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Bottom-up approach for flood risk management in developing countries: a case study in the Gianh River watershed of Vietnam

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Abstract

Flood effects are very serious, especially in developing countries where they are at high risk due to urbanization and socio-economic development. Reliable information is crucial to support decision-makers or planners to develop appropriate strategies to reduce flood risk. This article aims to develop a theoretical framework for assessing flood risk and adaptive capacity based on a bottom-up approach, in the Gianh River watershed of Vietnam, considered a very important task for flood risk management. Flood risk was computed by combining hazard, exposure, and vulnerability using hydrodynamic modeling and the Analytic Hierarchy Process method. The adaptive capacity of the population was assessed via interviews with 298 inhabitants. The results show that flood risk is high in areas with high population and construction density. Both the ability to access resources and communities' perceptions are important factors in improving the capacity to adapt. This study can provide an important theoretical framework complementing the existing literature and supporting studies related to flood risk management in the context of climate change and urbanization in other regions. Besides, the study fills in a gap in the knowledge of negative flood effects, providing important inputs for decision-makers to develop appropriate strategies for reducing damage in Vietnam and other countries in the world. From a methodological start point, this study underlines the importance of using hydraulic models and socio-economic surveys in flood risk management.

1. Introduction

Floods are one of the most popular natural hazards worldwide, producing damage cost almost equivalent to those of earthquakes (Kovacs et al., 2017). From 1900 to 2016, there were 4,630 floods, about 40 events each year, and average annual losses were estimated to be around US$104 billion (Crichton, 2006). It is estimated that floods now directly highly affect about 1.47 billion people all over the world (around 19 percent of the world). Most of them live in South and East Asia, China and India, while 89% live in low and middle-income countries. Among them, poor people always suffer the most (Rentschler and Salhab, 2020).

A lack of awareness, resources and resilience limits, the ability of developing countries to prepare for and recover from floods (Osti et al., 2008), at a time when climate change is seeing the number of flood events increasing exclude flood-prone land from human use often fail as the need for agricultural development trumps issues of safety (Juarez Lucas and Kibler, 2016). According to (Juarez Lucas and Kibler, 2016), flood-prone areas developing countries must properly assess flood risk and move toward more sustainable livelihoods to ensure environmentally sound development and planning.

The traditional perspective of flood risk management was that floods are a natural occurrence and therefore the focus was on reducing hazard and its consequences through structural interventions, such as the construction of dams and levees (Egbinola et al., 2017). In developing countries this has been considered the responsibility of government (Egbinola et al., 2017). Such a top-down approach often means insufficient involvement of stakeholders, particularly experts, scientists, and affected populations in the planning and implementation of potential risk reduction and adaptation options (Luu et al., 2018).

Integrated flood risk management has been enthusiastically proposed (Grabs et al., 2007; Juarez Lucas and Kibler, 2016), as the correct global response (Kovacs et al., 2017). (Hegger et al., 2016) concluded that the diversification of flood risk management strategies was the most effective way to improve flood resilience. In addition to traditional engineered measures, potential non-structural solutions have been proposed (Abbas et al., 2015; Kundzewicz, 2002; Nguyen et al., 2021a; Thanvisitthpon et al., 2020), where harmony is sought between environmental, social, and economic factors (Nguyen et al., 2021a). This represents a process of continuous adaptation that is also guided by local characteristics. So far, this approach has been applied mostly in developed countries (Kovacs et al., 2017).

Approaches to flood risk are limited by the subjectivity of consultants and other experts when weighting the indicators. In addition, there is always a significant distance between scientific recommendations of researchers and the extent to which they are implemented into practice by communities. The complexity of research is not well understood by users, limiting the applicability of important recommendations. Therefore, the use of bottom-up approaches (i.e. applying strategies and policies coming from local participants, such as local authorities and households) is considered the most appropriate. In developing countries, those living in poverty often settle along rivers, in areas with no adaptive capacity. According to Gusain et al. (2020), decision-making at a village-level administrative scale is considered best to resolve flood risk issues at local level (Gusain et al., 2020). (Nguyen et al., 2021b) underline that flood risk management is most effective when there is stakeholder participation, including governments, scientists, experts, and populations, in the planning and implementation of potential risk reduction and adaptation options.

This study aims to develop a theoretical framework for assessing flood risk based on the contributions of scientists, experts, and population, to support local land-use planning decision-makers. By highlighting essential criteria, risk memory, resources, and population needs, we identify the initial steps required in facilitating and optimizing future flood risk management strategies. The results can help minimizing negative effects of floods on the environment and people and contribute to land-use planning in countries often affected by floods.

2. Background And Context

2.1. Concept of flood risk

Flood risk is defined as damage to property and humans as a consequence of floods. It can be predicted by affected people (Birkmann and Welle, 2015). It is a combination of natural and human factors. The level of flood risk is computed using three essential indices: hazard, exposure, and vulnerability (Hill et al., 2020; Koks et al., 2015). Hazard is a natural and uncontrollable phenomenon; the term includes the extent of incident and probability of an incident both occurring and causing damage (Kron, 2002; Kron, 2005;

Lacina, 2012). Vulnerability is the classification of potential of individuals or groups to resist the destructive force of floods (Erman et al., 2019; Pagliacci and Russo, 2019). Exposure is defined as the presence of value, livelihoods, and people in the area of flood occurrence (Simonović, 2012; Weis et al., 2016).

Risk = f(Hazard, Exposure, Vulnerability)

Adaptive capacity refers to the ability of individuals and groups to prepare for and fight against natural hazard (LÓPEZ-MARRERO, 2010). This capacity depends on the characteristics and available resources of individuals, groups, and organizations. Understanding the level of socio-economic and political marginalization is therefore crucial when measuring adaptive capacity. Given the same hazard, a poor, unstable community would generally be at greater flood risk than more affluent neighbors. Flood risk reduction by "keeping people away" is not considered a necessary or desirable strategy in all developing countries (Juarez Lucas and Kibler, 2016).

2.2. Flood risk management in developing countries

Although floods pose a considerable threat to all countries, the impact of natural hazard in terms of GDP loss and death is greater in low-income than in high-income countries (Herold and Sawada, 2012). Over the period 1991–2005, 98% of people affected by natural disasters globally lived in developing countries and nearly nine in ten deaths attributable to these disasters have occurred in these countries (Bétard and Fort, 2014), among which floods have been the most damaging. What is the explanation for this?

Floods tend to be more destructive in developing countries where political, social, and economic instability results in poorly organized infrastructure and poor adaptive capacity (Herold and Sawada, 2012). In addition, rapid development often leads to unplanned sprawl over plains and coastal areas. Sprawl, combined with insufficiently prepared authorities and people, increases the risk (Nguyen et al., 2018; Nguyen et al., 2021a; Petrişor et al., 2020). Rich, developed countries such as the United States rank ahead of poor countries in terms of flood exposure, due to a higher value of insured goods; however, when goods are measured as a share of GDP, developing countries are more exposed (Bétard and Fort, 2014). For example, Hurricane Sandy, that hit the northeast coast of the United States in 2012, cost an estimated US$50 billion, making it the second most expensive natural disaster in history after Hurricane Katrina, but damage represented just 0.3% of US GDP. Typhoon Mirinae, when it struck Vietnam, caused damage of approximately US$289 billion, equivalent to 140% of Vietnam's GDP.

Faced with floods, societal responses vary greatly in terms of prevention and protection measures according to political choices of authorities and local communities. Unlike developed countries, developing countries have little infrastructure in terms of risk management and lack adequate policies or procedures regarding forecasting and protecting against risks (Keoduangsine et al., 2014). Therefore, flood risk management in these countries is reactive, focusing on three main activities: prevention, response, and remediation of consequences. This is often conducted on a national, top-down basis, which focuses primarily on structural measures aimed at controlling dangerous natural phenomena and limiting their impact (Luu et al., 2018; Salazar-Briones et al., 2020). An example of this technical management is the construction of dikes and gabions to protect against floods. In all cases, such structural measures prioritize the notion of resistance, i.e., the ability to face an unwanted event. This resistance is often limited to mitigation in developing countries. This is a bottom-up risk governance model, focused on the socio-economic root causes of daily vulnerability. It advocates participatory risk management, making it possible to promote the vernacular knowledge of populations (Ge et al., 2021; Knighton et al., 2018). Such management favors preventive measures and supports initiatives involving residents and local stakeholders in managing the alert phase (Luu et al., 2018). For example, in countries like Vietnam, Indonesia, India, and Nepal, flood risk prevention plans are not yet available; these systems are very popular in developed countries, such as France, the United Kingdom, and Germany.

To reduce the damage to humans and property due to floods, greater involvement is necessary from governmental, non-governmental, and community organizations. Developing countries do not always have the time, money, or human resources to establish adequate flood risk management tools. Adaptive capacity is seen as a tool complementing others. (Ashley et al., 2011) have used adaptive capacity in flood risk management. These strategies include improving awareness of flood risk, and avoidance (converting property to flood susceptibility zone or prohibiting new constructions in the flood zone). In the Netherlands, the government has determined four strategies of flood risk management, namely resilience capacity, coping capacity, resistance capacity and adaptive capacity. These highlighted the important role of adaptive capacity in flood risk management (de Graaf et al., 2009). (Disse et al., 2020) emphasized that adaptive capacity is equal to flood risk management in its potential to reduce damage to human life and property.

2.3. Flood risk management in Vietnam and Quang Binh province

The topographical characteristics of Vietnam in general, and Quang Binh province in particular, make the area particularly vulnerable to floods that cause enormous loss of human life as well as economic and environment harm (Luu et al., 2018). As a result of floods, in the period 1989–2014, 14,867 people died or went missing and there was an economic loss equivalent to 1% of the nation's gross domestic product (Luu et al., 2020). The country’s high flood risk is linked to its tropical monsoon climate and dense river systems (Chau et al., 2014). Alongside natural factors, human interventions such as deforestation and increasing urbanization are factors critically contributing to the high flood risk in Vietnam (Nguyen et al., 2021a; Petrişor et al., 2020).

