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# Using GIS to map impacts upon agriculture from extreme floods in Vietnam

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A B S T R A C T

The frequency of extreme weather events has been increasing in Vietnam, with 1:10, 1:20 and 1:100 year floods all experienced in central Vietnam in the last decade. A geo-spatial model is used in a case study to assess the impacts of extreme flood events on agricultural production in the Quang Nam province of Vietnam. Eighty-six flood depth marks were interpolated by the inverse distance weighting (IDW) algorithm to generate the water surface, and a digital elevation model (DEM) was employed to create the flood inundation map. Another overlay algorithm used the flood inundation map and land use map to estimate the potential impact of floods on agricultural land. The study demonstrates the value of geographic information system (GIS) modeling, particularly when meteorological and hydrological data are limited, and remote sensing images taken during flood events are unavailable. The maps that were generated showed that the 1:10, 1:20 and 1:100 year floods led to 27%, 31% and 33%, respectively, of arable land being inundated. Wet rice was the crop most affected, with the flooded area accounting for more than 40% of the province's supply under each flood scenario. Whilst the exact loss of agricultural production will depend upon a number of factors including crop variety, stage of plant development, length of flooding period and level of inundation, this study provides valuable information for flood disaster planning, mitigation and recovery activities in Vietnam.


## Introduction

Floods, tropical cyclones, droughts and other natural disasters are a part of everyday life in Asia, and no more so than in Vietnam, the world's most disaster-prone region (IFRC, 2010). Global disasters are being reported with increasing frequency (CRED, 2011) as can be seen in Fig. 1, which shows some 3646 floods alone reported between 1970 and 2011. Of these floods, only eight percent occurred during the 1970s, however, 15%, 27% and 49%, respectively, occurred during the 1980s, 1990s and 2000s.

Vietnam is highly susceptible to natural disasters, especially tropical cyclones and floods and these have taken their toll on the country and its people. According to a World Bank report (2010), natural disasters in Vietnam have taken more than 13,000 lives and cost an average one percent of Gross Domestic Product (GDP) annually for the last 20 years. The study also estimated that 59% of Vietnam's total land area and 71% of its population are susceptible to the impacts of tropical cyclones and floods. Furthermore, because of its geographical location and characteristics, Vietnam is often cited as one of the most vulnerable countries in the world, to the effects of climate change (Dasgupta, Laplante, Meisner, Wheeler, & Yan, 2009; IPCC, 2007a; World Bank, 2010). Agricultural land is situated in low lying regions where the soil is most fertile and in terms of rice-growing, where it can take advantage of normal flooding, bringing nutrients that increase soil fertility. This, however, leaves prime agricultural land susceptible to extreme flooding, leaving crops vulnerable to destruction.

Extreme floods are unavoidable, but the lessons learned from past experience can be used to reduce the damage they inflict and address "the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between (natural, human-induced or man-made) hazards and vulnerable conditions" (Westen, 2010). The success of flood mitigation measures depend upon detailed knowledge of the expected frequency, character and magnitude of floods in specific areas.

Various measures, both structural and non-structural have been undertaken to help strengthen Vietnam's resilience to natural disasters. Thousands of kilometers of sea and river embankments and hundreds of reservoirs have been constructed or upgraded.

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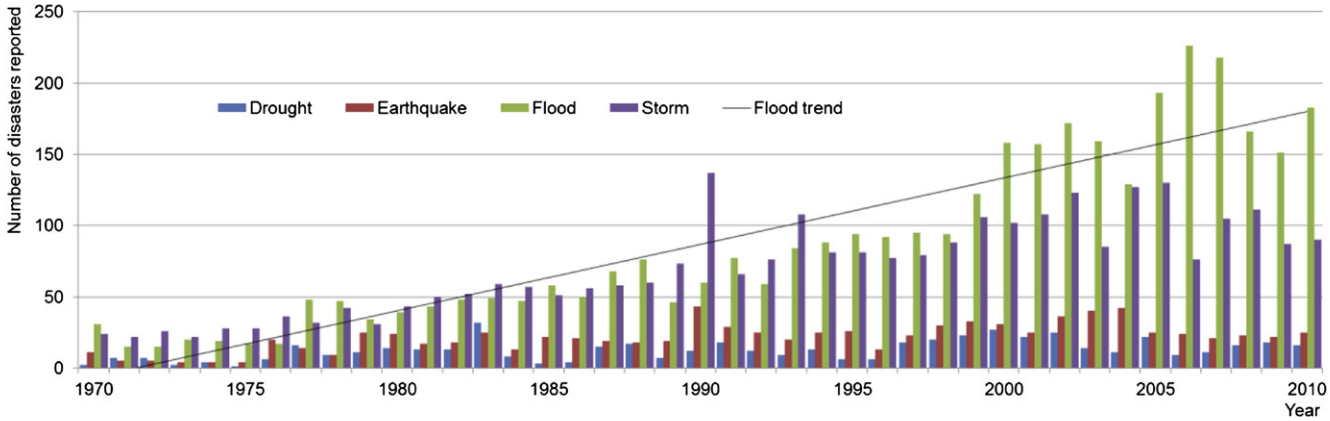


**Fig. 1.** Global natural disasters. Source (of data): Centre for Research on the Epidemiology of Disasters (CRED) (2011).

