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ORIGINAL ARTICLE

Assessment of the flood vulnerability of shrimp farms using a multicriteria evaluation and GIS: a case study in the Bangpakong Sub-Basin, Thailand

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Abstract Flood disasters associated with tropical storms have caused extensive and repeated damage to shrimp farms located in the Bangpakong River Basin, Chachoengsao Province, Thailand, which features the largest area of inland shrimp farming in the country. This study aims to assess the current vulnerability of shrimp farms to flooding and to examine the shrimp farmers' actual adaptation practices for coping with floods based on past flood events. A flood vulnerability map was developed based on the geo-environmental characteristics of the study area. The map was produced through the use of geographic information system methods and a multicriteria evaluation. The current vulnerability map indicates that the majority of shrimp farms in the Bangpakong River Basin are highly vulnerable to flooding when the 10-day cumulative rainfall is >250–300 mm. The highly vulnerable area identified by the map is consistent with the area impacted by flooding in 2011. Based on a questionnaire, the majority of shrimp farmers have developed various adaptation practices to cope with flooding. The most common practice for minimizing flood damage is to increase the height of dikes around shrimp ponds. Because of budgetary constraints, approximately 20 % of small-scale shrimp farmers did not implement any adaptation practices and risked potential damage. With increasing climate change threats, these research results are useful for planning and creating policies that can reduce flood damage to shrimp farms in vulnerable zones. The results can also be applied to other areas facing similar conditions.

Keywords Flood · Shrimp farm · Vulnerability · Geographic information system · Multicriteria evaluation · Bangpakong river basin

Introduction

In Thailand, flooding is probably the most devastating and widespread type of natural disaster. Floods are becoming more frequent, particularly during the monsoon season of June–September (Aon Benfield 2012; Limjirakan et al. 2009; Cruz et al. 2007; Salam 2000). One of the worst flood disasters occurred between July 2011 and mid-January 2012. Five tropical depressions and typhoons hit Thailand, resulting in severe flooding in 2011. The World Bank (2012) reported that 66 of the 77 provinces in Thailand were declared disaster areas by the government, and more than 5.5 % of the total land area of the country had been inundated by water. The total losses amounted to 1.43 trillion Thai Baht (USD 46.5 billion).

Thailand is the world's largest producer and exporter of cultured shrimp, with a profit of approximately 96,792 million Baht (3028 million US$) in 2011 and a 25 % share of the global market (Thailand Frozen Food Association 2011). Therefore, any adverse effects to the aquaculture industry, which is the fastest growing food-producing sector in Thailand, will affect the country's economy and will certainly lead to a shortage in the food supply. Many

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shrimp farms in Thailand were inundated by the huge volume of flood water in 2011. The Department of Fisheries reported that 1514 shrimp farms, covering an area of 5509 rai (881.44 ha), were inundated by the extreme flooding, which caused approximately 109 million Baht (3.41 million US$) worth of damage.

Chachoengsao Province, located near the outlet of a large drainage area, is one of the thirteen provinces in Thailand that experienced damage to the majority of its shrimp farms in 2011. In addition to shrimp farms, agricultural fields in Chachoengsao Province were waterlogged for more than a month. Recently, Chachoengsao Province has suffered from flooding almost every year. A spatial database on flood occurrences for the period 2005–2010 was developed by the Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand. Finding detailed maps of flood-vulnerable areas and post-disaster mitigation support is difficult for this region, despite the chance of severe flooding every year. The majority of shrimp farms in Chachoengsao Province have been repeatedly flooded, but attempts to develop a vulnerability map for the aquaculture sector have been meager. Additionally, no adaptation strategies have been used to support shrimp farmers in preparing to cope with flood events. The main support provided by the central government is a disaster relief fund for flood victims. Furthermore, limited vulnerability information is provided to farmers in these areas. To establish a long-term and sustainable solution for shrimp farming in this area, the development of a flood vulnerability map for shrimp farms will be significant in terms of future mitigation and adaptation.

In recent years, geographic information system (GIS) methods have been integrated with multicriteria evaluations to identify flood-vulnerable areas (Yahaya et al. 2010; Lawal et al. 2012; Musungu et al. 2012). The GIS and multicriteria decision analysis process combines and transforms geographical information into a different datum for further analysis by decision makers and has been useful in the analysis of natural hazards in geo-environmental studies (Fernandez and Lutz 2010; Dai et al. 2001; Malczewski 1999).

However, this tool has never been used to assess the vulnerable areas associated with aquaculture zoning in Thailand. The impacts of floods, the flood-vulnerable areas of shrimp farms, and the adaptation practices for reducing the effects of flooding in the Bangpakong Sub-Basin, Bangpakong River Basin, Chachoengsao Province, should be investigated because the sub-basin is within one of the top-five shrimp-producing provinces in Thailand. Our research objective is therefore to assess the vulnerable zones of shrimp farms that are likely to be inundated by floods and to investigate recent adaptation practices of shrimp farmers for coping with previous floods. Multicriteria evaluation and GIS are used in this study to assess the flood vulnerability of shrimp farms, classify non-flooded areas, and delineate previous adaptation practices of shrimp farmers in coping with floods at the district level. The high spatial resolution of the flooded areas delineated by the GISTDA of Thailand provides the necessary detail for developing adaption plans at a particular scale. This study illustrates and enhances the capability of using a spatial database to assess the vulnerability of shrimp farms and to accurately and precisely plan for the impacts of extreme flood events in the future.