Since the introduction of the Doi Moi economic reforms in mid-1980s, Vietnam has experienced significant economic growth and urbanization. This growth has continued and is currently particularly apparent in the Central region, especially Quang Binh province. Land in this area is abundant; river and maritime systems are instrumental in the province’s economic development. This process has induced certain conflicts and has forced compromises in the face of increasing demographic and economic pressure and environmental degradation (Nguyen et al., 2018; Nguyen et al., 2021a; Petrişor et al., 2020).

This degradation is one of the prime causes of floods and disproportionately impacts the poorest communities, more than in many other developing countries due to the "dangerous" locations of many Vietnamese settlements (Zaninetti et al., 2015).

The legislation related to flood risk management is very diverse with hundreds of legal documents, laws, and rules. The management of natural risks, and flood risk in particular, was included in the Constitution (22) of 1992, the Law on Water Resources (which the National Assembly passed on May 20, 1998), the law on water resources in 2012, the law on dikes in 2006, Ordinance on Flood and Storm Prevention and Control (2000), and the law on the fight against natural disaster risks (33/2013/QH13, issued on 19 June 2013 by the President of the Congress). These laws have created a legal foundation around disaster risk management (DRM), including flood risk management (FRM) in Vietnam. The other important legal document is the National Strategy for Natural Disaster Prevention, Response and Mitigation of 2020 which was approved in the Prime Minister's decision No. 172/2007/QĐ-TTg dated 16/11/2007, a milestone for Vietnam's approach to both disasters and sustainable development. This strategy marked a new level of attention being paid to integrating natural disaster management with the socio-economic development of communities, in order to reduce damage.

At the national level, DRM is under the responsibility of the Central Steering Committee for Natural Disaster Prevention and Control (as regulated by Prime Minister's Decision No. 367/QD-TTg, dated 17/3/2015) and has the role of inter-sectoral coordination, disaster prevention, response, and recovery covering the whole of Vietnam. The Ministry of Agriculture and Rural Development (MARD) chairs the committee and the Vietnam Disaster Management Authority (VDMA, under MARD) is the standing office of the central committee responsible for the management and reduction of natural disaster risks, coordination of responses, and recovery from natural disasters. This national organization has corresponding operations at the levels of province/municipality, district, and commune (as illustrated in Fig. 1). With this approach, flood management is now recognized as the basis of national and regional flood prevention, control, and mitigation strategies. Figure 1 shows the participation of the entire political system in the flood risk management steering process. The hierarchical structure of the administrative system highlights the role and responsibilities of different government organizations. Due to the top-down approach, specific guidance on flood risk management comes from higher hierarchical levels (Bollin et al., 2006). The decision-makers in the steering committees are government officials. However, there is a considerable gap between policies and follow-up actions due to the lack of cooperation on flood management between these organizations, regional authorities, and local populations (Nguyen et al., 2021b). Due to legal and institutional obstacles, scientific research and data sharing regarding flood management in these government organizations is very limited (Huan et al., 1996). Although the definition of the respective roles of many organizations can contribute to a better understanding of the processes and problems of floods, coordination and communication are unfortunately often insufficient and the overlap of responsibilities is still too often an issue.

Flood risk management is still not central to flood control considerations. The defense system has not been sufficient in recent floods (Bangalore et al., 2017). To reduce damage, previous research emphasizes that participation of public administrative system in flood risk management is in itself insufficient, while decisions must be based on the integration of scientific knowledge with the participation of local population in order to analyze what they consider unsafe conditions, their vulnerabilities, and their capabilities (Huu, 2011; Nguyen et al., 2021b).

3. Study Area And Methods

3.1. Study area

The Gianh River basin is located in Quang Binh province, in the Central region of Vietnam, and has an area of 4 462 km2 (Fig. 2). The 158km-long Gianh River is the main trunk, originating in Cobi Mountain, in the Truong Son range, at 2 000 m above sea level and flowing southeast into the East Sea. The annual average precipitation in the river basin ranges from 2 000 mm to 2 500 mm. Rainfall is mainly concentrated in September and October, which is also the yearly peak of floods, accounting for 50% of the total annual rainfall. There are locations where precipitation intensity in 24-hour intervals reaches 600–700 mm. Due to the steep terrain and heavy rainfall intensity, the time of watershed concentration is short. The flood intensity at Dong Tam gauge is high, around 120–260 cm/h, causing huge human loss downstream of the river basin.

This province is affected by floods and typhoons every year, causing significant damage to human life, property and lives. Notable major floods took place in Quang Binh Province in 2010 and 2020. According to statistics from the National Committee for Incident and Disaster Response and Search and Rescue, the historic October 2010 flood in Quang Binh Province led to 74 deaths and affected 188 628 houses. It also caused significant damage to agriculture and transport infrastructure. Ten years later, the October 2020 flood caused around $3.5 trillion damage, 106 000 homes were flooded and 25 people die.

3.2. Methodologies

3.2.1. Flood hazard modeling

In this study, the hydraulic coupled 1–2D Mike FLOOD model software was used to simulate flows in both the river channels (1D Mike 11) and over the ground surface (2D Mike 21). The upstream boundary and lateral inflow for the 1D hydraulic module are simulated using the MIKE NAM module. The local rainfall on the flood plain is taken into account in the 2D module.

The hourly rainfall time series for four hydrological gauges and two meteorological gauges in the Gianh River basin were collected and used as input data for the hydrological model MIKE NAM for streamflow simulation. The study area was divided into seven subbasins and flow hydrographs for these subbasins have been produced by the MIKE NAM model with a calibrated parameter set. The observed data used in this study were provided by the National Centre for Hydrometeorological Forecasting (NCHMF) for the period 2010–2020.

The river network map, the topographic map, and the land-use map, each at a scale of 1:10 000 and published in 2010 by the Ministry of Water Resource and Environment, were used to generate a 1D hydraulic network and the computational mesh structure for a 2D model. Other crucial data used in the determination of 1D hydraulic model MIKE 11 included a network of 53 cross-sections in the mainstream of Gianh and Son rivers, of which 42 cross-sections were located along the Gianh River (from Dong Tam to the mouth of the Gianh River), with a length of 56.5 km, and 11 cross-sections along the Son river (from Vooc gauge to the conjunction with the Gianh River), with a total length of 21.5 km. The data from Dong Tam discharge gauge and Tam My water level gauge has been used as upper boundary and lower boundary for the 1D hydraulic model of Gianh River respectively. The inflow boundaries and discharge upper boundary of Son River were provided by using MIKE NAM module.

The flood plain region downstream was then modeled in MIKE 21 and linked with MIKE 11 through MIKE FLOOD. The 2D computational domain modeled here is bounded by Mai Hoa gauge and the mouth of Gianh River, an area of 181 km2, as depicted in Fig. 2. A flexible mesh is generated by discretizing the computational domain into 60 362 elements with 30 644 mesh nodes. The size of cell is in the range 70–100 m.

3.2.2. Flood exposure identification

Population density is an essential indicator when computing flood exposure. The population density by commune used in this study was collected from five districts' statistics (Bo Trach, Quang Trach, Ba Don, Tuyen Hoa, Minh Hoa). Land use data from 2020 in the study area were obtained from the Department of Natural Resources and Environment of Quang Binh Province.

3.2.3. Indicators of flood vulnerability

Flood vulnerability indices were constructed from data on poverty and populations with physical disability, young children, older people, and farmers. Poverty data on municipalities was collected by statistics offices of five districts (Bo Trach, Quang Trach, Ba Don, Tuyen Hoa, and Minh Hoa). The data on poverty, population with physical disability, young children and older people in the communes were obtained from the Department of Labor, War Invalids and Social Affairs of five districts (Bo Trach, Quang Trach, Ba Don, Tuyen Hoa, and Minh Hoa). The numbers of farmers per commune were collected from agriculture and rural development departments of the same five districts (Bo Trach, Quang Trach, Ba Don, Tuyen Hoa, and Minh Hoa).

3.2.4. Flood risk modeling and mapping using Analytical Hierarchical Process (AHP)

The flood risk was computed using measures of hazard, exposure, and vulnerability. Sub-components separated each index and AHP was used to assess the weights of each index and each sub-component. This is one of the multi-objective decision-making methods proposed by Thomas L. Saaty. It works on the principle of pairwise comparison and quantifies multi-criteria rating preferences by expert opinion to make the best possible decisions. Some of the advantages of AHP include direct expert consultation, a system of criteria and sub-criteria, and consistency of judgment. The weight of the constituent criteria will be computed in 3 steps:

Step 1: Determine the priority of the criteria. The pairwise priorities of the criteria have positive integer values from 1 to 9 or the reciprocal of these numbers (Table 1, 2).

Table 1
Comparison matrix for flood hazard, exposure and vulnerability

Hazard	**Flood depth**	**Velocity**
Flood depth	1	3
Velocity	1/3	1
Colum total	1.33	4
Exposure	Population density	Land use
Population density	1	3
Land use	1/3	1
Colum total	1.33	4

Table 2
Comparison matrix for vulnerability

Vulnerability	**Population of young children and older people**	**Population of people with a physical disability**	**Poverty level**	**Number of agricultural worker**
Population of young children and older people	1	2	3	5
Population for people with physical disability	1/2	1	2	4
Poverty level	1/3	1/2	1	2
Number of agricultural worker	1/5	1/4	1/2	1
Column total	2.033	3.75	6.5	12

Step 2: Compute the weights of the criteria. After filling in the comparison matrix between pairs of criteria, the evaluator will compute the weights for the criteria by adding the values of the matrix by column, then taking each value of the battle matrix divided by the sum of the corresponding column. The resulting value replaces the computed value (Table 3, 4).

