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Economic impact upon agricultural production from extreme flood events in Quang Nam, central Vietnam

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Abstract Quang Nam province, central Vietnam, is situated within the tropical monsoon and typhoon zone of south-east Asia and is susceptible to extreme floods. Historical water level data from 1976 to 2009 for the Vu Gia-Thu Bon river system have been used to simulate flood frequency, concluding that the floods experienced in 2004, 2009 and 2007 were congruent with 1:10-, 1:20- and 1:100-year floods, respectively, all occurring within the last decade (Institute of Geography 2012; Institute of Water Resources Planning in Review and update the flood prevention plan for central provinces: Vu Gia-Thu Bon river. Water Resources Planning Institute, Hanoi, 2011). Since the most productive agricultural land is concentrated along the low-lying sections of river systems, losses to agriculture in extreme flooding can be significant. Using ex-post data, this study estimates the direct damage to agricultural production caused by three flood classes, 1:10-, 1:20- and 1:100-year floods in Quang Nam. Utilising geo-spatial inundation maps together with the timing of the floods with respect to crop rotation, calculation is made of flood-depth susceptibility rates for the four main crop types. These susceptibility rates are then applied to calculate the damage value and also the percentage loss in value for the four crop types under the three flood classes. Benefit-cost ratios were calculated under 'with' and 'without' extreme flood events. In addition, both scenario and sensitivity analyses were conducted. The estimated value of direct losses to the four main crops for a 1:10-, 1:20- and 1:100-year flood is approximately VND22 billion, VND115 billion and VND147 billion, respectively. These represent a percentage loss in value in the inundated areas for 1:10-, 1:20- and 1:100-year floods, of 12, 56 and 62 %, respectively. Benefit-cost ratios, already very low for subsistence farmers, are further eroded in years of extreme floods, with many farmers experiencing a net loss. This study will help to inform flood management decision-makers in central Vietnam.

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1 Introduction

There is no doubt that natural disasters are being reported with increasing frequency across the globe (CRED 2013). Such disasters leave developing countries like Vietnam particularly vulnerable as their capacity to respond is so much less than developed countries (Mechler 2003). The total damage caused by floods in Vietnam was estimated at USD3.7 billion from 1990–2013, of which 62 % occurred in the last decade (2004–2013) (CRED 2013). Subsistence farmers, who rely upon agriculture as their main source of income, are most vulnerable to extreme floods, which have the potential to significantly reduce their production, exacerbating their poverty (Biltonen 2001).

The focus of this study is Quang Nam province, central Vietnam, 10,408 km^2 in area and home to 1.4 million people, more than 80 % of whom live in rural areas (GSO 2011). The per capita Gross Domestic Product (GDP) of Quang Nam province is relatively low, around VND11.22 million (US$560) in 2010 and ranked 48th out of the 63 provinces in Vietnam (GSO 2011). Annual rainfall for the province averages 2,600 mm, with 2,500 mm of this falling during the rainy season from September to December. Quang Nam is situated within the tropical monsoon and typhoon zone of south-east Asia and as such is susceptible to extreme flood events. The most productive agricultural land is concentrated along the low-lying sections of river systems and is vulnerable to flooding. Whilst the annual cost attributed to natural disaster damage averages around 6.3 % of the province's GDP, this can be as high as 20 % of GDP in years of extreme floods (Institute of Geography 2012).

The Institute of Geography (2012) and the Water Resources Planning Institute (2011) for Vietnam have analysed the historical discharge and water level data from 1976 to 2009 for the Vu Gia-Thu Bon river system (the main river system in Quang Nam). Of the 34 years of data collected, the five highest water levels were recorded in the last 12 years of data (1998–2009). When using the data to simulate flood frequency, they concluded that the floods experienced in this river system in 2004, 2009 and 2007 were congruent with 1:10-, 1:20- and 1:100-year floods, respectively, all occurring within the last decade.

In more recent years, the focus of flood management has moved beyond structural mitigation measures such as dams and flood ways towards a "more adaptive and integrated" approach (Ward et al. 2013). Flood risk management is defined by Simonovic and Carson (2003) as a broad spectrum of water resource activities aimed at reducing the potentially harmful impact of floods on people, economic activities and the environment, and by Samuels and Gouldby (2009) as "continuous and holistic societal analysis, assessment and mitigation of flood risk". Simonović (1999) identified three flood management stages: the planning stage, the flood emergency management stage and the post-flood recovery stage. Activities associated with each stage are reliant upon results of risk assessment, and in particular on economic assessment of the impact of floods (Duttaa et al. 2003; Li et al. 2012).

For a time, flood damage evaluation of agricultural production was either neglected or accounted for using over-simplified approaches and rough estimates because expected losses were relatively insignificant in comparison with those in urban areas (Förster et al. 2008; Merz et al. 2010; Brémond et al. 2013). It is now widely recognised as being necessary to provide economic flood damage information to help decision-making in efforts to mitigate the impact of floods (Okuyama 2007; Merz et al. 2010; Penning-Rowsell et al. 2013; Brémond et al. 2013). Estimation of potential flood damage provides important information for the assessment of support needed in the short term, and policy development in the long term for flood control planning, land-use planning, and allocation of resources for recovery and reconstruction (Duttaa et al. 2003; Downton and Pielke 2005; Merz et al. 2010). It could also serve to avoid some of the controversies highlighted by Changnon (2003) that have arisen over government relief payments for natural disasters. Further, flood damage evaluation is critical when, for example, determining the economic efficiency of adopting an intervention strategy against flood damage (Messner et al. 2007; Brémond et al. 2013). A large number of studies have now been conducted which provide some level of economic analysis of flood damage specifically to agriculture and an excellent review of many of these has been executed by (Brémond et al. 2013).