Methodology

Study area

The study area covers the Bangpakong Sub-Basin of the Bangpakong River, which passes through Chachoengsao Province. For decades, the Bangpakong River Basin has hosted a wide range of activities involving agriculture and fishery. For instance, high yields of shrimp and other agricultural products, particularly irrigated rice, are the main products of the fertile land along the Bangpakong River (Szuster and Flaherty 2002). Over the last 50 years, the central plains of Chachoengsao Province have experienced extensive development of inland shrimp farming (Braaten and Flaherty 2000). Both industrial and smallholder shrimp farms are widespread throughout the province. Shrimp farms have not declined thanks to the high market prices of raw shrimp products (Fisheries Information Technology Center 2011). Shrimp farms in the Bangpakong Sub-Basin, Chachoengsao Province, were investigated in this study, as shown in Fig. 1. Currently, more than 8000 shrimp farms and more than 29,157 shrimp ponds exist in Chachoengsao Province, based on identification using Google Earth Maps (released on 13 January 2011). Geo-physically, the study area is located in the low Bangpakong River Basin. This basin is located downstream of the Prachinburi and Nakhonnayok Rivers near the Gulf of Thailand. This low basin has a very limited capacity to control extreme hydrological events that originate in the upper catchment of the Prachinburi and Nakhonnayok Rivers and their tributaries. Consequently, the Bangpakong Sub-Basin has been overtopped by huge volumes of water from both rivers. Although a decline in the average annual rainfall in the basin, which normally ranges between 1100 and 1200 mm, has been observed by the Thai Meteorological Department, the intensity of precipitation events will likely increase on average. Shrimp farms in the study area were flooded in 7 of the last 9 years: 2005, 2006, 2008 (twice in 2008), 2011, 2012 and 2013. High levels of

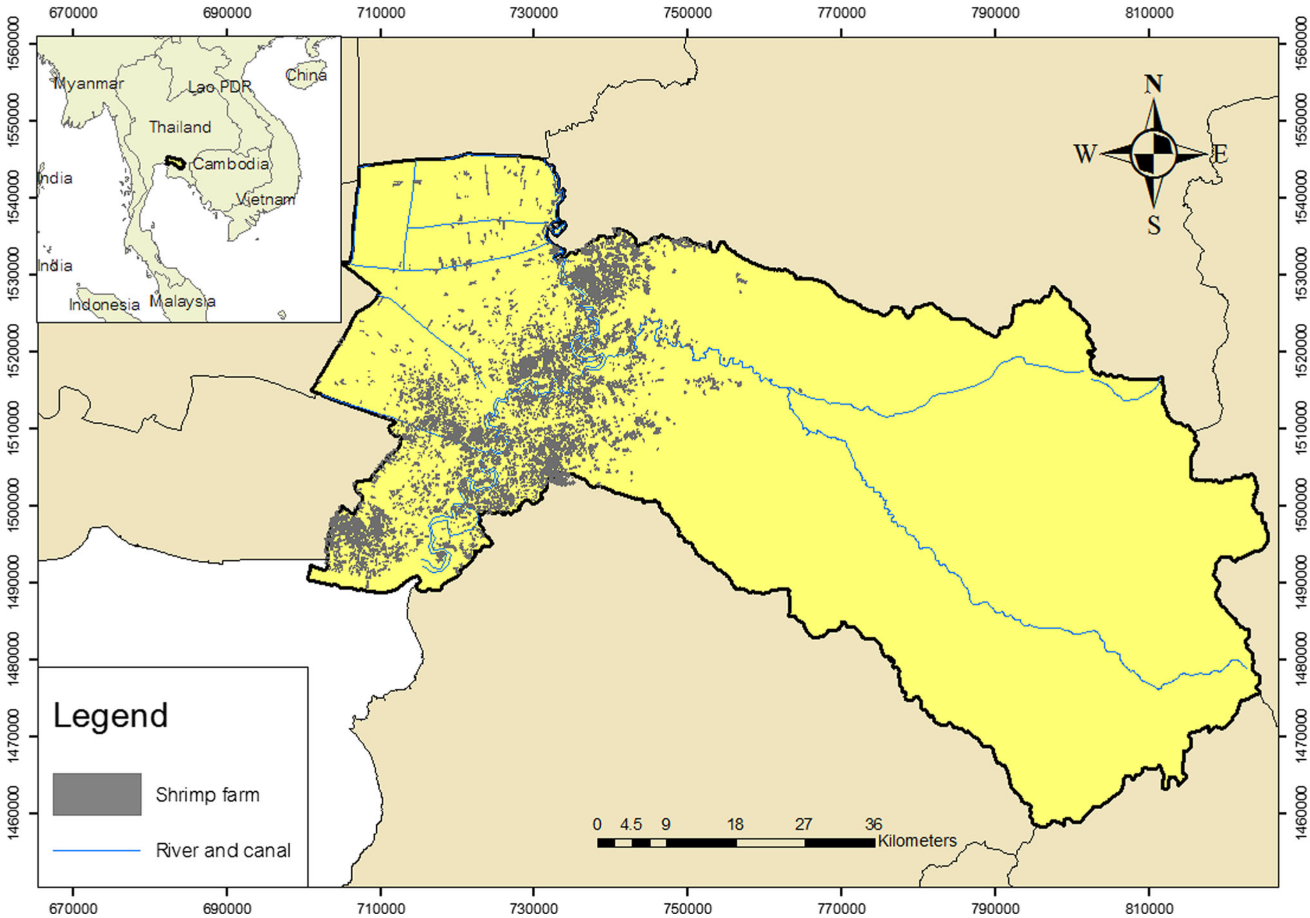

Fig. 1 Map of the study area and the shrimp farms located in Chachoengsao Province

precipitation over a short period are cited as the most important factor responsible for triggering severe flooding in the Bangpakong River Basin. Therefore, the Lower Bangpakong Sub-Basin is a flood-prone area, and Chachoengsao Province has experienced a flood every year over the last 3 years.

Framework for vulnerability and adaptation analysis

The assessment of the flood vulnerability of shrimp farms in Chachoengsao Province comprises two components adopted from the Adaptation Policy Framework by Downing and Patwardhan (2012): (1) assessing the current vulnerability of shrimp farms to flood occurrence by using typical hydrological, physical and environmental components as the primary data and (2) understanding the adaptation practices of the shrimp farmers who have suffered from floods in recent years and the effectiveness of these practices. Geo-environmental characteristics have been applied to assess the flood-vulnerable areas in the first component of this study. The second component involves incorporating a site survey and interviews with the shrimp farmers who have been affected by severe floods to identify their adaptation practices and capability of coping with floods. Although the results of each aspect were interpreted separately in this study, the associations between the two aspects were considered in the conclusion.

It is important to note that this study is a part of a larger study on vulnerability and adaptation assessment for shrimp farming in relation to extreme flood events. The whole vulnerability assessment considered exposure, susceptible, coping capacity and adaptation as well as spatial and temporal dynamics. Meanwhile, exposure indicators with regard to physical characteristics of the study area were the main focus to assess physical vulnerability before aggregation with other components of vulnerability.