Table 3
Normalized matrix of flood hazard, exposure, and vulnerability

Hazard	**Flood depth**	**Velocity**	**Average**
Flood depth	0.66	0.66	0.66
Velocity	0.34	0.34	0.34
Exposure	Population density	Land use	**Average**
Population density	0.66	0.66	0.66
Land use	0.34	0.34	0.34

Table 4
Normalized matrix of vulnerability

Vulnerability	**Population of young children and older people**	**Population of people with a physical disability**	**Poverty level**	**Number of agricultural worker**	**Average**
Number of agricultural worker	0.49	0.53	0.46	0.42	0.475
Population of young chilfren and older people	0.25	0.27	0.31	0.33	0.29
Poverty level	0.16	0.13	0.15	0.17	0.1525
Population of people with a physical disability	0.1	0.07	0.08	0.08	0.0825

Step 3: Computed the coefficient of consistency. The consistency rate (CR) is determined as follows: CR = CI/RI where CI is the consistency index is computed using the formula CI = (λmax-n)/(n-1); λmax is the largest eigenvalue of the pairwise comparison matrix (n*n); the eigenvalue λmax is always greater than or equal to the number of rows or columns n. Thus, the more consistent the statement, the closer the computed value is to n. RI is a random index determined from a given table.

After computing the weights of the indicators of three components: flood hazard, exposure, and vulnerability, the components will be computed according to the following equations:

Flood hazard = 0.66 flood depth + 0.44 velocity

Flood exposure = 0.66 population dénity + 0.34 land use

Vulnerability = 0.47 population of young children and older people + 0.29 population for people with physical disability + 0.15 poverty level + 0.08 number of farmers

3.2.5. Socio-economic survey

To analyze the flood adaptation capacity of people in the Gianh River basin, a sociological survey method was applied, based on direct interviews. 298 households were randomly selected from 3 communes along the Gianh River watershed: Quang Hai (98 responses), Quang Phong (101 responses), and Ha Trach (99 responses). Quang Phong, located near the riverside, where urban growth was rapid, ranked specially high. Quang Hai is located on the small island in the middle of Gianh River. The inhabitants work mainly in agriculture and flood exposure is moderate. In Ha Trach, located further downstream, where flood vulnerability is very low, there is more diversity in livelihoods. After examining the collected data, 298 responses were used as the basis for further data processing and analysis.

Structured interviews focused on obtaining data relating to natural resources, physical resources, human resources, social resources, and financial resources, as well as information about interviewees' lives, particularly in relation to the historic flood of October 2020.

4. Results

4.1. Flood risk assessment

4.1.1. Flood hazard

Calibration and verification

The model system was calibrated with the catastrophic flood event in October 2010 and verified with the flood event in October 2020 (Figs. 3, 4, and 5). The gauged streamflow data at Dong Tam hydrological gauge have been used to test how well the hydrological model simulates. The result shows good agreement between observation and simulation with Nash-Sutcliffe being above 90% at Dong Tam gauge for calibration and validation. These parameters then were used to simulate discharge for neighbor basins being used as input for hydraulic model MIKE 11.

The calibration and verification phase of the combined 1–2D hydraulic model were carried out at Mai Hoa water level gauge. The result showed high agreement between observation and simulation with Nash-Sutcliffe being 0.92 and 0.95; the flood peak error was only 0.3–0.4 m for calibration and validation time series, respectively. The results indicated that the model was highly reliable in simulating inundation for Gianh River basin. The flood map was produced using the simulated result, showing high reliability (Table 5).

Table 5
Index for error evaluation

Index	Dong Tam gauge	Mai Hoa gauge
Nash	94% (Calibration)	0,92 (Calibration)
	92% (Verification)	0,95 (Verification)
Error peak of flood event	1,3% (Calibration)	0,3 m (Calibration)
	1,7% (Verification)	0,4 m (Verification)

After validating the hydrodynamic model, the flood and velocity map were constructed (Fig. 6a, 6b). Approximately 37.86 km² (20.6%) of the flood zone was flooded below 0.5m; 59.32 km² (32.28%) of the flood zone was flooded from 0.5 to 1m; 44.92 km² (24.44%) of the flood zone was flooded with 1 to 1.5 m; 23.69 km² (12.89%) of the flood zone was flooded from 1.5 to 2 m; 9.51 km² (5.17%) of the flood zone was flooded from 2 to 2.5 m; 8.49 km² (4.62%) of the flood zone was flooded over 2.5m. 64.38 km² (35%) of the flood zone was affected by velocity minus 0.4 m/s; 53.24 km² (28.98%) of the flood zone was affected by velocity of 0.4 to 0.9 m/s; 16.75 km² (9.12%) of the flood zone was affected by velocity of 0.9 to 2 m/s; approximately 50 km² (27%) of the flood zone was affected by velocity of over 2 m/s (Figs. 6a and 6b).

The flood hazard map was constructed by combining the flood depth map with the velocity map (Fig. 6c). 30.42 km² (16.7%) of the flood zone was in the very low zone; 105.45 km² (57.87%) of the flood zone was in the low zone; 35.09 km² (19.26%) of the flood zone was in the moderate zone; 10.35 km² (5.68%) of the flood zone was in the high zone and 0.89 km² (0.49%) of the flood zone was in the very high zone.

4.1.2. Flood exposure

Figure 7a shows land use in 2020 in the flood zone of the Gianh River catchment area. Artificial surfaces accounted for 53.56 km² (28.28%) of the flood zone, mainly concentrated in the communes of Ba Don, Quang Tho, Quang Thuan, Quang Van and Thanh Trach. The fish farming areas occupied about 11.29 km² (5.96%) and were located along the Gianh River in Ha Trach, Bac Trach, My Trach, Quang Phuc, Quang Thuan, Quang Van, Quang Phong, and Quang Hai communes. 69.65 km² (36.78%) belonged to the agricultural category and was mainly in Quang Hoa, Quang Loc, Quang Phong, Quang Phuc, Quang Thuan, Bac Trach, and Ha Trach communes.

Figure 7b shows the population density in the flood-prone area of the Gianh River watershed. The commune of Ba Don has a high population density with more than 4 000 inhabitants per km²; followed by the commune of Quang Hoa with 1 500 inhabitants per km²; the communes of Quang Van, Quang Tho, Quang Tan, and Quang Loc, with 1 300 inhabitants per km²; and the municipalities of Quang Thuy, Quang Thanh, Quang Phong, and Quang Thuan, with approximately 1 000 inhabitants per km². My Trach, Bac Trach, Ha Trach, Thanh Trach, and Quang Phuc communes were lower in population density, with around 200–500 inhabitants per km².

The flood exposure map was produced combining the 2020 land use map and population density map (Fig. 7c). Figure 7c shows the flood exposure; 41.43 km² (22.53%) of the flood zone is located in the very low exposure zone, 53.88 km² (29.3%) in the low zone, 55.78 km² (30.33%) in the moderate zone, 31.67 km² (17.22%) in the high zone, and 1.14 km² (0.62%) in the very high zone.

4.1.3. Flood vulnerability

Figures 8a and 8b show the poverty level and number of agricultural workers. Most of the communes downstream of the Gianh River have a low level of poverty (less than 5%) because, in addition to the primary income from farming and aquaculture, inhabitants receive income from cottage industries such as the manufacture of building materials and conical hats. Other communes, including Quang Son, Quang Thuy, and My Trach had a high level of poverty (more than 10%) as the population work mainly in the agricultural sector, which is one of the sectors most affected by floods. In addition to agriculture, the inhabitants of Quang Truong, Quang Thanh, Quang Hai, Quang Phong, Ba Don, Quang Thuan Quang Phuc, Bac Trach, Ha Trach, and Thanh Trach communes have cottage industries. This is why the numbers of farmers in these communes (less than 2 500 per commune) are lower than in others, such as Quang Loc, Quang Hoa, Quang Tho, and Quang Minh, where 80–90% of the population (over 3 500 farmers) work in the agricultural sector.

Figures 8c and 8d show the distribution of children, older people, and people with physical disability. Most municipalities in the flood zone contain populations with physical disability under 300. Other communes in the north, such as Quang Luu, Quang Tung, Canh Duong, Quang Tien, Quang Xuan, Canh Hoa, Quang Lien, Quang Truong, and Quang Phuong, have over 300 people. In addition, the towns Quang Hung and Quang Long have more than the other towns, i.e., over 500 people. With more than 6 000 people, Thanh Trach commune has the largest population of children and older people than the other communes, followed by Quang Tho commune with more than 5 000 people, and then the communes Tien Hoa, Ba Don, Quang Thuan, Quang Loc, and Quang Phuc with over 3 000 people. The remaining communes have fewer than 3000 children and older people; Quang Hai has the fewest, i.e., 1 200.

Approximately 27.23 km² (14.81%) of the flood zone was in the very low vulnerability area, 22.37 km² (12.16%) of the study area was in the low vulnerability area, 26.48 km² (14.4%) of the area was in the moderate vulnerability area, 50.53 km² (27.47%) of the flood area was in the high vulnerability area, and 57.29 km² (31.15%) of the study area was in the very high vulnerability area (Fig. 9).

4.1.4. Flood risk map

The flood risk map shown in Fig. 10 is a combination of the results for flood hazard, exposure, and vulnerability. Approximately 62 km² (34%) of the flood zone was in the very low and low categories. 64.36 km² (35.53%) was in the moderate category and 55 km² (30%) of the flood zone was in the high and very high categories (Fig. 10).