Whilst the damage estimation method is selected based on the scale and objective of study, data availability and flood damage categories (Messner et al. 2007; Brémond et al. 2013; Meyer et al. 2013), the full cost of extreme floods include both tangible and intangible costs (Changnon 2003; Downton and Pielke 2005; Penning-Rowsell and Parker 1987; Parker et al. 1987; Smith and Ward 1998). Intangible costs, however, are difficult to both identify and quantify, due to lack of data availability and insufficient knowledge of full disaster damage (Meyer et al. 2013). Downton and Pielke (2005) identified three particular reasons that made accounting for the cost of disasters inherently complicated. First, disasters have both direct and indirect costs and benefits. Direct flood costs may include the destruction of crops and livestock, whilst floodwater inundation may result in indirect costs, such as interruptions in transportation, trading activities and consumption and a temporary increase in unemployment (Okuyama 2007). Indirect benefits may be, for example, the supply of nutrients resulting in an increase in soil fertility. Second, "disaster's losses are a function of the spatial and temporal scale that the analyst chooses as the focus of a particular loss analysis" (Downton and Pielke 2005). Widespread damage can cause a decrease in food supply, inflating commodity prices and compounding the problem of estimating the economic loss associated with crops that never went to market. Third, many losses incurred as a result of natural disasters are intangible, such as psychological damage and impacts on health (Duttaa et al. 2003), which are extremely difficult to measure (Meyer et al. 2013).

A number of methods to estimate the cost of agricultural flood damage have been developed and reported (Messner et al. 2007; Pantaleoni et al. 2007; Brémond et al. 2013; Morris and Brewin 2013; Meyer et al. 2013). Brémond et al. (2013), the most comprehensive review, described 42 studies on economic evaluation of flood damage to agriculture, reviewing 26 of these in detail. The studies either used or looked to created damage functions for *ex-ante* appraisal, and whilst a few took an experimental approach, most were based on *ex-post* analysis of past events.

Messner et al. (2007) reviewed and categorised existing methods in European countries, providing guidance for quantification and evaluation of flood damage. The guidelines introduce a set of recommended steps for direct and tangible flood damage evaluation, beginning with the objective and the area under investigation, through to ascertaining the damage categories under consideration, gathering the information and available data, determining the method and finally calculating the damage. In addition, the inclusion of uncertainties needs to be reflected in the results.

Recently, an evaluation of the impact of a one-off extreme flood event upon agriculture in Somerset, England was undertaken by Morris and Brewin (2013). They conducted a survey of farmers 4 weeks after the onset of the flooding. The data collection focused on type of impact, farming system and land use to estimate the impacts of seasonal flooding, as well as to understand how farmers coped with the effects of the flooding upon their farm businesses. The results showed that the damage cost of floods to agricultural production can be substantial, depending on timing and the ways that farmers coped with the flooding.

In a simulation method, Kotera and Nawata (2007) conducted an experiment to explore the connection between yield reduction and inundation for rice growth stages. Three factors, including start date, duration and depth of submergence, were used to determine yield reduction. The results showed that yield losses vary, not only by flood characteristics, such as duration and water depth level, but also the growth stage of the crop. For example, the yield loss of rice that was inundated in the early vegetative stage was greater than plants inundated during the reproductive stage.

Banerjee (2010) used rice and jute productivity data to estimate the short- and long-term impacts of extreme floods on agricultural productivity in Bangladesh. The short-term impact was assessed by comparing average annual yield rates in 'normal' flood years with those in 'extreme' flood years. The long-term impact was analysed by comparing the area under cultivation and the agricultural productivity in 'more' and 'less' flood-prone districts over a 20-year period.

Penning-Rowsell et al. (2013) used a depth-loss rate relationship to assess flood damage on land-use categories (including residential, agriculture, industry, business and infrastructure) in the Taihu Basin, China. They established the depth-loss rate by asset categories and flood depth based on an existing flood loss rate or susceptibility, which was a percentage of the pre-flood property value at varying flood depths, and associated flood damage data from past floods. They tested their model using 1999 flood data and found that their damage loss differed only slightly from the widely accepted records of loss issued by the Taihu Basin Authority.

A number of studies, from both local and international institutions, have been undertaken to study flood hazards in Quang Nam province (Chau et al. 2013; Cologne University of Applied Sciences 2013; Ho and Umitsu 2011; Institute of Geography 2012; Institute of Water Resources Planning 2011); however, none of these studies have quantified the impact on agricultural production of extreme flood events. This study aims to fill that gap by conducting an economic assessment, restricted to flood damage incurred by three flood classes (1:10-, 1:20- and 1:100-year floods) on agricultural production in Quang Nam province. Estimated are the direct tangible economic losses from these three flood classes, on the four main crop types grown in the province. The main crop types have been identified and grouped as rice, corn (maize), beans (predominantly long beans, haricot beans, green beans, soybeans and black beans) and 'other vegetables' (including garlic, chillies, water spinach, kohlrabi, aubergines, various Chinese cabbage and leafy green salad vegetables). The analysis utilises geo-spatial inundation maps developed by Chau et al. (2013) that portray the extent of the flooding upon agricultural land by the three flood classes. Using *ex-post* data, including the timing of the extreme floods with respect to crop rotation, a damage function is used to estimate the resulting damage and evaluate the economic efficiency of agricultural production, under these three extreme flood scenarios without further mitigation.

2 Data used

The floods of 2004, 2009 and 2007, congruent with 1:10-, 1:20- and 1:100-year floods, respectively, form the basis of this study. In order to estimate the flood damage costs to agriculture, the submersion results generated by the inundation mapping of the Chau et al.'s (2013) study are used in conjunction with 2010 economic data (described later in this section) collected during a field trip to Quang Nam province from November 2011 to February 2012. Data were collected from the Quang Nam Statistics Office,[1] and from semi-structured interviews at the provincial level, with officers of the Department of Natural Resources and Environment and the Department of Agriculture and Rural Development (DARD). At DARD, interviews and discussion took place in both the Agricultural Extension and the Agricultural Planning divisions and also the Flood and Storm Control division. At the district level, interviews were conducted with officers at each of nine districts' Agricultural Division.[2]

In Chau et al. (2013), inundation maps were generated using the geographic information system, flood depth marks from the floods of 2004, 2009 and 2007, respectively, and a digital elevation model. The agricultural land affected by these inundations was identified by overlaying the flood inundation maps over the agricultural land-use map for the province. The map of the agricultural land predicted to be affected by a 1:100-year flood event (like that which occurred in 2007) in Quang Nam province is presented in Fig. 1.