Assessment of flood-vulnerable areas of shrimp farms

A multicriteria evaluation is a fundamental step for rational decision making, and GIS is commonly used for flood risk analysis. Based on the study of other relevant basin sites, vulnerability assessments typically focus on physical vulnerability. Physical characteristic changes (especially land cover change) usually result in a decrease in the potential infiltration and an increase in the runoff rate (Mustafa et al. 2005; Bojie Fu et al. 2013). To generate a flood map and examine the vulnerability, this research used a cumulative rainfall threshold for flooding. The assessment of the flood-vulnerable areas of shrimp farms involved the following steps:

Identifying a vulnerability indicator

The available data on the flood vulnerability index (FVI) and the results of similar studies (Balica 2012, 2013; Agbola et al. 2012; Marchi et al. 2010; Borga et al. 2011; Kia et al. 2010) were used to identify vulnerability indicators of flood occurrence. The vulnerability indicators in this study relate only to exposure, i.e., rainfall, slope, drainage density, soil texture, land use, and basin size, according to the geo-environmental characteristics of the study area. At this stage of the study, two components (sensitivity and adaptation capacity) were not incorporated into the vulnerability assessment; these components should be studied in the next stage of the research. The effects of the exposure indices on flood occurrence were defined as follows:

1. Rainfall (Rf) represents the volume of water available for infiltration and runoff (Adiat et al. 2012). Extremely heavy rainfall events are often associated with flash floods. The daily rainfall records for Chachoengsao Province were provided by the Meteorological Department of Thailand and were used to produce a rainfall map for the study area.
2. Slope (Sl) is a factor that controls the rate of infiltration (Prasad et al. 2008). The surface runoff is low when the slope of an area is rather flat because low-angle slopes allow rainwater to percolate. Consequently, flat areas are highly susceptible to flooding. In contrast, steep slopes facilitate high runoff, allowing less time for rainwater to percolate. Hence, steep areas are less vulnerable to flooding. To generate the slope map of the study area, a digital elevation model (DEM) with a 3-m spatial resolution was obtained from the Royal Thai Survey Department. The slope (percentage) was classified in accordance with Adiat et al. (2012) using ArcGIS10 (ESRI 2011).
3. Drainage density (Dd) is calculated as the total length of all of the streams and rivers in a basin divided by the total area of the basin. The spatial analysis tool of ArcGIS was used to generate and classify a gridded drainage density map. The drainage density indicates the spacing of channels (Prasad et al. 2008). When the drainage density is high, the soil is largely impermeable, leading to a low infiltration rate and high flood vulnerability.
4. Soil texture or lithology (Lt) is an important factor in determining the infiltration rate. The soil type or texture greatly influences the rate of infiltration in soil and in the drainage development. When a low infiltration rate or high degree of runoff is observed, the flood susceptibility is high (Eze and Emi 2011; Chandra Pal and Debnath 2012; Hegedus et al. 2013). A 2009 soil map showing 39 soil series in the province was obtained from the Department of Land Development of Thailand. The infiltration rates estimated by the Department of Land Development were used to classify the soil series into four categories in ArcGIS10: poor, moderate, good and very good infiltration rates.
5. Land use (Lu) is associated with the intensity of runoff and flood frequency. A 2010 land use map provided by the Department of Land Development of Thailand was used for this research. A total of 14 land use types were grouped into five classes, as suggested by Chawala (2008) and Rosca and Iacob (2012), in ArcGIS10.
6. Size of basin (Sb) is the area that accumulates rainfall in a basin. The basin size directly influences the total volume of runoff. A small basin or catchment, i.e., <1000 km^2, can be commonly affected by flash floods as a result of intense rainfall, and response times are on the order of a few hours or less (Marchi et al. 2010). To determine the basin size, the spatial analysis tool in ArcGIS was used.

Assessment of areas currently vulnerable to floods

1. Pairwise comparison method

The pairwise comparison method is a powerful tool used to establish the relative order between different concepts in situations in which explicit weighting and rating are difficult and to support the decision-making process in the form of a reciprocal decision matrix (Kulakowski 2015; Deng 1999). In this study, a pairwise comparison matrix was used to determine weights of flood plain characteristics based on the findings of several studies that conducted similar flood assessments (Lawal et al. 2012; Musungu et al. 2012). Then, the weights assigned by these results were applied to rank the factors from 1 to 9 according to the fundamental scales of the analytic hierarchy process (AHP) (Saaty 1980), as shown in Table 1. Based on the results of Agbola et al. (2012), Borga et al. (2011), Kia et al. (2010), and Marchi et al. (2010), the major factors that cause flooding in the watershed include annual rainfall, watershed/basin size, slope, gradient of the main drainage

Table 1 Scale for pairwise comparison (Saaty 1980; Saaty and Vargas 1991)

Magnitude of importance	Description
1	Equal importance
3	Moderate importance
5	Strong importance or essential
7	Very strong or demonstrated importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between adjacent scale values

channel, distance from main river, drainage density, land use and soil texture. In this study, 6 factors were selected: drainage density or capacity of existing drainage, rainfall, soil texture (lithology), slope, basin size, and land use/land cover. With guidance from an expert from the Department of Fisheries, Thailand, and the relevant literature, we determined the weight of each indicator shown in Table 2 for the decision-making process of AHP (Saaty 2008). To determine the weights of each factor, a pairwise comparison matrix between two factors (row and column) was constructed. For instance, if the factor in the row has more importance than the factor in the column, then the magnitude of the importance (i.e., 1, 3, 5, 7 or 9) is indicated. If the factor in the row has a lower importance than the factor in the column, then the value of the weight is equal to 1 divided by the magnitude of the importance. The results of the nth roots, which were summed over the first row, were used to normalize the eigenvector elements. Then, the first element in the eigenvector was derived from the sum of the first row divided by the summed nth roots product value (Table 3). To ensure consistency in the determined weights from the pairwise comparison, the consistency ratio (CR) was analyzed using Eq. 1. To be consistent, the CR value must be <0.1 (Saaty 1980; Vahidnia et al. 2008).

$$CR = \lambda_{max} - n/(n-1)/RI \quad (1)$$

where λ is the maximum eigenvalue of the matrix, n is the number of elements in the matrix, and the RI (random index) values were adopted from Saaty (1980), as shown in the table below. The table shows the average consistency index, which was randomly generated (i.e., inconsistent) using the pairwise comparison matrices.