Examples of non-structural measures include media and public education and also mitigation policy. One such policy is the Vietnam Government's National Strategy for Natural Disaster Prevention, Response and Mitigation to 2020 (Prime Minister of Vietnam, 2007), which emphasized community-based endeavors through four 'on the spot' initiatives: command on the spot; man-power on the spot; materials on the spot; and logistics on the spot. In this way the responsibility for both prevention and response to natural disasters are decentralized to the local community. A number of programmes and projects have been implemented, funded by central and local government, as well as international donors, all with the aim of minimizing the negative impacts of extreme weather events. Despite these measures, the country still remains extremely vulnerable to damage from extreme weather events, particularly floods.

Many disciplines, including environmental planning and management, hydraulic engineering, agriculture and earth science contribute to flood simulation and assessment research and prediction studies (Abdalla, 2009a, 2009b). Flood risk assessment, that provides reliable information for pre-, during and post-flood management, is the focus of current research and represents a shift from classical flood protection with an engineering focus, toward more integrated flood risk management concepts (Büchele et al., 2006). Among the assessment tools available is the flood risk map that shows the at-risk locations and determines the elements at risk, for example, the location of the population, building and civil engineering works and economic activities (Thieken, Merz, Kreibich, & Apel, 2006). A quick determination of the extended flood area during an extreme flood event provides significant information on land use and land cover types under water. This information can be used in developing a comprehensive relief effort (Wang, Colby, & Mulcahy, 2002).

Integrating hydrological, meteorological and geomorphological mapping techniques can produce both qualitative and quantitative risk maps (De Moel, Van Alphen, & Aerts, 2009). Results of a number studies show positive results from informative and efficient flood risk management. For example, by comparing agricultural yields in 'more' and 'less' flood-prone districts in Bangladesh, Banerjee (2010) found that areas under cultivation are more common and hence agricultural production is higher in the 'more' flood-prone districts and confirmed that, while floods can act as an open-access resource in supplying irrigation input to agriculture, severe inundation destroys crops. Wang, Zhong, Cui, and Lv (2010) used a flood inundation analysis method based on DEM to predict villages threatened by extreme flood events in China. Their results demonstrated that the inundation analysis method can reasonably accurately predict flood inundation and guide rescue work and villagers' resettlement. Meanwhile, Lee and Lee (2003) analyzed synthetic aperture radar (SAR) images acquired before, during, and after flood inundation in central Korea and found that the actual damage to a standing rice crop depends on the duration of inundation and the subsequent recovery efforts. However, the satellite's optical sensors show serious limitations in during and post-flood data acquisition, due to the bad weather conditions and cloud coverage always associated with flood events (Gianinetto, Villa, & Lechi, 2006). Meanwhile, the availability of accurate data and efficient modeling tools are bounding factors for effective flood risk assessment (Abdalla & Niall, 2009).

The traditional method of flood mapping uses hydraulic modeling and employs historical discharge data to model flood frequencies and design flood flows (Hosking & Wallis, 1997; Wang et al., 2010). However, the fact that historical discharge data are not always available is a significant limitation of this approach. As an alternative, Anselmo, Galeati, Palmieri, Rossi, and Todini (1996) used an integrated hydrological and hydraulic modeling approach, that combined hydro-meteorological with cartographic data to evaluate extreme rainfall events and estimate probable maximum precipitation. They then used recent flood event data to calibrate a rainfall-runoff model for the upstream area, making it possible to generate flood inundation maps from simulation of the critical meteorological events. Later, Zheng and Wang (2006) used a 1-D DEM-inundation model to calculate an artificial water height surface using surface water heights of streams (available at gauging stations) and compared the artificial surface with the DEM to determine flooded and non-flooded areas. The artificial water height surface was created by interpolating surface water heights between stations. In the delineation of the extent of the flood, they superimposed the calculated surface water height layer over the DEM layer. If the location's elevation was greater than the regular water level and below or equal to flood water levels, then the location was deemed a flooded area. The validity and accuracy of the model was then assessed by Zheng and Wang who compared the modeled results with those derived from the Hydrologic Engineering Centers – River Analysis System (HEC-RAS) model, which was a widely used standard and complex 1-D hydraulic model. They then verified their model against the 1999 flood event on the lower Tar River, North Carolina and concluded that, with its simple inundation and ease of parameterization, the 1-D DEM-inundation model is a potential alternative to the complex hydraulic model.