4.2. Community adaptive capacity assessment

4.2.1. Capacity of acces to resources

The access a community has to natural, human, and economic resources is one of the essential factors for reducing flood impact. Approximately 53% of those surveyed in the study area had just a high-school education; the level of education is often closely related to profession, level of income, and ability to access to information, which in turn affects flood response strategies.

For approximately 72.4% of households, the primary source of income came from cultivation, with aquaculture accounting for 13.8%, and animal husbandry accounting for 5.4%. According to statistics from the Bo Trach and Ba Don District Statistical Office in Ha Trach Commune, in addition to income from agriculture, additional sources of income came from crafts and groceries. The average per capita income in Ha Trach commune is VND7 900 000 (about 350 US$) per month. Next is Quang Phong with VND6 800 000 (about 300 US$); Quang Hai commune was the lowest, at VND5 100 000 (about 200 US$)per month, due to approximately 80% of population working primarily on crops, mainly rice. Agriculture, livestock, and aquaculture activities are highly dependent on weather conditions and therefore more vulnerable to floods than other livelihoods. Municipalities derive their primary source of income from agriculture; therefore, the industry has a higher level of sensitivity and household income is not stable.

4.2.2. Anticipatory strategies of adjustment to flood

In the three communities surveyed, several factors determine altogether the extent of adaptive capacity to floods. Anticipatory (long-term) strategies were the most popular actions in three communes, enabling the inhabitants to successfully fight against floods.

The strategies are linked to people's access to material, economic, and institutional resources. With the structural enhancement of accommodation, residents are successfully reducing flood exposure and the adverse effects of floods. 52% of households questioned have implemented such strategies. Structural enhancement differs by household: average ground floor height in the three communes ranged from 0.1 m to 3 m and was most concentrated at 0.6 m to 1 m. Quang Hai is the commune at the alluvial site most affected by floods. Therefore, the height of houses is higher than that in the other two communes.

Different strategies were applied sometime before or during the flood, namely anticipatory-tactical strategies (short term). 77% of people in the study area mentioned there being neighbourhood meetings. These play an essential role in integrating the opinions of local government and people in order to phrase a sound strategy for reducing the damage caused by floods. In addition, the local government of communes has also set up a support fund to help households dealing with challenging circumstances. This was mentioned by 4% of participants. In addition, households also have their own individual strategies: 69% of households (64.3% in Quang Hai, 66.6% in Ha Trach, and 76.2% in Quang Phong) raise furniture from ground level or move it to the first floor in anticipation of a flood. 25% of households employ portable water barriers, which require the glueing of wooden panels at the entrance to the house. Users describe this strategy as very effective.

Food and water storage is required in the event of a prolonged flood; 60.1% of households stockpile food. Only 3% of households had a boat ready to help them evacuate, 3% of households prepared life jackets, and 2% carried medicines. The proportion of households with attics or second floors is 47%; those with clean backup water accounted for 34%. One of the other essential strategies for ensuring maximum flood losses is implementing an early harvest, with 32.2% of households participating in this strategy. Flood season in Quang Binh is usually in October every year, so people have to prepare for an early summer-autumn harvest in September under the direction of local authorities and the initiative of each family.

Although the study area residents have all prevention strategies before floods occurs, they face many obstacles such as the use of movable water barriers, lifting furniture off the floor, or moving furniture upstairs, which requires a certain level of physical ability. This can be particularly difficult in the households of people with disabilities, single parents, elderly, and children.

4.2.2. Respons strategies

In addition to the strategies put in place before floods to limit damage, those implemented after the flood are even more necessary. Such intervention strategies involve human and social resources. For example, after a flood, family members clean and rearrange furniture. Larger households and those with healthy, able-bodied family members have an advantage over smaller households and those with elderly or unwell members. In addition, households also receive external aid (from local government, volunteer groups, and NGOs) including life jackets, boats for evacuation and safety (accounting for 3.4%); support for plant and animal species (9.7%); financial aid, food such as instant noodles and rice (representing 90.6%); and loan support (3%). Many participants said that without this support, they could not have recovered. Most did not have alternative plans, although they expressed concerns about how aid is distributed and the potential for future cuts in government aid. Around 22% of respondents felt very satisfied with the support of local authorities, 52.2% felt satisfied, 18.4% felt neither satisfied nor dissatisfied, 9.5% felt dissatisfied, and 2.1% felt very dissatisfied.

Government help may not be the same for everyone, so social resources are significant. 14.1% of those surveyed borrowed money from relatives to overcome the consequences of floods. 9% of those surveyed said they relied on support from their neighbours, including emotional support, help with cleaning, money, food, and household equipment. 29.6% of participants depend on banks for cash loans. 8.3% of those surveyed were not able to take out a new loan to overcome the consequences of the floods. Participants also describe how both mutual aid between community members and collective action have become less common. Therefore, they want to implement as many predictive strategies as possible to reduce flood damage.

4.2.3. Flood risk perception

Community awareness is a decisive factor in finding appropriate strategies to reduce flood risk. Residents in the study area are experiencing unusual and unpredictable weather as well as an increase in the intensity of storms and floods compared to many years ago. During 2020 there were many unusual occurrences in terms of rainfall and frequency of floods. 99% of people think that the intensity of floods is increasing and each year the flood will increase from 0.2 to 0.5 cm.

In the survey on causes of increased floods, 63.3% of people said that climate change was the cause; 26% of people were not sure; 7% said that it was due to deforestation; and other reasons suggested included urbanization, digging of ponds for shrimp farming, and narrowing of river mouths.

To reduce flood risk, it is necessary to modernize the dike system, reforest and manage deforestation. Using an intelligent warning system to give accurate warning forecasts to people before disaster strikes will ensure people evacuate in time.

5. Discussion

5.1. Significance and validation of results

To establish a flood risk assessment and management framework for reducing the risk of human and material damage, international researchers are employing numerous strategies to detect flood risks and flood locations. However, flood risk persists and is likely to increase in the future. Traditional conceptions of flood control must be replaced by holistic flood management strategies (Merz et al., 2010; Meyer et al., 2009a; Molinari et al., 2014). For example, the integration of of expert and community opinions aimed at reducing vulnerability instead of raising dikes (Hoang et al., 2018; Luu et al., 2018; Meyer et al., 2009b; Saleem Ashraf et al., 2017) has been successful in the Netherlands and the United Kingdom. These measures can be adapted to developing countries where there is a large low littoral zone. Population growth and the development of urbanization both influence the environment of the flood plain. Aging road networks and flood defense systems have many weak points. Repairing and rebuilding is expensive and time-consuming; therefore, a bottom-up approach is appropriate for developing countries and especially countries such as Vietnam. Several previous studies have emphasized that flood risk management decision-making must be supported by flood risk assessment and analysis of the adaptive capacity of populations (Vu and Ranzi, 2017). The results of this study are necessary, as they can support reducing the damage to human life and provide appropriate strategies to ensure sustainable socio-economic development. Although this study was applied to a study area in Vietnam, the results can be extrapolated to other affected regions.

In the introduction of this study, we examined factors such as land cover, population density, and socio-economic status and their relationship with flood risk and indicated that one of the research objectives was to analyze its roles in the risk. The damage to property and humans during floods can be reduced by scientifically integrating reliable information in the flood risk map. This is one of the primary objectives accomplished in this study. We identified the flood risk areas in Gianh River in 2020 and provided information on flood risk in these periods. The combination of high exposure (i.e. population density and urbanization) and vulnerability (poverty is high, and there are high number of agricultural workers, people with physical disability, children and older people) explains the high flood risk. In 2013, Quang Trach district was split into Ba Don town and Quang Trach district. Ba Don town is the northern administrative center of Quang Binh province. According to the provincial planning strategy, in 2030, the area will be fully urbanized. The urbanization process triggers increasing population and more social welfare facilities, especially schools and hospitals. These crucial services may be exposed to a high risk due to the consequences of floods, increasing the region's vulnerability as a whole if they are built in flood-prone areas without commensurate mitigating measures. Weaker and unwell people may have lower resilience to the flood effects.

The effect of urbanization on flood risk was noticeable in Ba Don, Quang Tho, Quang Phong, Quang Phuc, Quang Thua, Quang Van, Quang Hoa, Quang Loc, and Thanh Trach (Fig. 10). This trend is typical of many cities around the world. (Nirupama and Simonovic, 2007) analyzed the flood risk in London, Ontario (Canada). The authors pointed out that urbanization was the major cause of increased flood risk. This was confirmed by Agraw et al. in 2021 (Beshir and Song, 2021). The authors showed that increasing urbanization was the main cause of floods in Addis Ababa. Jianxiong et al. (Tang et al., 2021) reported that rapid urbanization had resulted in flood risk area spreading in the coastal watershed of southeastern China. In 2020, (Handayani et al., 2020) reported that population growth and urbanization were increasing flood risk near the northern coast of central Java, Indonesia. This was confirmed by the study of (Ferdous et al., 2020). The authors justified the growth of population and artificial surface area in the flood zone as the main causes.

Three major issues were addressed in this study. First, the components and sub-components of risk were weighted using the AHP method, based on both the authors' experiences and scientific literature. The hydrodynamic model in this study yielded reliable results with high calibration and validation values (over 90%). Flood depth and velocity values are reliable; however, these weights are used to construct the flood hazard map using AHP, which is still subjective (Table 1, 2). They are the same for flood exposure and vulnerability sub-components. Second, the size of agricultural sector and level of poverty are important elements that impact flood risk in a given area (Fig. 8). First, the agricultural sector is the most affected by floods, particularly in the context of climate change. At the same time, poverty reduction can improve resilience to floods. However, the weights are attributed to the agricultural and poverty level sectors in Table 1, 2, 3 and Table 4, which are hard to justify clearly. Because agricultural losses depend so much on the type of agriculture – e.g. aquaculture and livestock lose more than crops – the extent to which floods affects crops also varies (Klaus et al., 2016; Nguyen et al., 2017). In general, crop losses are controlled by flood characteristics (e.g. flood depth, duration, flood timing, flow velocity, water contamination, and sediment load), crop varieties (e.g. rice or cereal), and crop physical characteristics (e.g. growth stage, height, and submergence tolerance). For example, the effects of complete submergence during a crop's vegetative stage causes more serious yield loss than when it is in the reproductive stage (Nguyen et al., 2021c). Third, while the sturdiness of buildings decreases flood damage, the city wealth can increase the ability to support residents after a flood reduces the flood risk. However, these factors are hard to find in developing countries (Nguyen et al., 2021a).