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

By adopting the steps described by Saaty (1980), the consistency ratio was 0.073 divided by 1.24 (0.06). Because this value is <0.1, the estimated weights shown in Table 3 can be reasonably adopted.

2. Assigning vulnerability rating to the indices

The index ranges of flood vulnerability are based on the exposure vulnerability factor. The classes of thematic layers for all indices and their corresponding ratings are shown in Table 4. The flood vulnerability rates were assigned to each class according to the magnitude of influence of the class on flood occurrence. The ratings range from 1 to 5: (1) very low, (2) low, (3) moderate, (4) high, and (5) very high flood potential. To classify the influence of each index on flood occurrence, the results from relevant studies (Table 4) were reviewed and used as a reference, with the exception of cumulative rainfall, which relied on actual statistics. The cumulative rainfall in September and the beginning of October in 2005, 2006, 2008, 2011 and 2012, when flash floods occurred in the study area, were used to assign the classes. The worst flood in Chachoengsao Province occurred in 2011, when flood water from upstream of the basin flowed into the study area at the same time heavy rainfall caused a flash flood. The cumulative rainfall levels in Chachoengsao in September of 2005, 2006, 2008 and 2011 from Thai Meteorological Department rain gauge stations were 350.5, 404, 381.5 and 362.8 mm, respectively. These rainfall amounts were 26.3,

Table 2 Square pairwise comparison matrix for the selected flooding vulnerability indicators

	Drainage density	Size of basin	Cumulative rainfall (10 days)	Soil texture	Slope	Land cover/use
Drainage density	1	1	0.33 (1/3)	3	3	5
Size of basin	1	1	0.33 (1/3)	3	5	5
Annual rainfall	3	3	1	5	5	9
Soil type	0.33 (1/3)	0.33 (1/3)	0.20 (1/5)	1	3	3
Slope	0.33 (1/3)	0.33 (1/3)	0.20 (1/5)	0.33 (1/3)	1	3
Land cover/use	0.20 (1/5)	0.20 (1/5)	0.11 (1/9)	0.33 (1/3)	0.33 (1/3)	1
Column total	5.87	5.87	2.18	12.67	17.33	26.00

Table 3 Determination of the relative criterion weights

	Drainage density	Size of basin	Cumulative rainfall (10 days)	Soil texture	Slope	Land cover/use	nth root of products of value	Eigenvector
Drainage density	0.17	0.17	0.15	0.24	0.17	0.19	1.10	0.1827
Size of basin	0.17	0.17	0.15	0.24	0.29	0.19	1.21	0.20193
Annual rainfall	0.51	0.51	0.46	0.39	0.29	0.35	2.51	0.418544
Soil type	0.06	0.06	0.09	0.08	0.17	0.12	0.57	0.09548
Slope	0.06	0.06	0.09	0.03	0.06	0.12	0.40	0.067478
Land cover/use	0.03	0.03	0.05	0.03	0.02	0.04	0.20	0.033868
Column total	1.00	1.00	1.00	1.00	1.00	1.00	6	1.00

45.5, 37.5 and 30.7 % higher, respectively, than the normal monthly rainfall quantity based on the 30-year September average (277.5 mm for 17 rainy days). Furthermore, the 300 mm of cumulative rainfall that fell during Tropical Storm Gaeme during September 16–25, 2012, as reported by the Chachoengsao Provincial Office of Disaster Prevention and Mitigation, was the threshold for flash floods in 2012. Therefore, this situation, i.e., 300 mm of cumulative rainfall over 10 days leading to flooding in September 2012, was used to classify the areas that are highly susceptible to floods. The current rainfall threshold for triggering floods in the study area does not differ significantly from the Extreme Rainfall Alert (ERA) service launched by the Environmental Agency and the Methodological Office for England and Wales: The rainfall thresholds are set to 30 mm in 1 h, 40 mm in 3 h, and 50 mm in 6 h (Hurford et al. 2012). The average intensity of storms that leads to flooding in Greece is 4.5 mm/h; this threshold was also taken into account (Diakakis 2012) to guide the rainfall index classification, i.e., high, moderate, low and very low flood susceptibility.

3. Conversion of thematic layer to point layers for the flood vulnerability index (FVI)

The proposed general FVI in Eq. 2 links the values of all indicators to flood vulnerability components and factors (Balica 2012, 2013), where E, S and R represent exposure vulnerability, sensitivity vulnerability and resilience or adaptation vulnerability, respectively.

$$FVI = E \times S/R \tag{2}$$

At this stage, the research primarily aims to map the flood-vulnerable area of shrimp farms based on geographical and hydrological characteristics. The resilience and sensitivity factors were omitted from the FVI assessment (Eq. 2); these factors will be further assessed in the next phase of the research to identify the adaptation capacity to reduce the flood vulnerability. Therefore, only 6 factors from the vulnerability indicators were used to generate the raster map and to analyze the flood vulnerability with the assigned weight (W) and rating (R). The flood vulnerability index (FVI), which is the summation of the products of the normalized weight and the rating for all the factors, was calculated as follows:

$$FVI = Rf_W Rf_R + Dd_W Dd_R + Sb_W Sb_R + Lt_W Lt_R + Sl_W Sl_R + Lu_W Lu_R \tag{3}$$

4. Assessment of the flood-vulnerable area

Overlaid raster layers consisting of a gridded array of cells in ESRI ArcGIS and a multicriteria evaluation using the FVI equation were used to determine the area vulnerable to flooding. The factors were weighted and rated according to their relative importance using the spatial analysis tool in ArcGIS. Then, the flood-vulnerable area was identified. Flood vulnerability was divided into 5 categories based on the vulnerability potential in the event of flooding (Table 5) according to percentile thresholds (i.e., 0–20, 20–40, 40–60, 60–80 and 80–100 %). The locations of shrimp farms in Chachoengsao Province were overlaid with the flood-vulnerable area to identify areas where shrimp farms are susceptible to flooding and where adaptation practices should be prepared in advance. Shrimp farms that are located in the flood-vulnerable areas are likely to be severely damaged. According to the study by Muralidhar et al. (2010), the flooding of shrimp ponds causes total damage to cultured shrimp.