This study draws on the approach taken by Zheng and Wang (2006) to present a geospatial assessment of flood impacts on agricultural land in Quang Nam province, Vietnam to demonstrate how the results can inform economic assessments of natural disaster impacts and associated policy responses to mitigate extreme

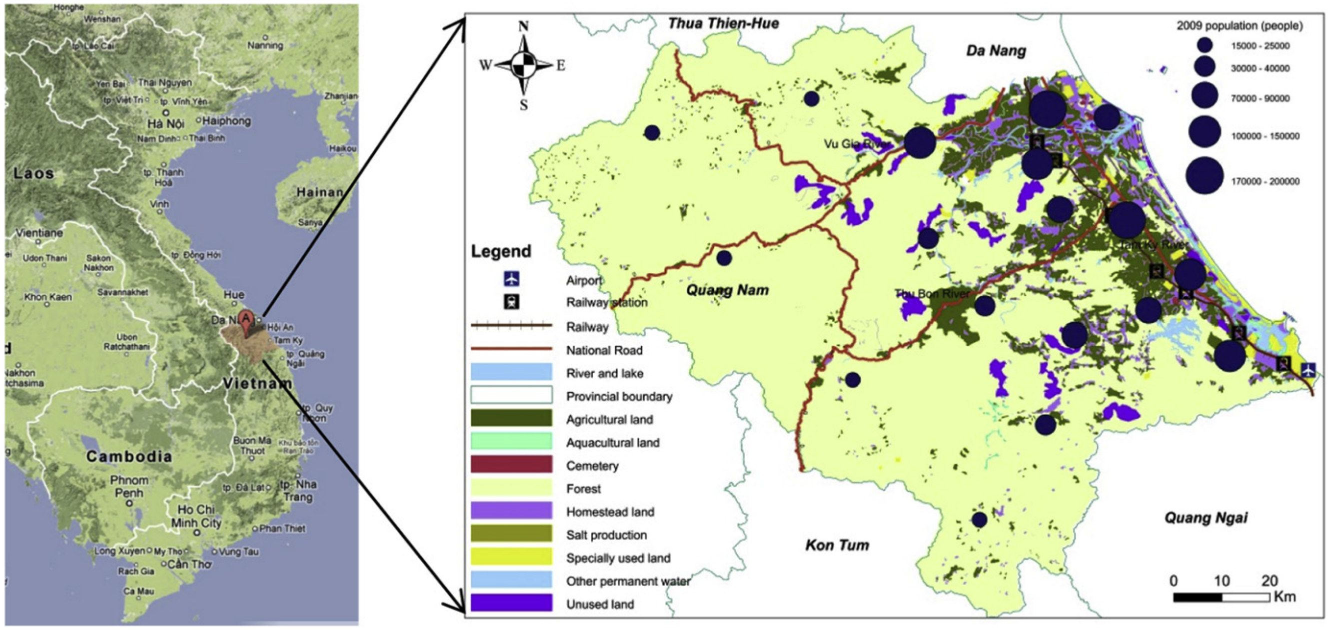


**Fig. 2.** The location and land use map of the Quang Nam province in central of Vietnam.

weather events. A case study approach has been adopted and Quang Nam province has been chosen as it is representative of the country as a whole, both in terms of topography and its economy. The method of this study could reasonably be applied to a national study.

## Study area

Quang Nam province is located in the central region (Fig. 2) of Vietnam with a total area of 10,408 km$^2$ and is home to 1.4 million people (Quang Nam Statistics Office, 2011).

The agricultural sector is extremely important to the province with nearly all agriculture production being consumed locally (Quang Nam Statistics Office, 2011). Fig. 2 shows that most of the province's agricultural land is located in the Vu Gia-Thu Bon River's alluvium plain. About 72% of the province is mountainous or hilly and is mostly forested. Quang Nam's climate is tropical with two distinct seasons: dry and rainy. The rainy season, from September to December, has an average rainfall of 2500 mm and an average of 85% humidity. The dry season is from January to August with an average rainfall of 50–70 mm. Quang Nam has higher rainfall than other regions, but precipitation is unevenly distributed, with approximately 2000 mm annually in the coastal area and some 3000–4000 mm in the upland area (Ho & Umitsu, 2011). This combination of topography and rainfall means the province is prone to flooding during the rainy season. Water-related disasters, and floods in particular, cause widespread devastation in Quang Nam province. The annual cost attributed to natural disasters damage averages around 6.26% of the province's GDP, but can be as high as 20% of the provincial GDP in years of extreme floods (Institute of Geography, 2010).

According to the Quang Nam Statistics Office (2011), the province's economy has been growing rapidly in recent years, with the annual GDP growth rate varying between 12% and 15% since 2005. The economy of the province has become more diversified during the last 10 years, with industry becoming the main driving force of the local economy. In 2000, industry contributed 25.3% of the province's GDP and by 2010 its contribution had risen to 40.5% of GDP. Conversely, the combined contribution of agriculture, forestry and fisheries to the GDP of the province decreased from 41.5% in 2000 to 21.4% in 2010. However, 60% of the work force (500,000 people) is still employed in the agricultural sector where 75% of agricultural land is planted in rice. Productivity of this commodity has increased from just over 300,000 tonnes in 2000 to 412,000 tonnes in 2010. Despite the declining contribution of agriculture as a percentage of the province's GDP, the value of agricultural output has increased significantly since 2000 and the sector remains important to the economy of Quang Nam.