The findings of this study explored the ability of adaptive populations to fill in the gaps of the AHP method. The adaptive capacity of people in the Gianh River watershed depends on activities such as strengthening the capability to access natural, economic, human, and social resources, particularly inhabitants who find themselves in less favorable economic situations; improving risk memories; and increasing awareness of flood risks. Questionnaires completed by local inhabitants show the relationships between factors determining the adaptive capacity of population to floods. In particular, access to natural, human, and technical resources plays an important role in reducing the impacts of floods by enabling improved techniques for the land and residents. However, the ability to access these resources is uneven between populations. In the case of the Gianh River watershed, local authorities are helping widen access loans to reinforce housing. Although improved access to materials and technologies improve the adaptive capacity of populations, these resources are not available to everyone. Many residents lack the economic resources to implement the most effective strategies. Costs of materials and technology are growing increasingly rapidly; financial insecurity and inequitable labor limit the capacity to adapt and increase vulnerability in the study area. The leveraging of human resources is seen as a cheaper route to flood control.

In Vietnam, flood risk management at the provincial and district levels is mainly focused on directing and monitoring activities at lower levels, such as the reinforcement of dyke and drainage systems. At the commune level, the focus is mainly on prevention, emergency response and recovery. Mitigation remains limited to preparing facilities, storing food, and organizing meetings before the flood occurs. The decision-making process of provincial and district governments is a top-down one. At the commune-level, the trend is reversed. Officials report to the district, whereas steering committee make a summary and create a final action plan. These plans rely on the experience of commune staff and are tailored to the geographical characteristics of each place, but local people do not participate in developing these plans. Therefore, a bottom-up approach in flood risk management adds a very important layer, where involving local people in developing plans and acting proactively can significantly reduce the loss of life and property.

This study highlights the important role of combining flood risk assessment and adaptive capacity analysis in flood risk management. Mitigating flood risks using a bottom-up approach is essential to protect urban areas (such as the case study area, the Gianh River basin). This provides the opportunity to develop settlements on flood plains, which may face frequent natural disasters including extreme rain or water-related disasters, such as storms and floods.

5.2. Limitations and future research directions

This study faces general limitations due to the use of topographic data. This study uses DEM, extracted from a 1:100,000 topographic map, to simulate floods using a hydrodynamic model, however, in future research, we will use DEM from Lidar or UAV, as it detects more details on the ground, such as flow direction, slope, vegetation, and buildings. There are also limitations due to lack of available data; this is a significant problem in Vietnam. In general, studies show the need for the government to make socio-economic data access easier to more people. Here, this study has been limited because of this poor availability. Future studies can add vulnerability data, such as family income, education level, and agricultural land use area. However, this data does not exist for the study area yet. Another issue to bear in mind is that AHP is mainly based on subjective evaluations of experts (De Brito et al., 2018). Future research can use new methods including Linear Programming Technique for Multidimensional Analysis of Preference (LINMAP), Integrated Determination of Objective Criteria Weights (IDOCRIW) and Step-Wise Weight Assessment Ratio Analysis (SWARA). Future research may be able to integrate all these changes with the novel elements of the current study; additional data on future vulnerability and climate change scenarios will also be needed.

6. Conclusions

Floods are one of the most frequent disasters in Vietnam in general and in the Gianh river watershed in particular, causing significant damage to people and property. The country's flood risk reduction strategies have mainly been based on the top-down approach. This approach has put a strain on the country's budget and proven ineffective, especially in light of the rapid increase of the frequency of floods in recent years. This study presents a bottom-up approach based on hydrodynamic modeling and the adaptive capacity of populations to manage flood risk in the catchment area. Flood risk management was analyzed by combining the flood risk map and adaptive capacity to compute comprehensive flood risk. The results show that 62 km^2 (34%) of the study area was in very low and low categories, 64.36 km^2 (35.53%) was in the moderate category and 55 km^2 (30%) of the flood zone was in the high and very high categories. This study assessed flood risk spatially and added factors such as access to economic, technical, natural, social, and human resources in the assessment of community adaptive capacity. Results demonstrate that easy access to economic, social, and human resources can reduce flood risk.

The country's economic, industrial, and technological development has brought and will undoubtedly continue to bring new ways of adapting to the constraints associated with floods. However, the social changes that accompany them, including urbanization and increasing population density, mean that flood risk is more dangerous when the protection systems collapse. This study plays an essential role in improving the understanding of future urban growth in flood risk areas. Previous studies show that some common tools may only be useful in certain regions, while in the context of climate change and urban growth, flood risk will increase in the future. This underlines that it is crucial to look for new and more efficient tools. This study successfully built a new approach illustrating how to deal with urbanization in the future in the context of climate change. It provides a basis for analyzing the strategies needed to reduce risk. The results also highlight the potential of spatial planning to minimize the negative impacts of floods.

Declarations

Confict of interest: The authors declare no confict of interest.