Table 4 Rating for classes of factors

Influential indices	Category (classes)	Susceptibility to flooding	Rating (*R*)	Normalized weight (*W*)
Drainage density (Dd) (km/sq.km)	0–0.019[a]	Very low	1	0.1827
	0.019–0.06[a]	Low	2	
	0.06–0.13[a]	Moderate	3	
	0.13–0.28[a]	High	4	
	> 0.28[a]	Very high	5	
Size of basin (Sb) (sq. km)	<1,000[b]	Very high	5	
	1001–1800[b]	High	4	0.20193
	1801–2600[b]	Moderate	3	
	>2601[b]	Low	2	
Cumulative rainfall (Rf) (mm within 10 days)	<150	Very low	1	
	150–200	Low	2	0.418544
	200–250	Moderate	3	
	250–300	High	4	
	>300[c]	Very high	5	
Soil texture (Lt)	Very good infiltration rate[b]	Low	2	0.09548
	Good infiltration rate[b]	Moderate	3	
	Moderate infiltration rate[b]	High	4	
	Poor infiltration rate[b]	Very high	5	
Slope (Sl)	0–2 % (flat)[a]	Very high	5	0.067478
	2–8.47 % (undulating)[a]	High	4	
	8.47–15.88 % (rolling)[a]	Moderate	3	
	>15 %[b] (steep)	Low	2	
Land cover/use (Lu)	Paddy field and moorland[b,d]	Very high	5	0.033868
	Area with complex crops[b,d]	High	4	
	Pastures urban and rural space[b,d]	Moderate	3	
	Perennial and horticulture area[b,d]	Low	2	
	Forest area[b,d]	Very low	1	

Sources: [a] Adiat et al. (2012)

[b] Chawala (2008)

[c] Rakwatin et al. (2013)

[d] Rosca and Iacob (2012)

Surveyed adaptation practices of shrimp farmers affected by flooding

Adaptation practices, if appropriately implemented in advance, can play an important role in reducing vulnerability to natural hazards. Cochrane et al. (2009) addressed the precautionary option of increasing resilience and adaptability as a standard practice to improve aquaculture management. This study assessed types of adaptation practices and the ability of shrimp farmers to adopt each practice to deal with floods that have occurred in the last 5 years as the latter. The primary data on adaptation practices were collected by interviewing shrimp farmers who were victims of the 2011 flood. Based on the records of the Chachoengsao Provincial Fisheries Office on the financial relief fund given to shrimp farmers after the 2011 flood, approximately 812 shrimp farmers in 8 of the 11 districts in Chachoengsao Province were affected by the 2011 flood. The total number of victims in each district was used to calculate the sample size for the questionnaire using Yamane's formula (1967) at a confidence level of 95 %. Of the 138 expected respondents, 109 shrimp farmers in 6 districts (Bang Khla, Ratchasan, Khlong Khuean, Ban Pho, Bang Nam Priao, and Muang Districts) were interviewed between 31 January and 8 February 2013 (Table 6).

The qualitative data on adaption practices obtained from the survey were examined and evaluated. The data were divided into meaningful perspectives and were summarized to supplement information on responses and practices that were applied before and during flood events.

Table 5 Flood vulnerability categories/designations

Vulnerability category	FVI range	Description
Very low	<1–1	The area features a very low vulnerability to floods. Shrimp farms or residential properties located in this area are safe from floods, even in the event of a typhoon
Low	1.1–2	The area sometimes experiences floods. Few shrimp farms in this area are affected by floods during the high rainfall caused by typhoons
Moderate	2.1–3	The area is moderately vulnerable to floods. Uncertain amounts of rainfall induce a moderate potential for shrimp farming losses
High	3.1–4	The area is highly vulnerable to floods. A large amount of rainfall over a short period creates a high potential for shrimp farming losses
Very high	4.1–5	The area is very highly vulnerable to floods. A large amount of rainfall during a short period causes a very high potential for shrimp farming losses and/or extreme economic losses

Source: Modified from Balica et al. (2013) and Devkota et al. (2013)

Table 6 Number of shrimp farmers (interviewees) in each district of Chachoengsao Province

District	Number of shrimp farmers who were flood victims in 2011	Number of samples calculated in accordance with Yamane's formula	Number of interviewed victims
Bang Khla	258	26	26
Ratchasan	23	16	3
Khlong Khuean	69	22	22
Muang	14	13	5
Plaeng Yao	1	1	0
Ban Pho	418	43	50
Bang Nam Priao	26	14	3
Phanom Sarakham	2	2	0
Sanam Chai Khet	1	1	0
Total	812	138	109

Results and discussion

Current area of flood-vulnerable shrimp farms

For our assessment of flood occurrence, the precipitation data were combined with the vulnerability indictors of the existing raster map to generate the flood vulnerability map shown in Fig. 2. According to the Thai Meteorological Department, the average cumulative rainfall for Chachoengsao Province in September, when the maximum annual rainfall occurs based on the 30-year average, was 277.5 mm. This value was used as a key indicator to project the current flood-vulnerable area by assuming that the daily extreme precipitation in the first 10 days of September, averaged over 30 years, is 250–277.5 mm. The vulnerable area was classified into areas of moderate (3), high (4) and very high (5) susceptibility to flooding. Approximately 85.3 % of the area was classified as a highly vulnerable zone, 8 % was classified as a very highly vulnerable zone and 6.5 % was classified as a moderately vulnerable zone. The majority of the study area is highly vulnerable to flooding; thus, nearly the entire study area is susceptible to inundation when the cumulative 10-day rainfall is 250–300 mm.

More than 8000 shrimp farms and more than 29,157 shrimp ponds are located in Chachoengsao Province. These data were overlaid with the current vulnerable area to identify where shrimp farms are vulnerable to floods. The results revealed that almost all shrimp farms in Chachoengsao Province have high or very high vulnerability to flooding, as shown in Fig. 2. Flooding can cause the complete shut-down of shrimp farms because massive numbers of shrimp escape during flood events.

From July 2011 to January 2012, Thailand experienced severe flooding due to heavy rainfall from five intense tropical storms. The cumulative rainfall during January–October 2011 was 1647 mm, which is 42 % higher than the 30-year average (Rakwatin et al. 2013). The cumulative rainfall from the 2011 flood event was used to model the worst-case flash flood that is likely to occur in the study area. The highest 10-day cumulative rainfall in September 2011, calculated from the daily rainfall data obtained from the Thai Meteorological Department, was approximately 325.9 mm, which was higher than the rainfall volume that initiated the flood risk in the assessment. Additionally, the maximum 10-day cumulative rainfall quantity that caused flooding in 2012, 300 mm, was also taken into account. The cumulative rainfall quantity of 325.9 mm was used to model the worst-case scenario when the cumulative rainfall quantities deviate from the average. Other selected vulnerability indicators, e.g., slope, drainage density, and basin size, were assumed to remain the same.