Several studies utilized different methods to undertake mapping of the flood extended area of the Vu Gia-Thu Bon river system. The Institute of Geography (2010), using a hydraulic model, MIKE11 GIS found that about 64,000, 65,000 and 73,000 ha will be inundated by 1:10, 1:20 and 1:100-year floods, respectively. Meanwhile, Ho and Umitsu (2011) developed a method based on a geomorphological approach utilizing the Shuttle Topographic Mission (SRTM) and the LANDSAT Enhanced Thematic Mapper Plus (ETM +). Their results showed that 43.34% of this plain was associated with a high or very high flood hazard likelihood (Ho & Umitsu, 2011). Neither of these studies focused their investigation specifically on the level of flood inundation on agricultural land.

## Data used

DEM data with geographic latitude and longitude coordinates on a one arc-second (approximately 30 m) grid of the Quang Nam province (Fig. 3) was extracted from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) (ASTER GDEM[1]) version 2 (V.2). ASTER GDEM V.2 production involved automated processing of the entire 1.5-million-scene ASTER archive, including stereo-correlation to produce 1,264,118 individual scene-based ASTER DEMs, cloud

[1] The ASTER GDEM is a product of cooperation between The Ministry of Economy, Trade and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). It's free to users via electronic download from the Earth Remote Sensing Data Analysis Centre (ERSDAC) of Japan and NASA's Land Processes Distributed Active Archive Center (LP DAAC).

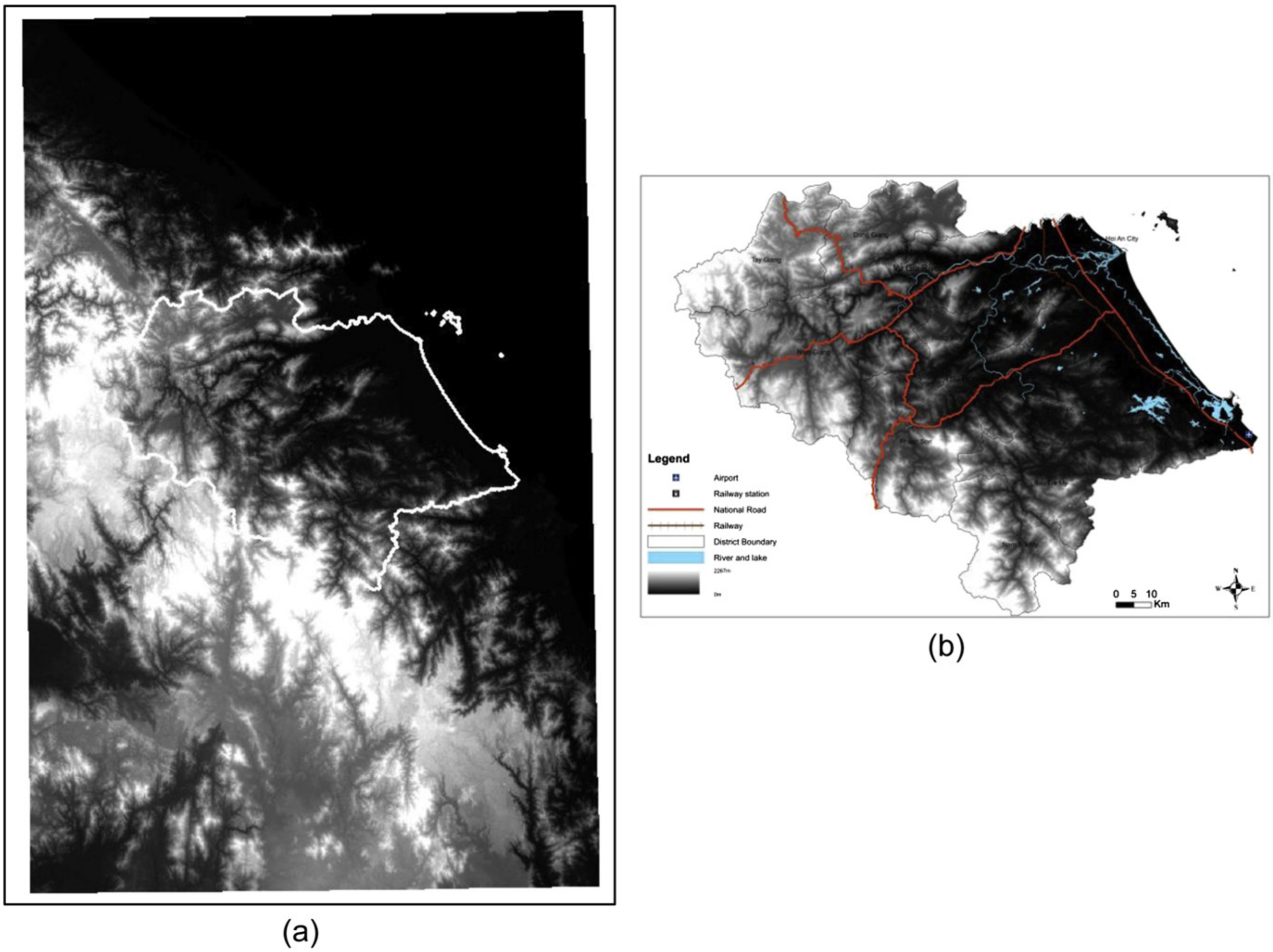


**Fig. 3.** Six adjacent DEM tiles (a) from ASTER GDEM V2 were clipped to create the 30 m resolution DEM of Quang Nam province (b).

