight the low resilience of these communities. In addition, flood risks and agricultural land abandonment have severe implications for local food security, which has worsened in response to ongoing climate change, increasing societal vulnerability, and decreasing community resilience.

Under the socio-economic development scenario, population growth will continue, while agricultural abandonment is predicted to become more frequent, this has significant effects on food security. However, several challenges remain in developing and implementing sound agricultural land abandonment management policies. The theoretical framework developed in this study can become an important tool for planning of agricultural activities; as it can assess the improvement of resilience of communities through access to diverse resources and the improvement of self-organization strategies. In this context, the Vietnamese government could improve the resilience of communities, especially small-scale farmers, to reduce agricultural abandonment. Finally, this study examined the impacts of human environmental factors, such as the relationship between a population's vulnerability/resilience and agricultural land abandonment trends. The spatiotemporal changes in agricultural land abandonment were also influenced by local authorities' intervention policies, however, which aim to improve community resilience to flood risks. Therefore, future studies should further analyze the influence of this factor to assess various agricultural land abandonment complexities.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ancene.2022.100341.

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