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Figures

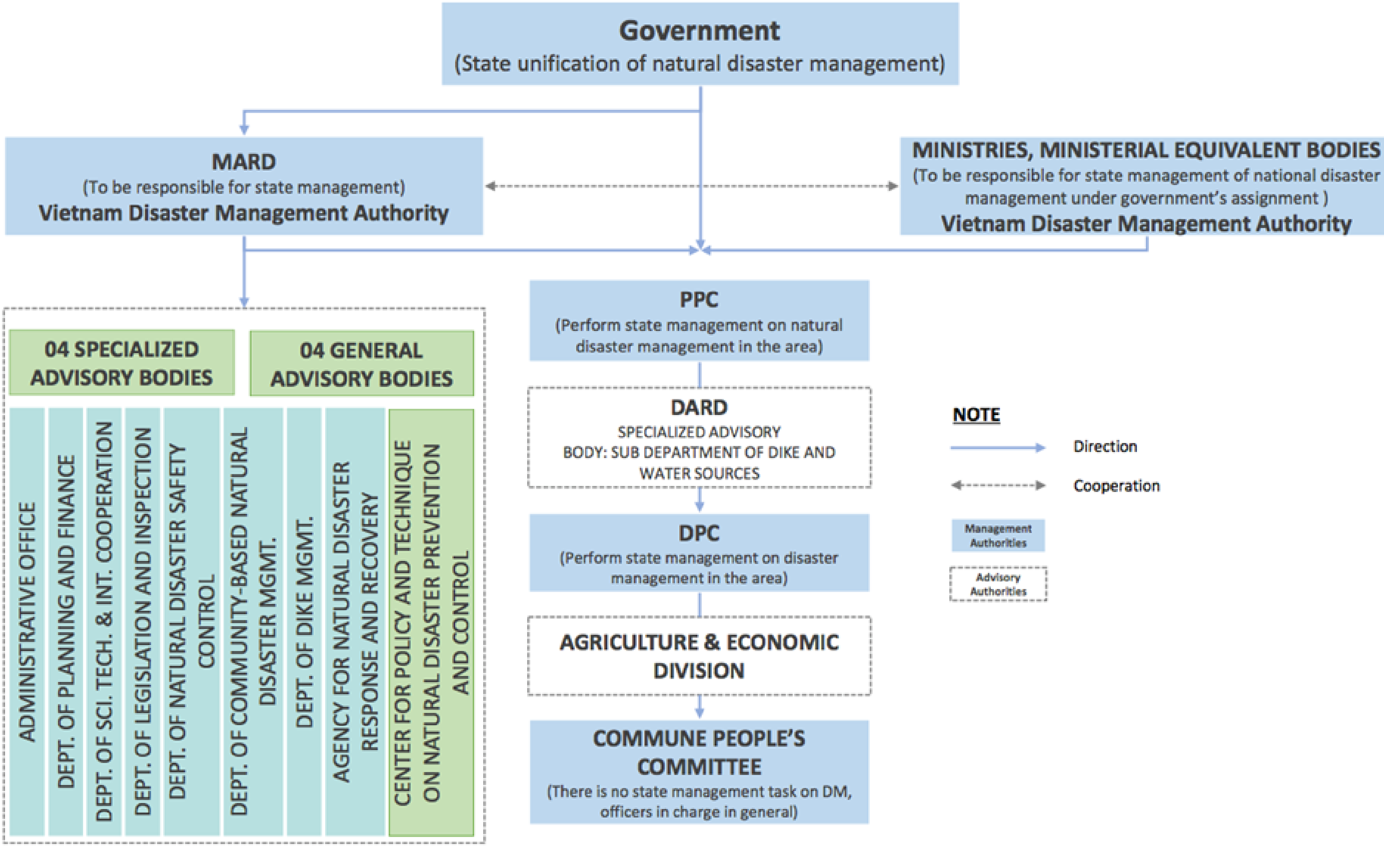

Figure 1

Organizational chart of agencies involved in natural disaster management

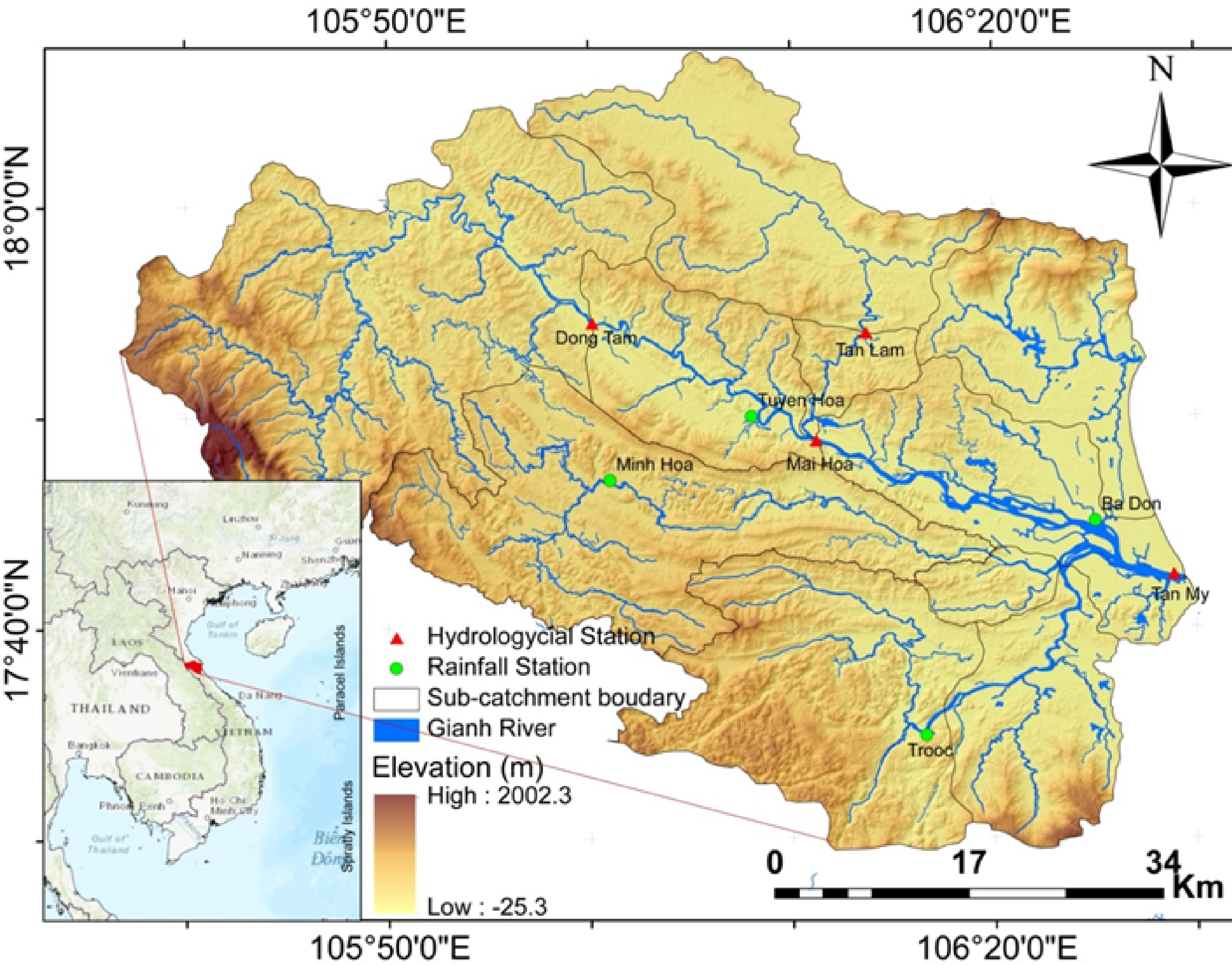

Figure 2

The Gianh river watershed in Quang Binh province

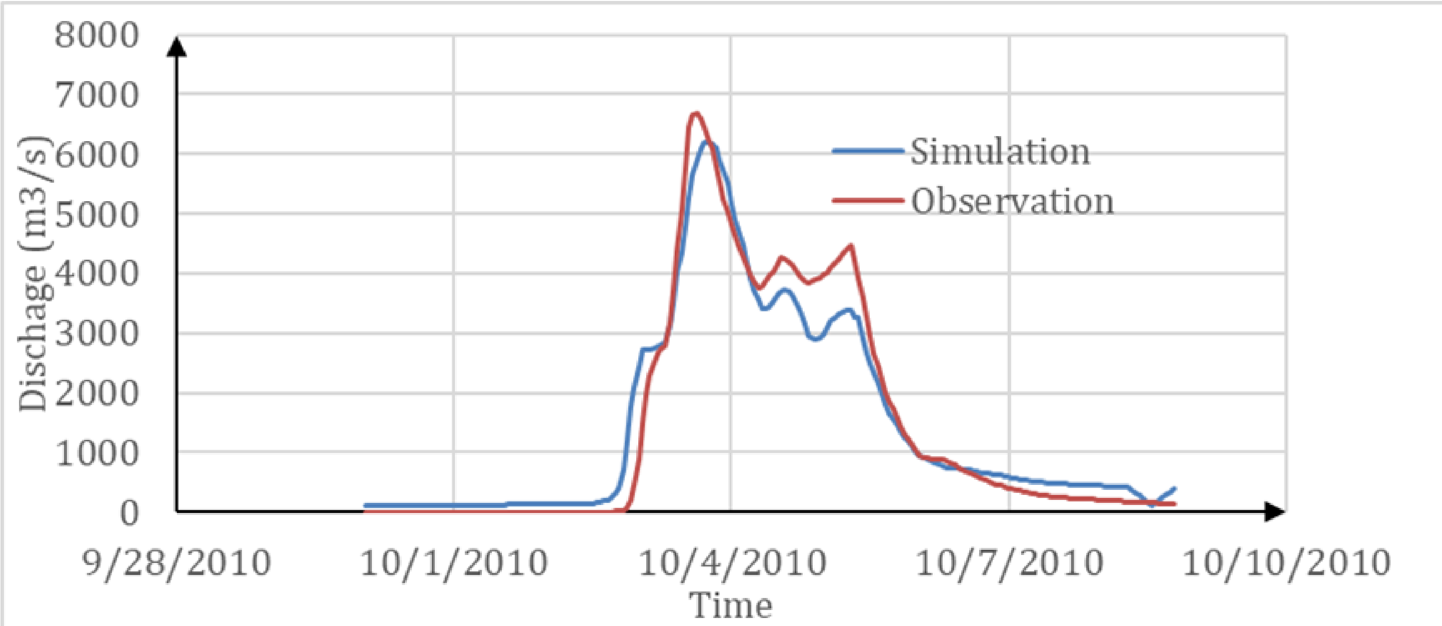

Figure 3

Verification of MIKE NAM at Dong Tam gauge with the flood event in October 2010

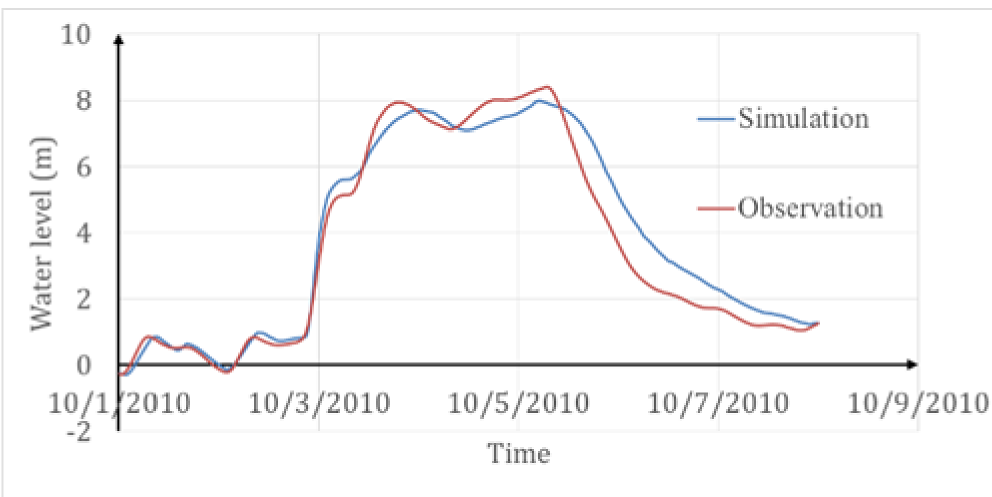

Figure 4

Calibration of MIKE FLOOD at Mai Hoa gauge with the flood event in October 2010

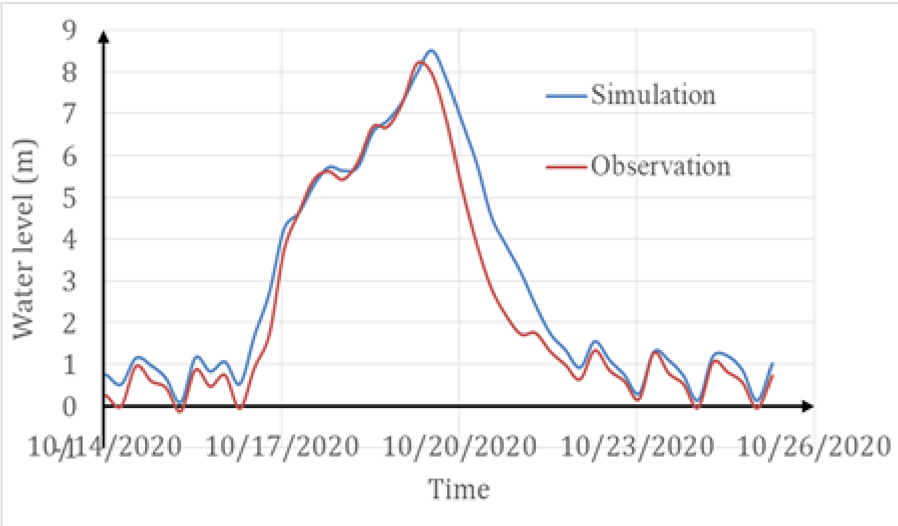

Figure 5

Verification of MIKE FLOOD at Dong Tam gauge with the flood event in October 2020