masking to remove cloudy pixels, stacking all cloud-screened DEMs, removing residual bad values and outliers, averaging selected data to create final pixel values, and then correcting residual anomalies before partitioning the data into 1°-by-1° tiles (METI & NASA, 2011). Compared with ASTER GDEM version 1 (V.1), the characteristics of ASTER GDEM V.2 have improved significantly. The elevation offset reduces to −0.7 m from −6 m (V.1), the voids decrease and the artifacts mostly disappear (Tachikawa, Hato, Kaku, & Iwasaki, 2011). Despite the advanced technology applied to generate the GDEM, it generally maps the tops of dense land covers rather than just bare earth and it may contain vertical errors. Consequently, underestimation of areas affected by flooding in built-up and forested areas is possible using these data. To construct the Quang Nam DEM, six adjacent tiles were downloaded from LP DAAC and imported to ArcMap and merged into a single DEM. The DEM was clipped to the provincial boundary to produce the DEM of Quang Nam as shown in Fig. 3(b).

There are no flood protection standards for Vietnam's Central Region (Institute of Water Resources Planning, 2011), however, the development of a national strategic water resources management plan was approved by the Prime Minister (2009) and this included flood management planning and the protection of agricultural land from 1:10 to 1:20-year floods. In its 2011 report, the Water Resources Planning Institute suggested using a 1:10-year flood standard for agricultural flood protection activities. In addition, a 1:100-year flood standard has become universally adopted to describe a reasonable flood protection level. This study used three flood scenarios, 1:10, 1:20 and 1:100-year floods to assess the impacts of floods on agriculture for Quang Nam province. The Institute of Geography (2010) and the Water Resources Planning Institute (2011) analyzed the highest annual water levels recorded from 1976 to 2009 at Cau Lau station, which is located in the centre of the floodplain, to simulate flood frequency for the Vu Gia-Thu Bon river system. Their results (Table 1) concluded that the 1:10, 1:20 and 1:100-year floods are compatible with the floods that occurred in 2004, 2009 and 2007, respectively.

The flood depth marks from 1996 to 2010 were collected immediately after floods, during flood impact assessments by local and central government agencies. The government established a series of flood level markers in the Vu Gia-Thu Bon river system. The flood level markers are normally poles or gauges on the sides of buildings. Eighty-six flood depth markers (Fig. 4), which were

**Table 1**
The flood frequencies calculated at the Cau Lau gauging station.

| Year | $H_{max}$ (cm) | Return period (year) | Flooded area (km$^2$) |
|---|---|---|---|
| 2004 | 459 | 10 | 64,150 |
| 2009 | 529 | 20 | 65,365 |
| 2007 | 539 | 100 | 73,460 |

Sources: The Institute of Geography (2010) and the Water Resources Planning Institute (2011).

spaced along the rivers and floodplain area, were analyzed for this study and were provided by the Disaster Management Center of the Ministry of Agriculture and Rural Development and Quang Nam's Department of Water Resource and Flood and Storm Control. Each flood depth marker has a number, code, location (longitude, latitude, place-names), time recorded, flood depth and sources of flood.

The land use map of Quang Nam province (Fig. 2) was provided by Quang Nam's Department of Environment and Natural Resources to the Vietnam Denmark Collaborative Project P1-08 Vie: Impacts of Climate Change in Mid-central Vietnam. The land use map was created by interpreting 2005 Landsat satellite data at a scale of 1:100,000 which is available for public use at the "Assessing effects of and responses to climate change on environment and socio-economic development in mid-Central Vietnam" project (Vietnam Academy of Science and Technology, 2011). The risk of using this map is two-fold, one being that it is potentially out of date (2005), and the second is lack of detail for annual crops. Despite this, there is currently no other readily available data that portrays these land cover classes at this resolution.

In addition, base maps showing administration units, transportation systems and rivers were extracted from a topographic map of the five central provinces (Department of Survey and Mapping Vietnam, Ministry of Environmental and Natural Resources). This is data was also available from the previously mentioned project of the Vietnam Academy of Science and Technology (2011). The inundation maps created from the flood depth markers and DEM were overlaid on the land use map to assess the impact of 1:10, 1:20 and 1:100-year floods on agricultural land in the Quang Nam province. All spatial analyses were implemented in ArcGIS 10 (Environmental Systems Research Institute Inc., Redlands, CA, USA) and the results are presented in section Five.