Figure 1 shows the areas of wet rice production, other agricultural land, aquaculture and forest land predicted to be inundated by a 1:100-year flood. The model estimated that agricultural land would be the land-use type most impacted by each of the three flood classes. The inundated agricultural areas for 1:10-, 1:20- and 1:100-year flood events are estimated to be 29,920, 33,850 and 37,000 ha, respectively, which account for 27, 30.5 and 33.4 % of the total agricultural area in Quang Nam, respectively. Wet rice (the main crop) was identified as being the most affected crop, with more than 40 % of the total wet rice growing area being inundated under each of the three flood classes. Corn, beans and 'other vegetables' accounted for less than 10 % of the total flooded area, whilst grazing land and perennial fruit production contributed to only a very small proportion of flooded land (Chau et al. 2013).

Nine districts affected by the floods, namely Dai Loc, Dien Ban, Duy Xuyen, Hoi An, Thang Binh, Phu Ninh, Que Son, Nui Thanh and Tam Ky, were grouped into the 'more' flood-prone districts. The remaining administration districts were identified as the 'less' flood-prone districts and, in general, were not affected by flood water inundation. Therefore, in this study, we use only the 'more' flood-prone group of districts for our analysis.

In Quang Nam, rice, corn, beans and 'other vegetables' production is carried out on small irrigated family farms, utilising family labour. Farm sizes are typically less than 0.2 ha in the low-lying areas (pers. comm. Agricultural Extension Officer, DARD). Farming families consume a considerable proportion of the farm output, with the remainder being sold or bartered locally. There is no official classification between skilled and unskilled labour in agricultural production in the province (Quang Nam Statistics Office 2011), so it is assumed that the same wage rate is paid to all labour.

Crop production costs and revenue data were adapted both from the Quang Nam Statistical Yearbook 2010 (Quang Nam Statistics Office 2011) and data collected via interviews with DARD and the Districts' Agricultural Divisions. Cost data included input costs for seeds, fertiliser (urea, superphosphate, KCL, lime), agrochemicals (e.g. pesticides), tractor hire, bags and boxes for packaging, transportation, labour costs for seedbed and land preparation, sowing, agrochemical and fertilizer application, irrigation maintenance, weed and pest control, harvesting, threshing, drying, packaging, delivering to

[1] Including both the agriculture statistics division and the meteorology division.

[2] In all some 36 interviews and discussions took place.

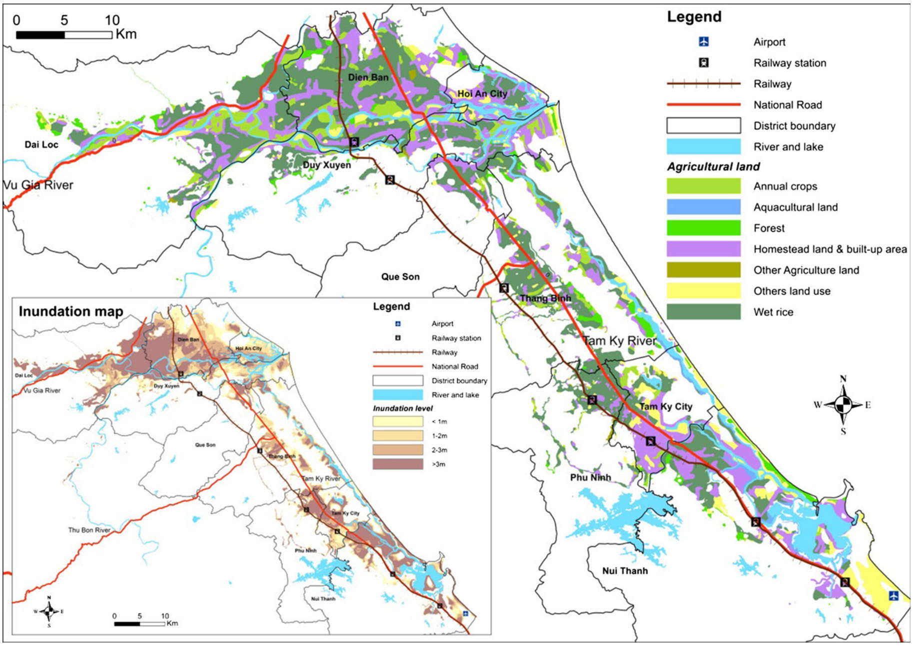


Fig. 1 Predicted inundation of agricultural land in Quang Nam province, Vietnam, resulting from a 1:100-year flood event

market and in addition, cooperative charges (pers. comm. Agricultural Extension Officers, DARD; pers. comm. District Agricultural Officers).[3] All costs are calculated on a per hectare basis as are benefits from output yields. These farm gate input and output prices are used to calculate the costs and benefits of primary agricultural production (rice, corn, beans and ‘other vegetables’) both in a ‘normal’ growing year without an extreme flood event and then agricultural production as impacted by the three flood classes.

Average crop yields were obtained from the Quang Nam Statistic Yearbook for 2010 (Quang Nam Statistics Office 2011). The average seasonal rice yields for both the ‘more’ flood-prone and the ‘less’ flood-prone districts for the period 2000–2011 are shown in Fig. 2.

Figure 2 shows the average yield (tonne) per hectare of the summer–autumn and the winter–spring rice crops, with differentiation made between the ‘more’ flood-prone and ‘less’ flood-prone districts. Trend lines (regression lines of best-fit) for both crop season yields have been included. Yields increased on average by a rate of 3.8 % per season for the summer–autumn crop and by 3.0 % for the winter–spring rice crop. Rice crop yields per hectare have been increasing for a number of reasons. These include the use of improved varieties of rice which have increased yields, more effective irrigation and also increased use of fertiliser. It is important to note that the 2004 and 2007 floods affected the winter–spring rice crops, which were harvested in April of the following year. Therefore, it is the 2005 and 2008 rice yields which are impacted by the floods, as can be seen in Fig. 2.

[3] Details of this data can be obtained from the corresponding author.