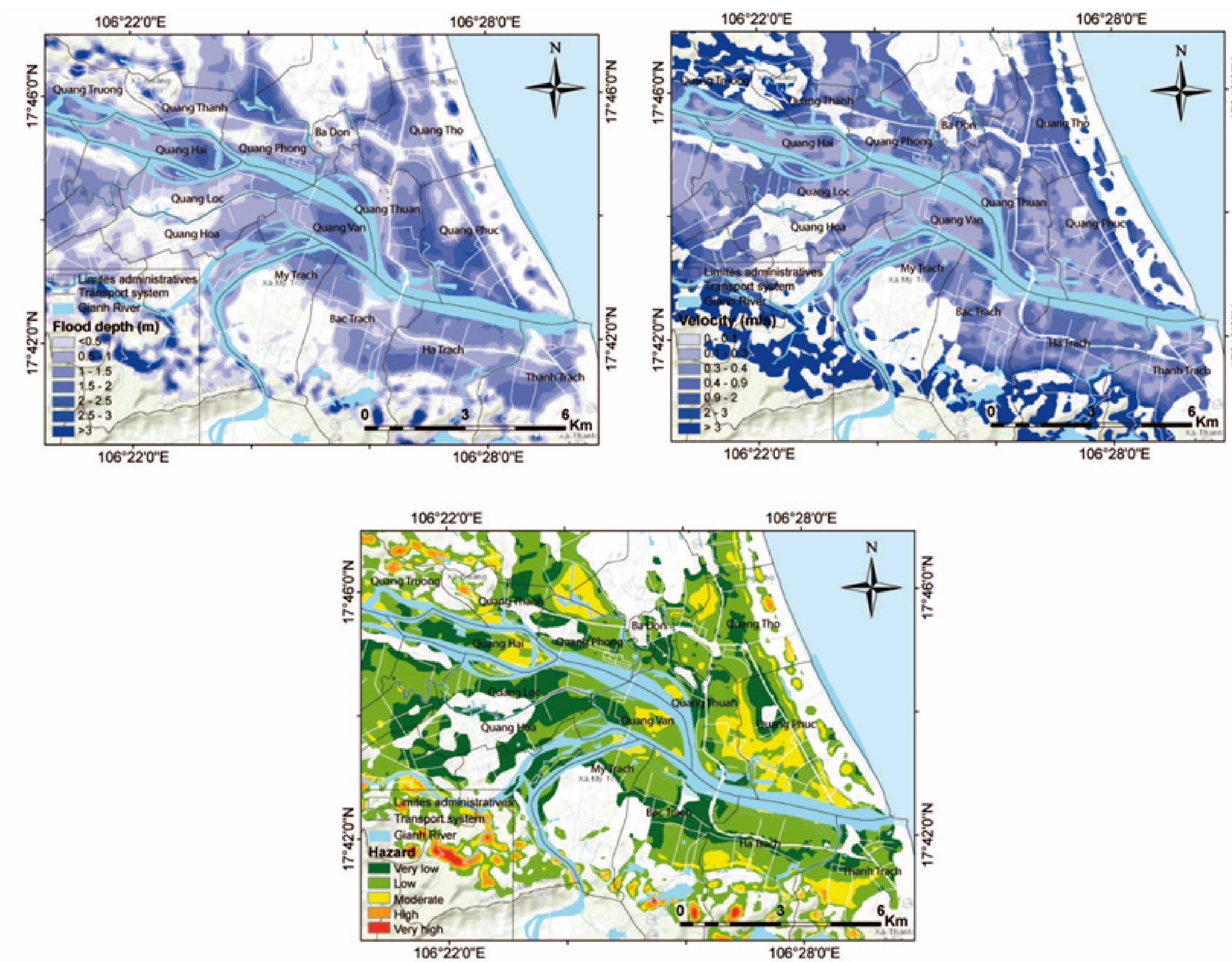

Figure 6

Flood depth, velocity, hazard in the Gianh watershed

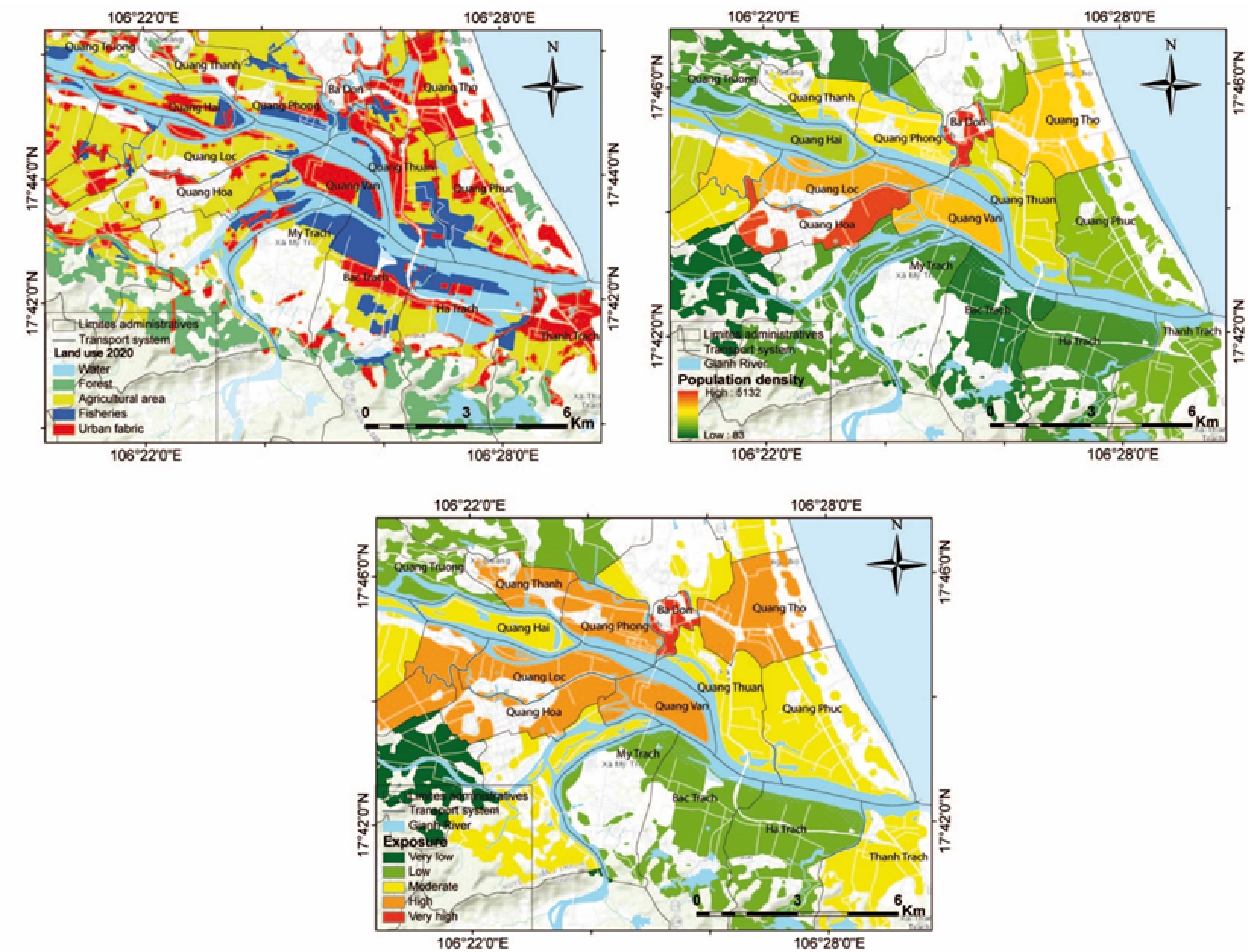

Figure 7

Land use, population density and Eexposure in the Gianh watershed

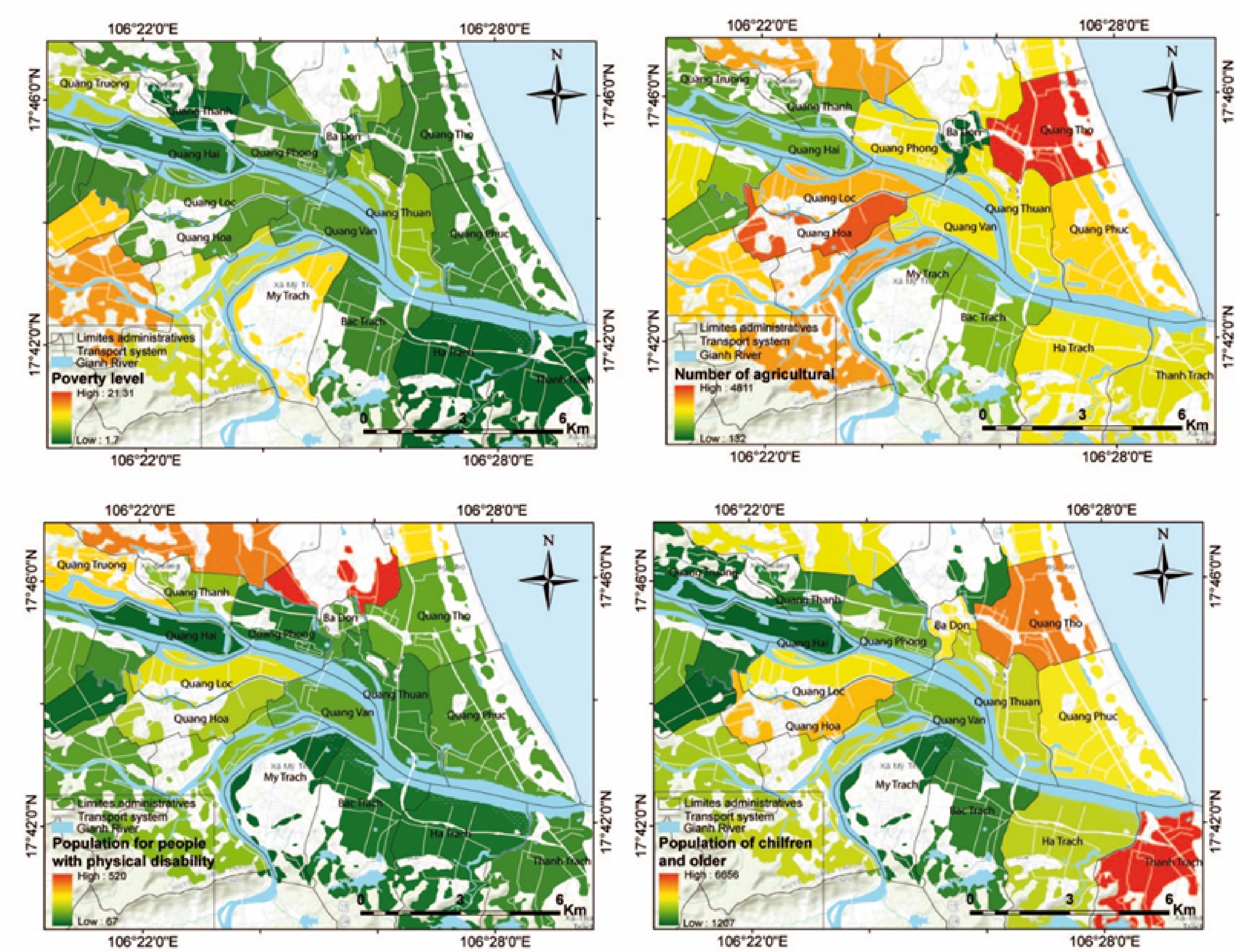

Figure 8