Other data used in this study were secondary sources from reports, surveys and projects from Quang Nam province and Central Government agencies and research institutes. The data include both geospatial data and socio-economic data. Since this study was not concerned with change detection, it was assumed that the land use and topography have remained unchanged since the data was gathered.

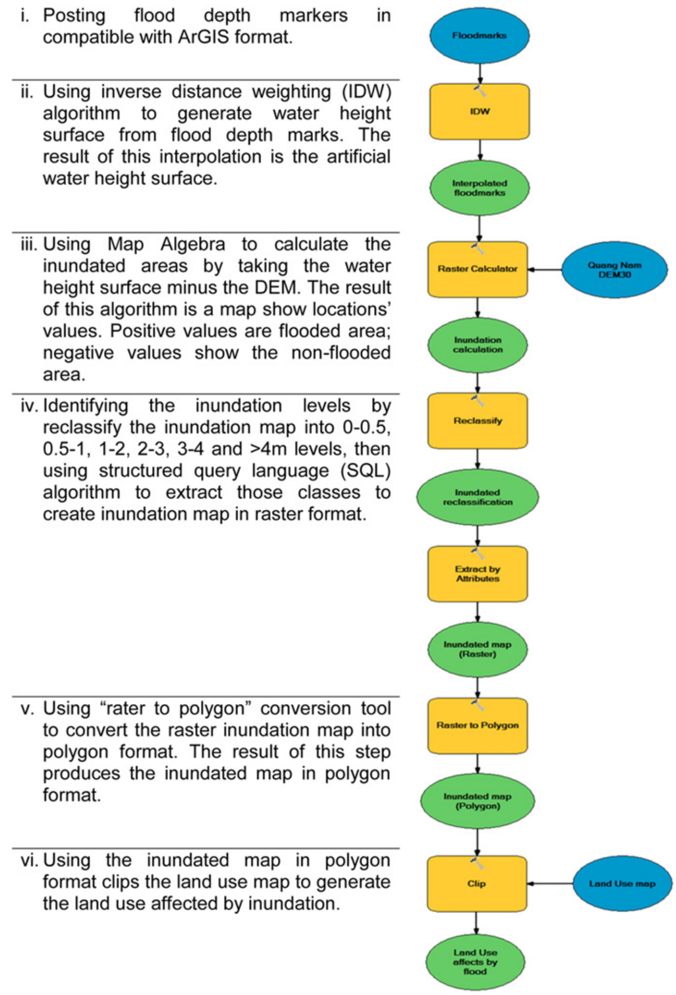


**Fig. 5.** The ArcGIS model created to automate processes for the output of land use maps affect by floods.

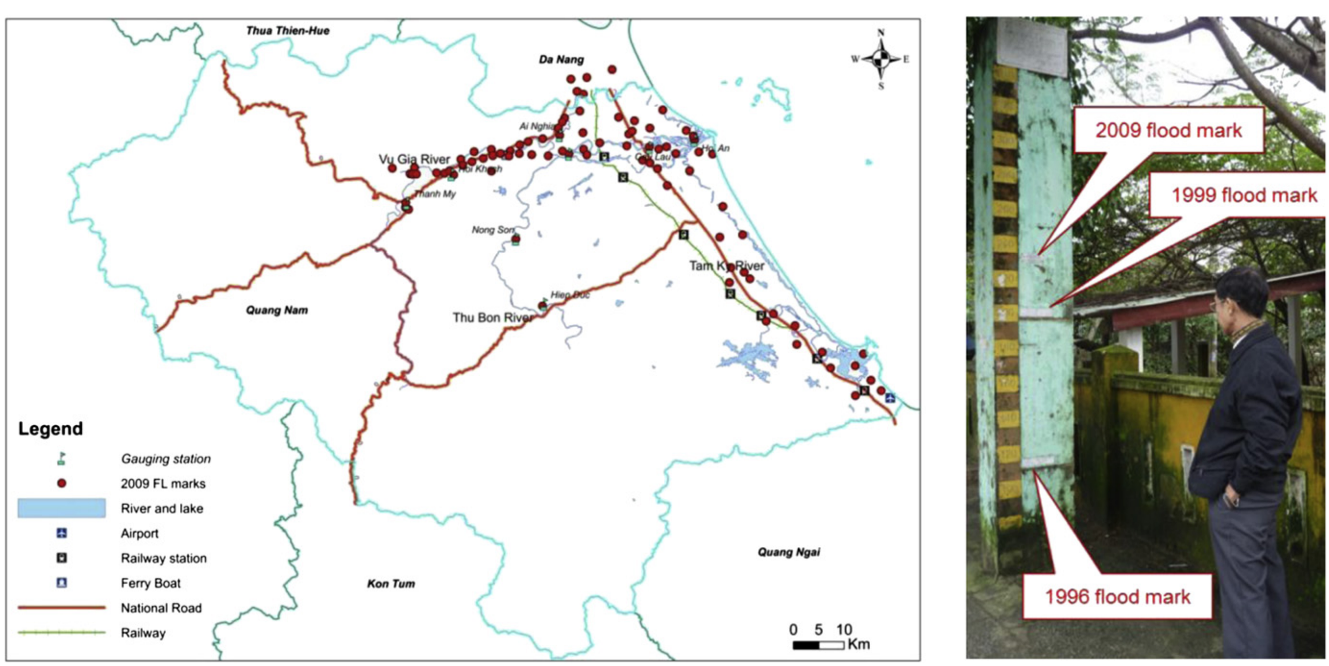


**Fig. 4.** The location of the measured flood depth markers (left) and a typical flood depth marker (right) in the Vu Gia-Thu Bon river system.

## Method

In this study we used the GIS technology to map the extent of flooding and measure the impact on agricultural land. The process is outlined in Fig. 5 showing how the GIS data are constructed from the base data and the spatial analysis method that is applied to evaluate the degree of impact in the case study area.

The flood depth markers were posted during site visits immediately post flood and then interpolated to model the flood surface area. A two-step process was used: first, ArcCatalog is used to convert flood depth marks from the longitude and latitude format to feature class, which is compatible with ArcGIS format. The flood depth marks were then interpolated by the inverse distance weighting (IDW) algorithm to generate the water height surface. Secondly, inundated areas are identified by taking the water height surface minus the DEM which is considered a platform to evaluate the level of inundation. The positive values from this operation were used to create a map of the inundated areas.

The inundated agricultural land was identified by overlaying the flood extension layer over the agricultural land use layer provided by Quang Nam's Department of Environment and Natural Resources. It should be noted that the study excluded flash floods that may have occurred in elevated and isolated areas.