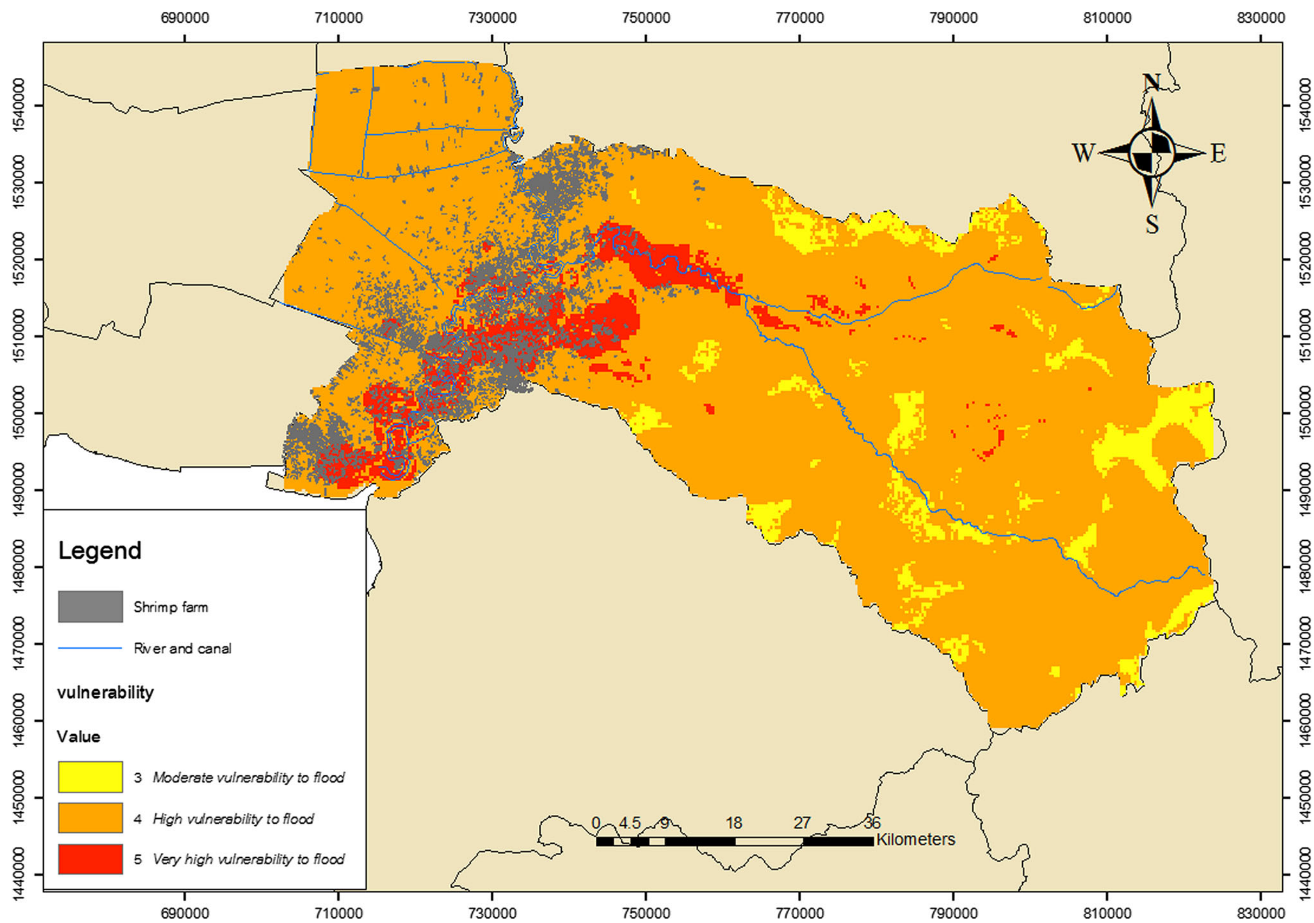

Fig. 2 Current flood-vulnerable shrimp farm areas

Figure 3 shows the result when heavy rainfall greater than the 30-year average occurs in the study area. The vulnerability area was classified as either highly or very highly vulnerable to flooding. Approximately 43.4 % of the area was classified as highly vulnerable to flooding, and approximately 56.6 % was classified as very highly vulnerable to flooding. Overlaying the shrimp farm map of Chachoengsao with the vulnerability map computed by the anomalous cumulative rainfall yielded significantly higher numbers of inundated shrimp farms and a large increase in the area very highly vulnerable to flooding.

The delineated flood-extent areas on 30 October 2011, based on GISTDA data, were overlaid with the results of the vulnerability map generated by the cumulative rainfall of 325.9 mm in September 2011 to validate the vulnerability map with the actual flooding events in 2011. According to Fig. 4, nearly all of the shrimp farms in the study area were flooded in 2011. These results are consistent with the vulnerability assessment, i.e., most shrimp farms in the study area will flood when the 10-day cumulative rainfall is >300 mm. Note that the mountainous and steeply sloping areas are located on the right side of Fig. 4. Therefore, these areas lack shrimp farms and are unaffected by floods.

The change in the rainfall pattern due to climate change in Bangladesh, for instance, was reviewed. Flood events increased by approximately 70 % compared with the annual average of 20.5 % associated with typical rainfall levels (Mirza 2002). Obviously, a major change in the rainfall amount, particularly from tropical storms, could severely damage the shrimp farming industry because of the industry's concentration in flood-prone areas. Because of uncertainties in climate change impacts, participatory approaches and the assessment of adaptation options within areas vulnerable to flooding require further study.