Poverty level, number of agricultural, population for people with physical disability, and population of chilfren and older in the Gianh watershed

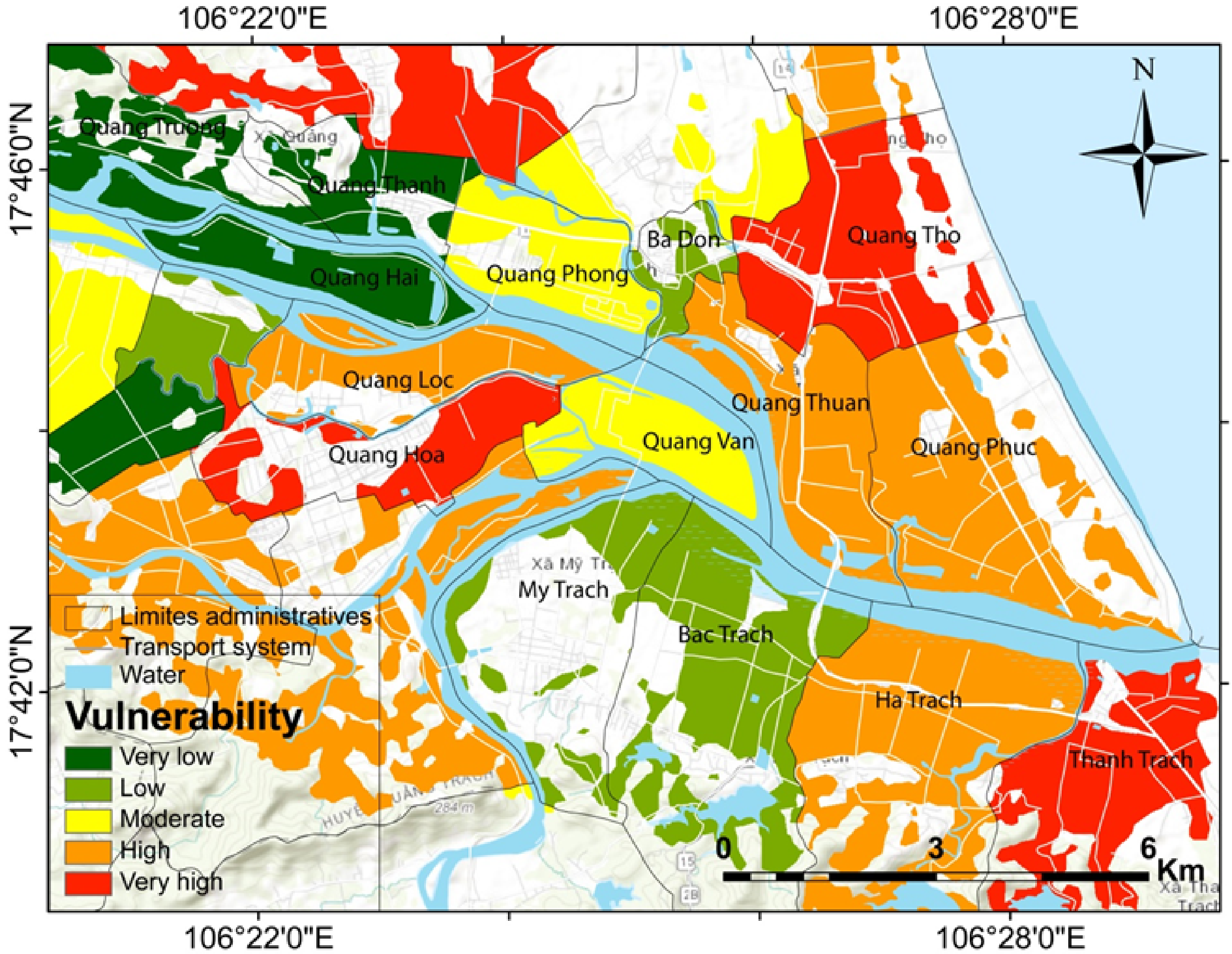

Figure 9

Vulnerability in the Gianh watershed

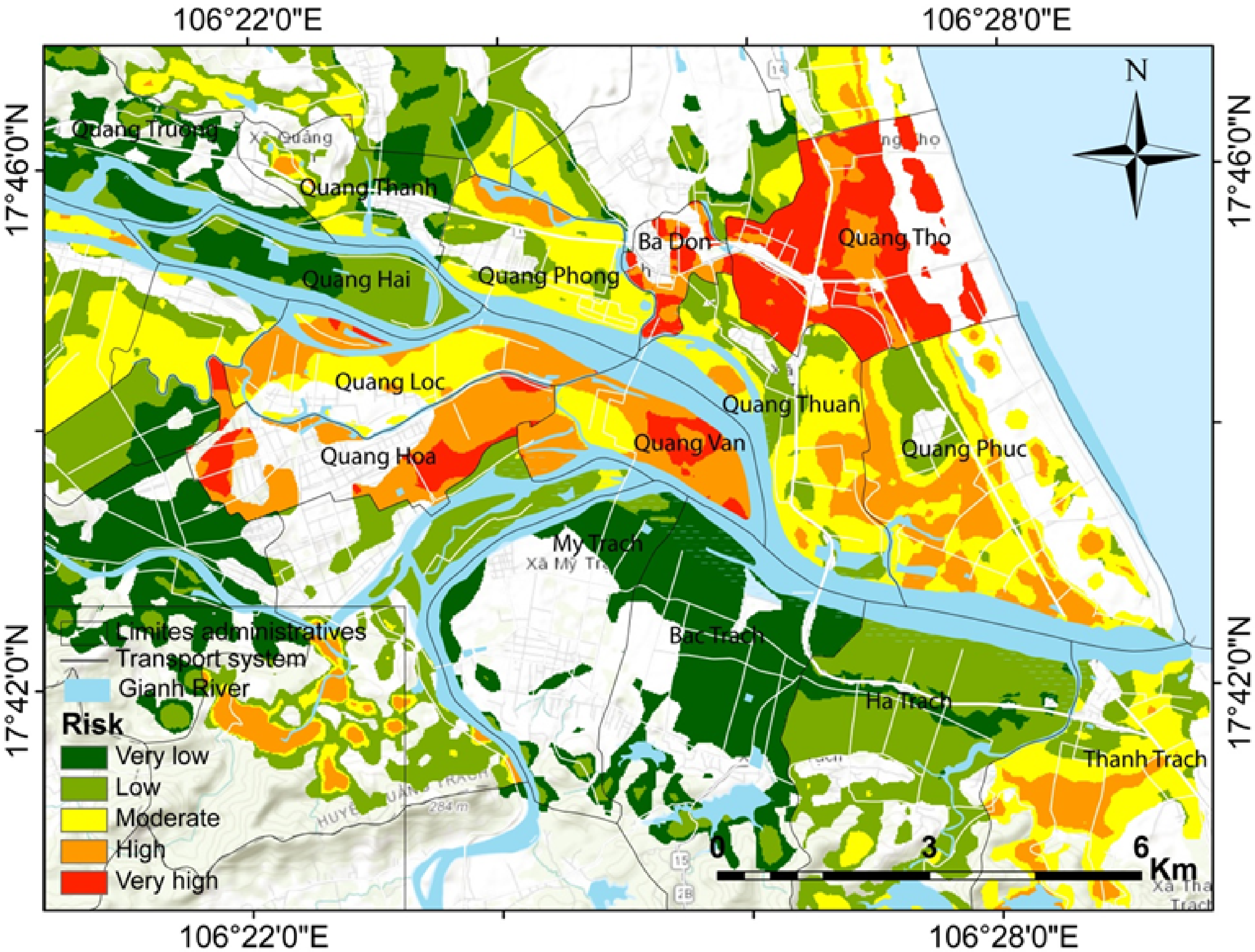

Figure 10

Flood risk in the Gianh watershed