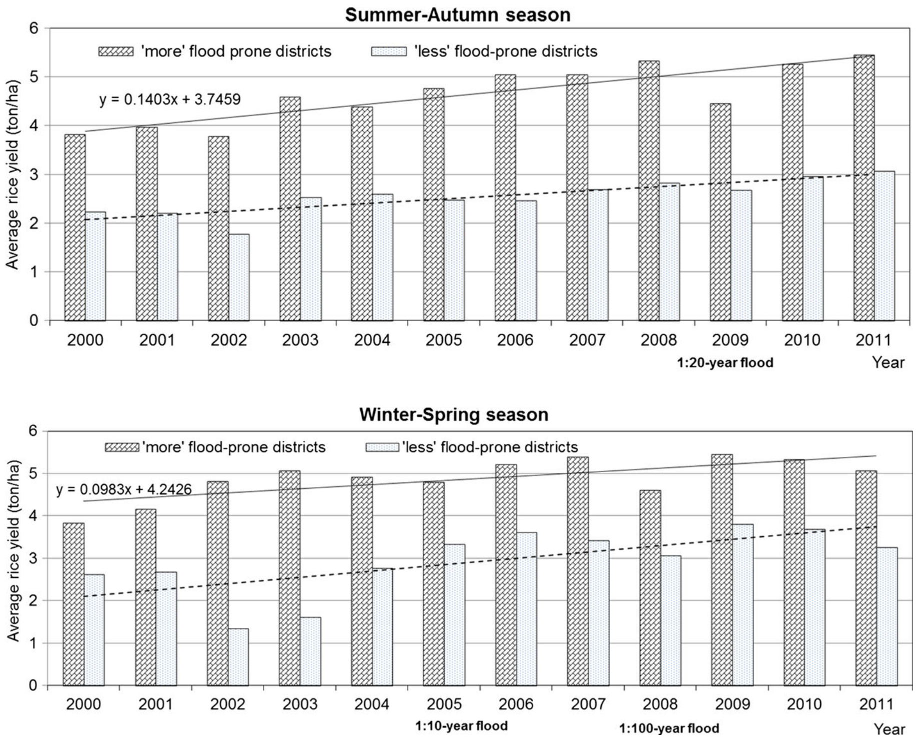


Fig. 2 Average annual rice yields/ha and trends in the 'more' flood-prone and 'less' flood-prone districts of Quang Nam province, 2000–2011

3 Method

A two-step method is used to determine the value of damage to agricultural production from 1:10-, 1:20- and 1:100-year flood events. First, using *ex-post* data to populate a damage function which incorporates susceptibility rates for the four main crop types, the direct tangible losses to agricultural production experienced under the three flood classes are estimated. The damage function and the susceptibility rates will be described in detail in Sect. 3.1. Second, benefit-cost ratios are calculated for each of the four main crop types under different scenarios for the three flood classes in order to compare the situation for farmers under the 'without' and the 'with' extreme flood scenarios. To do this, second step requires a simple one-year analysis since all costs (and benefits) are incurred (and realised) within each crop season, which is <1 year. In addition, there is no capital equipment used, with planting and harvesting done by hand. If a tractor is used, it is usually hired (pers. comm. Agricultural Extension Officer, DARD; pers. comm. District Agricultural Officer).

3.1 Damage function and susceptibility rates

Flood damage to agricultural production is dependent upon a number of variables, such as, type of crop, the crop's development stage, inundation depth and duration of inundation (Hansen 1987; Read Sturgess and Associates 2000; Messner et al. 2007; van Aalst et al.

2008; Peltonen-Sainio et al. 2010). Where available, damage predictions can be estimated based on 'real flood damage data' from previous flood events. Alternatively, predictions can be made by using depth-damage functions derived from past inundation characteristics and land use data (Messner et al., 2007). With regard to flood damage to agriculture, the damage function method estimates crop damage based on the relationship between inundation depth, duration of inundation and crop development stages (Hansen 1987; Messner et al. 2007; Penning-Rowsell et al. 2013).

Since the required level of historical flood damage data is not available for Quang Nam, this study has utilised the damage function method. However, some assumptions were necessary and these will be detailed later in this section. To calculate damage to the four main crop types, the generalised simple damage function reported in Messner et al. (2007) was used:

$$\mathrm{Damage}_{\mathrm{total}} = \sum_{i=1}^{n}\sum_{j=1}^{m} D_{i,j} = \sum_{i=1}^{n}\sum_{j=1}^{m}\left(\mathrm{value}_{i,j} \times \mathrm{susceptibility}_{i,j}\right)$$

where $i =$ category of crops at risk (n crops possible. In this study, there are four crop types: rice, corn, beans and 'other vegetables'); $j =$ inundation depth (m inundation levels possible. In this study, four inundation levels are used: <1, 1–2, 2–3 and >3 m); $D_{ij} =$ damage for crop i at inundation depth j; $\mathrm{value}_{ij} =$ yield per ha for crop i (based on previous year) $\times$ inundated area (at depth j) $\times$ crop sale price; $\mathrm{susceptibility}_{i,j} = f\left(E_{i,j}, F_k\right)$ measured as a percentage of crop yield (for rice and corn) and of replanted area (for beans and 'other vegetables'); $E_{ij} =$ characteristic of crop i under inundation level j of flood class k; $F_k =$ inundation characteristics of flood class k (In this study, there are three flood classes, $k =$ 1:10-, 1:20-, 1:100-year flood).

The susceptibility rate for each crop and each flood class (1:10-, 1:20-, 1:100-year floods) was estimated based historical data from the 2004, 2009 and 2007 floods, respectively. For rice and corn, the susceptibility rate reflects the loss of crop yield based on historical yields using the difference between the average crop yields in the year of extreme flood with that of the previous year. For the extreme flood year, average crop yields from the nine 'more' flood-prone districts were calculated and separated according to four inundation levels, namely <1, 1–2, 2–3 and >3 m. The crop losses for each district populating a particular inundation level were collected for each flood class. These yield losses were then averaged to obtain an estimate of the yield loss associated with that inundation level and expressed as a percentage of crop yields. These percentages are the susceptibility rates. For beans and 'other vegetables', the susceptibility rates reflect the percentage of the affected area that required replanting, again separated according to the four inundation levels. These two different approaches to susceptibility rates used here stem from the fact that $E_{i,j}$ (of which susceptibility is a function), in this study, represents the timing of the flood relative to the timing of the crop rotation (which for rice and corn impacts crop yield and for beans and 'other vegetables' results in some areas requiring replanting).