Analysis of adaptation practices and capability

Adaptive practices and capability are essential elements for vulnerability assessments (Kapetsky and Aguilar-Manjarres 2007). The detailed vulnerability assessment on adaptation practices focused on shrimp farmers who were flood victims. The questionnaire conducted in the study area showed that 100 % of interviewed shrimp farmers suffered

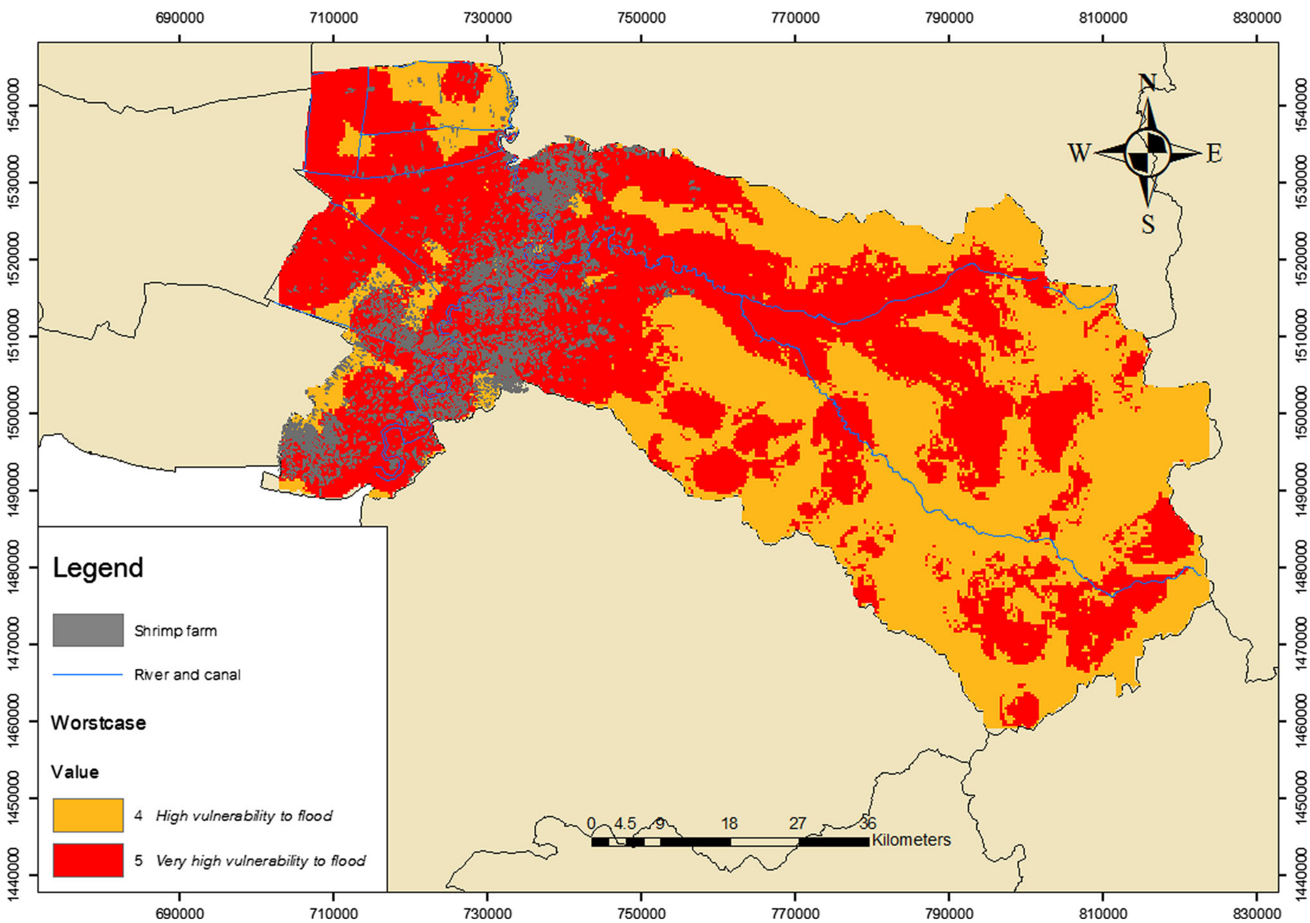

Fig. 3 Degree of vulnerability of shrimp-farm areas when the 10-day cumulative rainfall is >300 mm

from the severe flooding in 2011. These farmers experienced flooding in 2011 and 2012. Table 7 summarizes the adaptation practices undertaken after the shrimp farmers experienced the 2011 flood to cope with later floods (e.g., the 2012 flood). The practices were implemented after the 2012 flood warning by the Sub-district Administration Organization and Chachoengsao Provincial Fisheries Office. In terms of the adaptation capability, the majority of shrimp farmers were able to implement adaptation practices to prevent the negative effects of flooding and the loss of shrimp production. However, approximately 19.4 % of the total interviewed victims (small-scale shrimp farmers) did not implement adaptation practices due to budgetary constraints.

The adaptation practices implemented by shrimp farmers to prevent and reduce the effects of floodwater on their shrimp farm areas are as follows: (1) placing a net around the pond to prevent the escape of shrimp, (2) increasing the height of the dike by covering it with soil, and (3) harvesting the shrimp early to avoid the floods. The results reveal that shrimp farmers in all districts greatly affected by the 2011 flood preferred to increase the height of the dike around the shrimp pond. This technique was preferred among the majority of shrimp farmers because the floodwater could not cross the dike and hinder shrimp production. However, these farmers must be able to afford employing an external excavator to create the dike around the pond.

Additionally, one of the most important issues that limit the adaptation capacity at the farm level is the lack of appropriate attention and investments for reducing and minimizing the effects of flooding. The study revealed that even though a financial relief fund was offered to flood-victim shrimp farmers, the relief funds were inadequate to compensate for the losses. The relief fund of the Chachoengsao Provincial Fisheries Office only covered 5–10 % of the total cost of the estimated damage. A cost-effective approach would be to re-allocate the funds to increase the adaptability of farmers in advance.