## Results

This study assessed the impact of 1:10, 1:20 and 1:100-year floods on agricultural land use in the Quang Nam province. Whilst results of agricultural impacts are presented for each of three flood scenarios, the inundation maps for the 1:100-year flood scenario only, are presented in this paper. The map of the predicted inundation for a 1:100-year flood event in the Quang Nam province is presented in Fig. 6.

From this map it can be seen that inundation occurs in the low lying areas of the two main river systems, Vu Gia-Thu Bon and Tam Ky River systems and affects nine districts, namely, Dai Loc, Dien Ban, Duy Xuyen, Hoi An, Thang Binh, Phu Ninh, Que Son, Nui Thanh and Tam Ky. In order to evaluate the impact of flooding on agricultural land, the submerged area was classified into six depth ranges (0–0.5 m, 0.5–1 m, 1–2 m, 2–3 m, 3–4 m and greater than 4 m), which are identified in Fig. 6.

The model predicts the areas of inundation for the 1:10, 1:20 and 1; 100-year flood scenarios and these are presented in Fig. 7. The total inundation area includes the cumulative area of all depths including those above 4 m. Whilst it may appear from Fig. 7 that the 1:100-year flood has a lesser area of inundation than the 1:10 and 1:20-year floods for depths up to 4 m, this is simply a reflection of the topography of area. Once the total area of inundation is accounted for, the 1:100 year flood clearly covers the greatest area.

It can be seen from Fig. 7 that the model predicts for 1:100-year flood scenarios that up to a depth of 1 m 11,000 ha will be flooded. A further 13,600 ha will be flooded at a depth between one and 2 m making the total area flooded up to 2 m, 24,600 ha. Quang Nam province covers an area of 1.04 million hectares. The model predicts that a 1:10-year flood event would submerge 58,905 ha, which represents 5.7% of the province. The total affected area increases to 6.5% (67,267 ha) and 7.1% (73.835 ha) of the total area of the province for 1:20 and 1:100-year flood events, respectively. The Dien Ban district would be worst affected with a predicted 81% of its total area submerged by a 1:100-year flood. Tidal affects would exacerbate the drainage process and, in the long term, a predicted