Based on the inundation mapping and data collected during in-country interviews, estimation was made of the area of inundation for each of the four main crops at each of the four inundation levels. These results are presented in Table 1 for each of the flood classes.

Table 1 shows that for a 1:20-year flood, 31 % (8,472 ha) of the total affected rice growing area is inundated by more than 3 m of water. For a 1:100-year flood, this affected area increases to close to half (46.5 % or 13,857 ha) of the flooded rice crops being inundated by more than 3 m of water.

Table 1 The predicted area (ha) of each crop affected at the four inundation levels for the three flood classes

Flood	Crop	Area affected by inundation level				Total area
		<1 m	1–2 m	2–3 m	>3 m	
1:10 year	Rice	6,620	7,586	4,929	5,361	24,496
	Corn	659	583	501	285	2,028
	Beans	307	376	257	104	1,044
	Vegetables	**483**	**846**	**550**	**348**	**2,227**
	Total	*8,069*	*9,391*	*6,237*	*6,098*	*29795*
1:20 year	Rice	5,367	6,808	6,628	8,472	27,275
	Corn	610	563	488	413	2,074
	Beans	420	371	378	268	1,437
	Vegetables	**881**	**618**	**645**	**723**	**2,867**
	Total	*7,279*	*8,359*	*8,138*	*9,876*	*33,653*
1:100 year	Rice	4,021	5,778	6,159	13,857	29,815
	Corn	359	603	603	531	2,095
	Beans	388	351	426	672	1,837
	Vegetables	**913**	**690**	**630**	**884**	**3,118**
	Total	*5,681*	*7,422*	*7,818*	*15,944*	*36,865*

These totals differ from those given in the ‘Data used’ section as they are figures for all agricultural production, whereas these are the areas affected for the four main crop types

The susceptibility rates of the crops to flooding, at each inundation depth, were determined based on the reduction in yields (for rice and corn) in the year of the extreme flood from the previous year, and the percentage of replanted area (for beans and ‘other vegetables’) for the 2004, 2009 and 2007 floods. The results, expressed as a percentage, are shown in Table 2.

For example, for a 1:100-year flood, 30 % of beans inundated by 1–2 m have to be replanted. As seen in Table 2, the highest rate of rice yield loss, measured against the previous year, was for an inundation of more than three metres in 2009 when the summer–autumn crop was inundated prior to harvest. It is worth noting that this is for a 1:20-year flood, evidence that it is the timing of the flood that is the critical factor.

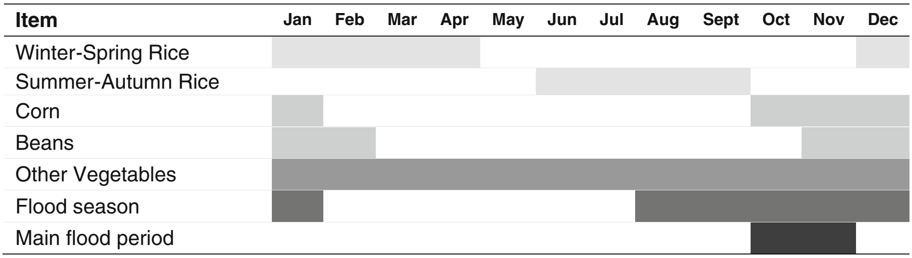
3.2 Assumptions made

The flood season in Quang Nam province is separated into early (August to September), main (October to November) and late flooding (December to January). The Provincial Committee for Flood and Storm Control note that, in conditions of no further rain immediately following a flood and with normal tides, the receding of the flood waters varies between one and 6 days, depending upon the level of inundation. An inundation of less than one metre is likely to have receded completely within one and a half days, causing no damage to either rice or corn; however, beans and vegetable crops may be affected. An inundation of one to two metres typically recedes within 2 days, 2–3 m in 3 days and more than 3 m takes between 3 and 6 days to recede. No information was available regarding duration of inundation and any associated damage impact; therefore, these durations of floodwater inundation are noted here, but are not used when calculating the damage

Table 2 Susceptibility rates in yield (rice and corn) and replanted area (beans and vegetables) as a resulting of flooding (%)

Inundation depth (m)	1:10-year (2004)				1:20-year (2009)				1:100-year (2007)			
	Rice	Corn	Beans	Vegetables	Rice	Corn	Beans	Vegetables	Rice	Corn	Beans	Vegetables
<1	0	0	10	10	0	0	0	20	0	0	10	20
1–2	0	1	20	20	7	0	0	30	7	3	30	40
2–3	3	3	50	40	15	0	0	50	16	6	50	60
>3	6	5	70	60	29	0	0	70	23	11	70	80

Table 3 The calendar for the main crop production and the flood seasons in Quang Nam province (2010)



function. The calendar for the flood seasons and the growing months for the four main crop types are presented in Table 3.

The past floods used in this study as representative of 1:10-, 1:20- and 1:100-year floods, occurred during 23–28 November 2004, 27 September to 3 October 2009 and 9–15 November 2007, respectively. As can be seen from Table 3, the 1:20-year flood (2009) occurred when the summer–autumn rice crop was ready for harvest. The 1:10-year flood (2004) and 1:100-year flood (2007) both occurred as the winter–spring rice crop was planted (although planting data from 2010, shown in Table 3 begins at the end of November). This meant that the damage from the 2004 and 2007 floods was reflected in crop losses for the years following, as the winter–spring rice crop was planted in November 2004 and 2007 but was harvested the following Aprils (2005 and 2008). This is clear to see in the Fig. 2 yields of the winter–spring season for the 'more' flood-prone districts. As will be seen later, the timing of these flood events is critical for their impact, regarding yield loss or replanting required.

3.3 Scenario and sensitivity analyses for the benefit-cost ratios

Since both the timing of the extreme flood in relation to crop growing cycles, and the severity of that flood (as reflected in this study by the susceptibility rates), are uncertain, scenario analyses were performed to estimate the crop yield losses for the three flood classes. The most significant impact on the level of loss to agriculture is the timing of the floods, particularly, the timing relative to the growing cycle of the rice crops, which are the staple crops in Quang Nam. According to Kotera and Nawata (2007), rice submerged at the end of the growth phase is subject to significant yield loss, as are rice plants inundated immediately following transplanting in the field. Three scenarios were developed by varying the timing of the flood event for each flood class and were identified as pessimistic, likely and optimistic scenarios. These scenarios were created in consultation with DARD (pers. comm. Flood and Storm Control Officer, DARD). The baseline for both the scenario and sensitivity analyses used was the 2010 crop yields and prices.