After the severe flooding in 2011, shrimp farmers have been aware of the need to address future floods. A minority of shrimp farmers have employed practices to avoid flood damage via practices such as changing the timing of culturing shrimp (e.g., finishing the rearing of shrimp by

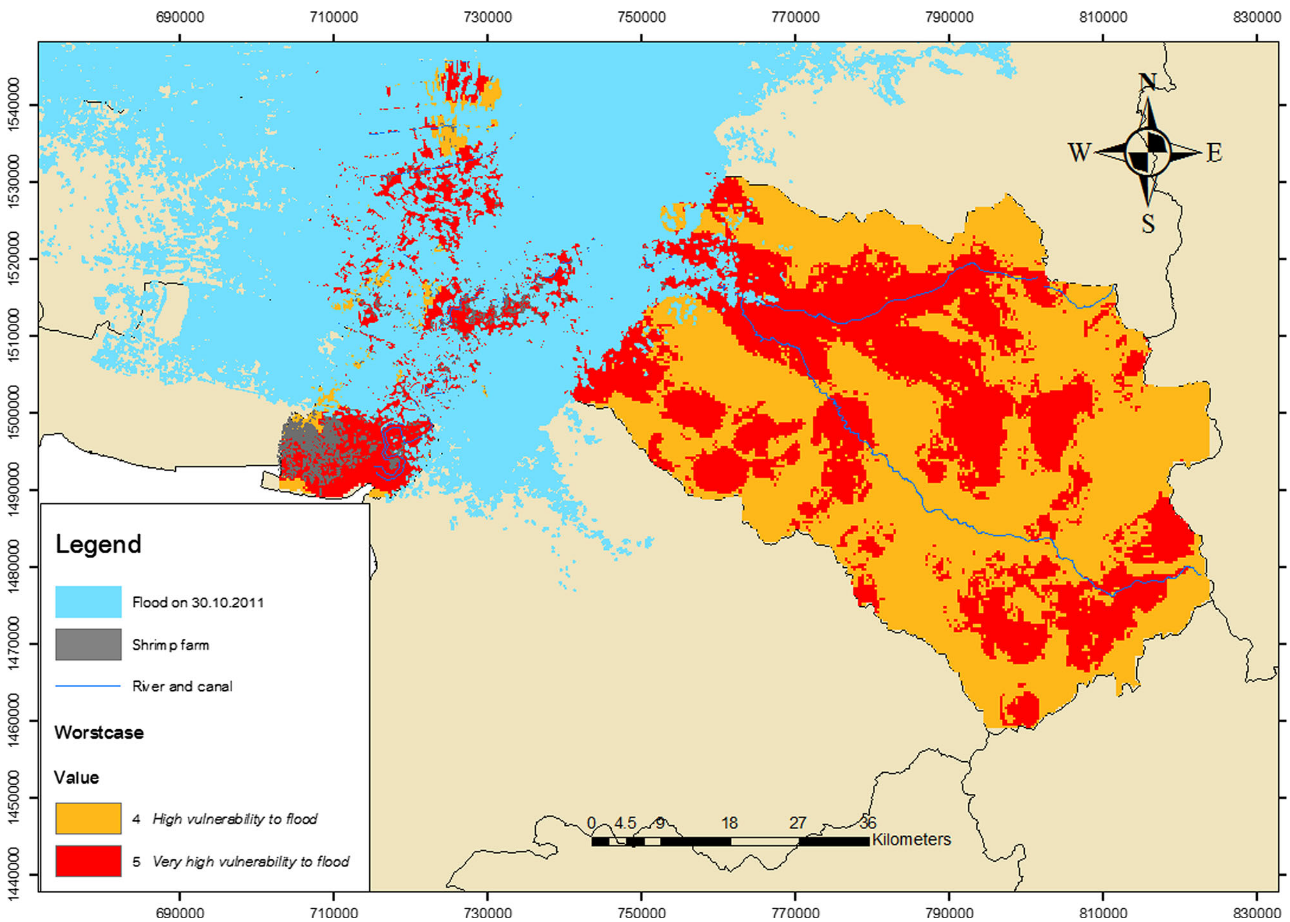

Fig. 4 Flood extent on 30 October 2011, and flood-vulnerable areas according to the assessment

Table 7 Adaptation practices undertaken to eliminate or reduce the impact of floods

Adaptation practices	Shrimp farmers in Chachoengsao Province (n = 109)		
	% of interviewees	% flood impact reduction	
		% of responses for complete reduction	% of responses for partial reduction
Practices to eliminate or reduce the effects of floods			
Placed a net around the pond to prevent the escape of shrimp	57.2	12.6	37.8
Increased the height of the dike surrounding the shrimp pond to 0.3–1 m above ground level	66.9	28.1	33.9
Harvested shrimp early	31.0	9.7	21.3
Practices to prevent flooding			
Changed timing for culturing the shrimp	6.7		
Obtained relevant information on flood occurrence from supporting agency/database	28.1		

Remark: The percentage of flood impact reduction was not taken into account for practices that prevented flooding because these activities were performed prior to the flood

Source: Survey data (2013)

September–October) and obtaining relevant information on flood occurrences from institutional agencies and local government offices. However, the questionnaire results showed that shrimp farmers preferred to take a risk even when acknowledging the potential loss of production in the event of a flood. A majority of the shrimp farmers are unwilling to change their regular practices and are reliant on flood warnings from relevant authorities. The farmers are likely unwilling to change the timing of shrimp rearing or stop rearing the shrimp during September–October because most shrimp farmers do not have an alternative occupation to generate supplemental income.

Conclusions

The combination of GIS and multicriteria evaluations has opened up new opportunities to overcome the challenges in assessing flood-vulnerable areas and implementing sustainable shrimp farming. GIS tools with a wide range of functions are now available for multiple purposes. In this study, flood vulnerability was assessed to identify the current flood-vulnerable shrimp farm areas in Chachoengsao Province, Thailand. Typical geo-environmental parameters were key components in the development of the vulnerability map of shrimp farms. The results revealed that shrimp farms in Chachoengsao are highly to very highly vulnerable to floods, although the assessment is only based on geographical data. Importantly, shrimp farms become more vulnerable to floods when the 10-day cumulative rainfall is >300 mm.

Based on the current vulnerability assessment, adaptation practices undertaken to reduce the impacts of flood were investigated. The majority of shrimp farms are already located in flood-prone areas. Therefore, all shrimp farmers have managed to implement practices to cope with the effects of flooding because they experienced the 2011 flood. These adaptation practices to reduce flood impacts include placing a net around the pond to prevent the escape of shrimp (57.2 %), increasing the height of the dike around the shrimp pond (66.9 %) and harvesting prior to flooding (31.0 %). However, these practices did not completely eliminate the effects of floods. Flooding will be more frequent and damaging to the shrimp farming industry in Thailand in the future. Minimizing damage from flooding in the future is a challenge due to the adaptation abilities of the stakeholders. The accuracy of the local governmental offices' notifications of the rainfall quantity before imminent flooding is essential. Without further investments in adaptation practices, planned management, particularly harvesting before flooding, could be a good approach for particular small-scale shrimp farmers to manage flood problems/concerns.

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