The likely scenario for each of the 1:10-, 1:20- and 1:100-year floods is that which occurred in 2004, 2009 and 2007, respectively. Therefore, the susceptibility rates calculated from these historical floods will be used on the 2010 crop yields for the likely scenarios.

For the pessimistic scenario, it was assumed that the extreme flood event would occur at the end of September, destroying the summer–autumn rice crop, just as it is ready for harvest. The crop calendar shows that 'other vegetables' is the other crop type affected at this time. The susceptibility rates for rice and 'other vegetables' for each of the inundation levels will be increased by 30 % to reflect the yield reduction (rice) and the replanting required ('other vegetables') for the worst-case scenario for each flood class.[4] Corn and beans are not affected in the pessimistic scenario as they are not in the ground at this time.

The assumption for the optimistic scenario is that flooding will occur during the main flood period, between early October and late November, after the summer–autumn rice has been harvested. In this scenario, the flood level both rises and recedes quickly as a result of low tides and no further rainfall. There is no rice crop planted at this time, and it is possible for corn, beans and 'other vegetables' to be replanted. It is assumed that the flood cost damage to the crops, which are young and highly vulnerable to inundation, is the cost of replanting. To reflect this, the susceptibility rates for each inundation level will be decreased by 10 % for the optimistic scenario (pers. comm. Flood and Storm Control Officer, DARD).

Sensitivity analyses are performed to estimate the impact on the benefit-cost ratio for each flood class as a result of changes in the product price, yield and labour costs. Variation in product prices are considered from −30 % (where the quality of the output is degraded by the flood) to +50 % (where food shortages during the flood season have pushed the prices up).[5] Variations in yield from −30 % (impact of disease) to +30 % (when taking advantage of technology[6]) were considered. Changes in labour costs (which are most often returned to the farmers themselves as income) were also considered since this is the most significant cost to the small scale farmer, where all work is done manually. A range of between −30 % (where farmers help each other (and any employees) out, for no payment, in difficult periods or periods of unemployment) and +50 % (the actual cost observed in 2012 during data collection in the field) of the labour cost, per person per day, was considered in this sensitivity analysis.

4 Results

4.1 Estimates of direct damage to agriculture

The per hectare yields, total costs and benefits (for 2010 yields and 2010 prices) for four the main crops in years 'without' extreme flood events are calculated and are presented in Table 4. Costs are separated into labour costs and non-labour costs.

Labour costs have been separately identified in Table 4 as these are a significant part of the total cost of agricultural production in Quang Nam. For rice growers, for example, labour costs are roughly half their total costs (pers. comm. Agricultural Extension Officers, DARD; pers. comm. District Agricultural Officers). It can be seen from Table 4 that the benefit-cost ratios (B/C) for rice production in 'normal' years is not particularly high, with an approximate 1.2 VND benefit for every 1 VND spent. The benefits per hectare for beans

[4] An increase of 30 % is used since in Table 2 an inundation depth of >3 m for the 2009 flood shows a susceptibility rate for rice of 29 %, and for 'other vegetables' of 70 %, so the more conservative option has been assumed for the worst-case.

[5] In rare situations (for example in remote areas) the price of rice can be double the usual price (pers comm. District Agricultural Officer).

[6] In 2010 the rice yield for the US was roughly 7.5 tonne/ha (FAO 2012), some 40 % higher than Vietnam's rice yield. Since the US is one of the most technologically advanced rice producing countries, we have assumed that a 30 % increase in yield would be possible. In addition, the average annual rice yields in the 'more' flood-prone districts increased 25 and 10 % in the 2000–2005 and 2005–2011 periods, respectively (see Fig. 2).

Table 4 Yields, economic benefits, costs and benefit-cost ratios for the major crops in the 'without' flood scenario (VND thousands, in 2010 prices)

Crops	Yield (ton/ha)	Benefits per ha (VND 1000's)	Costs per ha (VND 1000's)			B/C
			Total costs	Labour costs	Non-labour costs	
Winter–spring rice	5.33	25,628	21,296	10,500	10,796	1.20
Summer–autumn rice	5.26	25,310	21,296	10,500	10,796	1.19
Corn	4.94	23,430	16,797	5,880	10,917	1.39
Beans	1.16	24,360	14,323	4,680	9,643	1.70
Vegetables	13.00	43,680	19,770	10,800	8,970	2.21

Non-labour costs include seed/planting materials, fertilisers, agrochemical, transportation, tractor, bags and packaging, cooperative charge and irrigation maintenance

Table 5 The total damage (loss) to rice production (VND billion in 2010 prices) and the benefit-cost ratios for the three flood classes

Flood (1)	Depth level (m) (2)	Area (ha) (3)	Total cost (4)	Total benefit (5)	Total damage (6)	B/C (7)
1:10-year (2004)	< 1	6,620	141	157	0.00	1.11
	1–2	7,586	162	179	0.00	1.11
	2–3	4,929	105	113	3.45	1.08
	>3	5,361	114	119	7.81	1.04
	Total	*24,496*	*522*	*568*	*11.26*	*1.09*
1:20-year (2009)	<1	5,367	114	138	0.00	1.20
	1–2	6,808	145	162	12.77	1.12
	2–3	6,628	141	145	24.89	1.03
	>3	8,472	180	155	62.29	0.86
	Total	*27,275*	*581*	*599*	*99.94*	*1.03*
1:100-year (2007)	< 1	4,021	86	104	0.00	1.22
	1–2	5,778	123	139	10.56	1.13
	2–3	6,159	131	133	26.08	1.02
	>3	13,857	295	275	84.08	0.93
	Total	*29,815*	*635*	*651*	*120.73*	*1.03*

Total damage (rice) = susceptibility rate × previous year's yield/ha × area inundated (at that level, m) × price (2010)

The italics are used to highlight the total

and 'other vegetables' are considerably higher, at 1.7 times and 2.21 times their costs, respectively. This would explain why farmers are willing to risk planting beans and 'other vegetables' during the major flood period. However, these crops are only planted where the soil and land elevation are suitable (pers. comm. Agricultural Extension Officer, DARD).

Next, the costs and benefits (in 2010 prices) are calculated for the 'with' flood scenario for each of the three flood classes. The estimates of these, for rice only, are presented in Table 5.

As expected, the 1:100-year (2007) flood caused the greatest total damage (loss) to rice production in Quang Nam province at VND120.7 billion, since it inundated the greatest area and it impacted the larger yielding winter–spring rice crop. However, the B/C is equally low for the 1:20- and 1:100-year floods.[7] The reason for this is due to the timing of the 1:20-year flood (occurring in 2009) which came at a worse time, affecting the summer–autumn rice crop just prior to harvest so that the crop was seriously damaged. For individual rice producers, however, whose rice crop is inundated by more than three metres during a 1:20- or 1:100-year flood event, their costs outweigh their benefits (B/C < 1). Similar calculations were conducted for corn, beans and 'other vegetables' and these are presented, along with rice, in Table 6.

As expected, the 1:100-year (2007) flood caused the most damage to agriculture in the province at VND146.9 billion. The B/C is lowest for the 1:20-year flood since rice (the crop damaged most significantly by the 2009 flood) accounted for 87 % of the total damage

[7] For the province as a whole, benefits just outweigh costs for both these floods as well as for the 1:10-year flood.

Table 6 Total loss of income for the four main crop types over the three flood classes (VND billion)

Flood	Rice	Corn	Beans	Vegetables	Total	B/C
1:10 (2004)	11.3	0.7	2.4	7.1	21.5	1.17
1:20 (2009)	99.9	0.0	0.0	14.6	114.5	1.11
1:100 (2007)	120.7	2.6	6.5	17.0	146.9	1.12

Table 7 Estimation of the total crop loss value (using 2010 yields) due to extreme flood events under pessimistic, likely and optimistic scenarios (VND billion in 2010 prices)

Flood	Rice	Corn	Beans	Vegetables	Total	B/C
Pessimistic scenario						
1:10-year	15.9	0.0	0.0	55.3	71.2	1.05
1:20-year	128.3	0.0	0.0	73.2	201.5	0.86
1:100-year	155.4	0.0	0.0	81.1	236.4	0.85
Likely scenario						
1:10-year	12.2	0.9	2.4	7.1	22.7	1.26
1:20-year	100.0	0.0	0.0	14.6	114.6	1.11
1:100-year	118.0	2.9	6.5	17.0	144.5	1.10
Optimistic scenario						
1:10-year	0.0	5.0	1.6	4.7	11.2	1.52
1:20-year	0.0	5.8	2.8	10.0	18.5	1.41
1:100-year	0.0	7.1	5.1	13.6	25.8	1.32

to agricultural production caused by this event. Therefore, it is the timing of the floods that is most critical to the damage caused to agricultural production. In terms of the percentage loss in value for the four crop types, losses in the inundated areas of 12, 56 and 62 % are experienced for 1:10-, 1:20- and 1:100-year floods, respectively.

4.2 Scenario and sensitivity analyses

Scenario and sensitivity analyses were used to further estimate the total damage to agricultural production under the three flood classes (using 2010 yields and prices). The estimated losses for the four crop types under each of the pessimistic, likely and optimistic scenarios are presented in Table 7.

The likely scenario for the 1:10-, 1:20- and 1:100-year floods are losses of VND23.1 billion, VND114.6 billion and VND144.5 billion, respectively. However, it can be seen in Table 7 that under a pessimistic scenario, where the flood events occur in late September, destroying the summer–autumn rice crop and much of the 'other vegetables', the value of the losses could be as high as VND75 billion, VND201.5 billion and VND236.4, which would represent percentage losses in the inundated areas of 41, 98 and 100 % for 1:10-, 1:20- and 1:100-year floods, respectively.

Rice is the driver of agricultural production in the province; therefore, a relatively small amount of damage to the rice yield could change the B/C for agricultural production as a whole, from a situation of net benefit to one of net loss. The results of the likely and optimistic scenarios confirm that even under an extreme flood, beans and 'other vegetables' remain cost effective compared to other crops in Quang Nam's agriculture.

Table 8 B/C ratios for a 1:100-year flood as a result of simultaneous changes in product prices and either labour costs or, crop yields (for all crops)

1:100 year		Percentage change in all product prices								
		−30	−20	−10	0	10	20	30	40	50
Percentage change in labour costs	−30	1.01	1.10	1.20	1.29	1.39	1.48	1.58	1.67	1.77
	−20	*0.95*	1.04	1.13	1.22	1.31	1.40	1.49	1.58	1.67
	−10	*0.90*	*0.99*	1.08	1.16	1.25	1.33	1.42	1.50	1.59
	0	*0.86*	*0.94*	1.02	**1.10**	1.19	1.27	1.35	1.43	1.51
	10	*0.82*	*0.90*	*0.98*	1.05	1.13	1.21	1.29	1.36	1.44
	20	*0.78*	*0.86*	*0.93*	1.01	1.08	1.16	1.23	1.30	1.38
	30	*0.75*	*0.82*	*0.89*	*0.96*	1.04	1.11	1.18	1.25	1.32
	40	*0.72*	*0.79*	*0.86*	*0.93*	*0.99*	1.06	1.13	1.20	1.27
	50	*0.69*	*0.76*	*0.82*	*0.89*	*0.95*	1.02	1.09	1.15	1.22
Percentage change in crops yields	−30	*0.69*	*0.75*	*0.80*	*0.86*	*0.92*	*0.97*	1.03	1.09	1.15
	−20	*0.75*	*0.81*	*0.88*	*0.94*	1.01	1.07	1.14	1.20	1.27
	−10	*0.80*	*0.88*	*0.95*	1.02	1.10	1.17	1.24	1.32	1.39
	0	*0.86*	*0.94*	1.02	**1.10**	1.19	1.27	1.35	1.43	1.51
	10	*0.92*	1.01	1.10	1.19	1.28	1.37	1.45	1.54	1.63
	20	*0.97*	1.07	1.17	1.27	1.37	1.46	1.56	1.66	1.76
	30	1.03	1.14	1.24	1.35	1.45	1.56	1.67	1.77	1.88

The bold are used to highlight the B/C when nothing changes vertically and horizontally

The sensitivity analyses initially involved independently varying the product prices, yields and labour costs (for all four crop types simultaneously under the three flood classes). The results show that whilst a 20 % fall in the price of each of the four crops will still yield a B/C over one for a 1:10-year flood, for a 1:20- or 1:100-year flood, a 12 % and a 13 % (respectively) fall in price would result in the costs outweighing the benefits. A similar trend also occurs for the crop yields.[8] With regard to labour cost, for any year experiencing a 1:20- or 1:100-year floods, if there is an increase in labour cost of 24 and 23 %, respectively, the costs would outweigh the benefits. However, for a 1:10-year flood, labour costs could increase by more than 56 % before resulting in a B/C of less than one.

Finally, B/C ratios are calculated when there is simultaneously a change in all product prices as well as labour costs; and then, it is repeated for a change in all product prices as well as crop yields. The results for a 1:100-year flood are presented in Table 8.

The italicize area in Table 8 shows the simultaneous changes required to move from net benefits to net losses. For example, for a 1:100-year flood, a 10 % decrease in product prices accompanied by a 10 % increase in labour costs means that costs outweigh benefits. Similarly, if both yields and product prices simultaneously fall by 10 %, costs will outweigh benefits. These results are for the four main crop types as a whole, individual farmers could be affected to a greater (or lesser) degree depending on the level of inundation on their own land, under each flood scenario.

[8] A reduction in crop yields of more than 27, 12 and 13 % would result in a B/C $<$ 1.0 for a 1:10, 1:20 and 1:100-year flood, respectively.

5 Discussion

When comparing the results of this study (based on 2010 prices) with the actual reported losses to agricultural production in Quang Nam province for the corresponding years, the comparisons for two flood classes are favourable. In this study, the estimated loss from flood damage for a 1:10-year flood (that occurred in 2004, where the loss is realised in 2005) was VND22 billion as compared to the reported damage bill of VND21 billion from the Quang Nam People's Committee (2005) and the Central Committee for Flood and Storm Control's (CCFSC) disaster database (2012). The estimated loss of 1:100-year flood (occurring in 2007, where the loss realised in 2008) was VND146.9 billion, which represents a 62 % loss in value for the four main crops in the inundated area. However, under a pessimistic scenario, this estimate rose to VND236.4 billion (a 100 % loss in crop value), if flooding occurred at the end September, before the summer–autumn rice harvest. The total damage of the 2007 flood was reported at VND1500 billion, 8 % of which was damage to crops, that is approximately VND120 billion (Quang Nam People's Committee 2008). This is less than this study's actual estimates and the 'pessimistic' estimates using 2010 prices.

The total reported damage for the 2009 flood, by the Quang Nam People's Committee (2010) and recorded in the CCFSC disaster database (2012) was VND3,500 billion, of which, VND1,400 billion was agricultural damage. However, the Vietnamese Prime Minister (2012) stated that the 2009 natural disaster damage reports were deliberately excessive in order to claim higher relief payments from the central government in 2009. Therefore, direct comparison with estimates from this study cannot easily be made. To provide a more realistic estimate of agricultural production loss, the results of the pessimistic scenario in this study (with the estimation of damage at VND201.5 billion) could be used as a 'maximum' flood damage estimate for a 1:20-year flood. In the same report, the Prime Minister (2012) also revealed that there were no natural disaster damage assessment criteria in Vietnam, which highlights a gap in the knowledge of post-natural disaster recovery.

Whilst return on investment for rice is less than for other crops (with a B/C of around 1.2 in the 'without' flood scenario), rice remains the most important crop in Quang Nam province. This is because rice is the staple crop on which farmers are extremely reliant, and as such, does not experience the fluctuation in demand experienced by other crops. Almost 50 % (VND10.5 million) of the total cost per ha of rice production is labour cost, which, since they do the work themselves, is considered direct income. Further, the smaller but higher returns from 'other vegetables' explains why some farmers are willing to take the risk of crop loss using their land to grow vegetables during the main flood season.

The estimated cost of flood damage to agriculture used in this study is a function of the inundation depth, land-use type and timing of floods. However, no consideration was given to potential loss incurred indirectly, for example, through traffic interruption (getting produce to market), delayed crop planting and intangible costs.

With all three flood classes having occurred in central Vietnam in the last decade, attention is being given to flood prevention measures. Current proposals, such as upgrading dykes and improving drainage by removing excess sedimentation in the river basins, aim to reduce the susceptibility of agricultural production to loss, resulting from extreme flood events. The results of this study can give weight to the decisions made.

6 Conclusion

This study estimated the direct damage caused by 1:10-, 1:20- and 1:100-year floods to agricultural production in Quang Nam province, Vietnam. The estimates of the total direct losses (in 2010 prices) to the four main crops in the agricultural sector for a 1:10-, 1:20- and 1:100-year floods are approximately VND22 billion, VND115 billion and VND147 billion, respectively. These results can be used for *ex-ante* predictions as they have been verified by losses recorded by the local government in the corresponding years for both 1:10- and 1:100-year floods. Further, these direct losses represent a percentage loss in value (for the four main crop types) in the inundated area of 12, 56 and 62 % for 1:10-, 1:20- and 1:100-year floods, respectively. Furthermore, for many individual farmers, total crop loss will be experienced. In addition, if a 1:100-year flood occurs at the end of September when the summer–autumn rice crops are ready to harvest, the returns will be devastating.

This study utilises a method of analysis that can be replicated elsewhere. Using flood inundation maps and the likely timing of the flood event relative to crop rotation, the extent of devastation to specific crop types can be quantified and an economic assessment conducted. This study extends our knowledge of agricultural flood damage in Vietnam. However, gathering of additional flood duration data and greater detail on crop development stages would improve future studies. Furthermore, the release of additional water into the river systems from hydro-dams during extreme floods exacerbates the flooding to agricultural land. With increasing demand for renewable power, more hydro-power stations are being planned and developed; therefore, this needs to be monitored and included in future analyses to provide better information for mitigation decision-making. Future research is needed to estimate the indirect damage incurred by extreme floods, not only on the agricultural sector, but also other sectors and the economy as a whole.

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