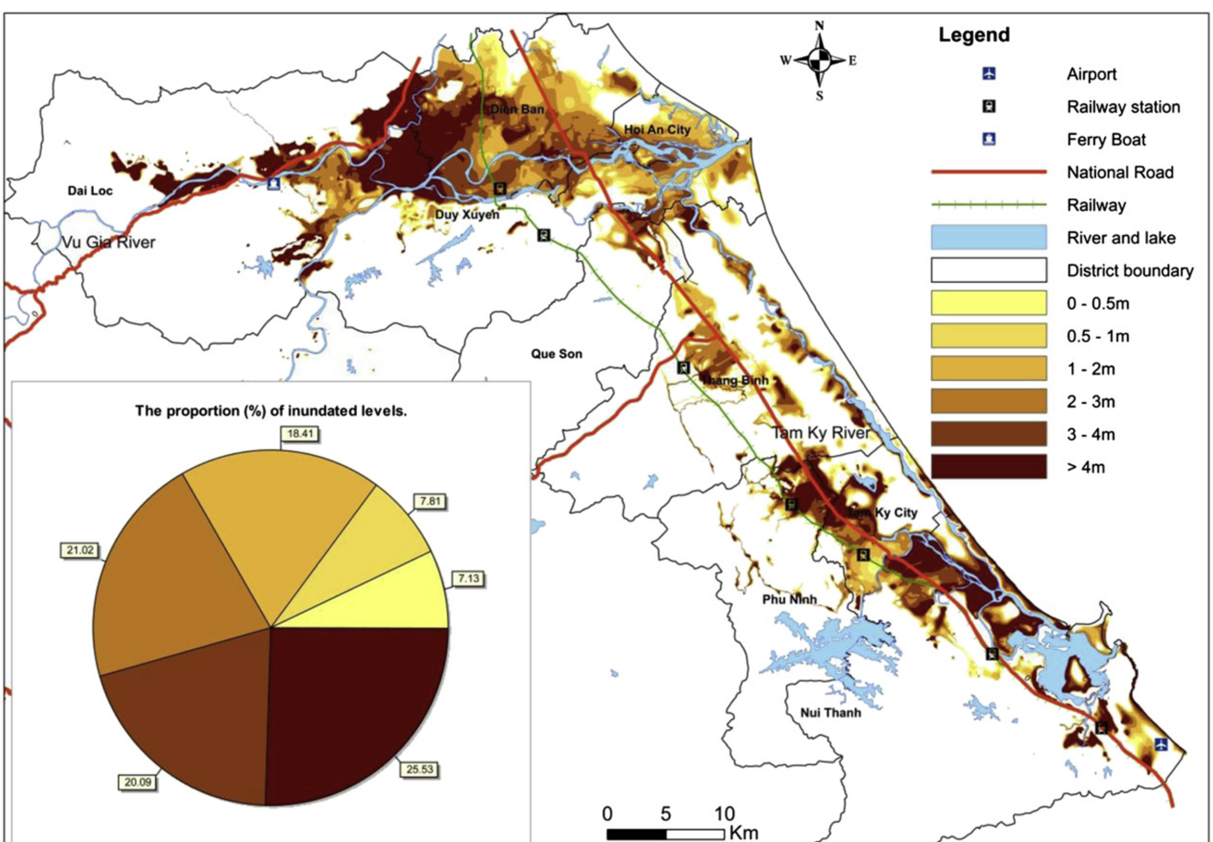


Fig. 6. Predicted inundation of Quang Nam province resulting from a 1:100-year flood event.

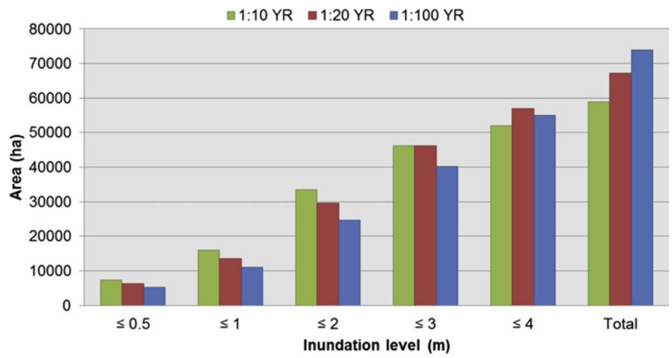


**Fig. 7.** The predicted cumulative area of inundation in Quang Nam province resulting from the three flood scenarios.

sea level rise of up to 30 cm by 2050 (Ministry of Natural Resources and Environment, 2009) and 59 cm by the end of this century would add to the impact of the disaster (IPCC, 2007b).

Among the inundated land uses, the model estimates that agricultural land would be the land use type most impacted by each flood scenario. The impact of a 1:100-year flood event on different land uses is shown in Fig. 8.

Overall, each of the flood scenarios would lead to just more than 50% of the inundated area being agricultural land. The second largest affected land use type is the homestead land and built-up area (30.12% for 1:100 year flood) and approximately 14% (for 1:100 year flood) of the inundated area comes under other land uses, including industrial and commercial land.

Typically, a district has more than 80% of its agricultural land in rice fields, with grasslands for animal grazing and perennial fruit production contributing only a small proportion of agricultural land. An estimation of agricultural land in Quang Nam that would be inundated under the three flooding scenarios is presented in Table 2.

The model calculates the larger affected area for the more severe flooding scenario. The predicted flooded agricultural areas for the 1:10, 1:20 and 1:100-year flood event scenarios are estimated to be 29,917, 33,846 and 37,043 ha, respectively, which accounts for 27%, 30.5% and 33.4%, respectively, of the total agricultural area in Quang Nam. Wet rice is the crop most affected. The agricultural land submerged by more than 3 m increases significantly as flooding intensity rises, from 20% (1:10-year flood) to 47% (1:100-year flood). While rice crops are vulnerable to long periods of inundation, they are better able to recover from this than annual crops such as maize, sweet potatoes, sesame, beans and other vegetables which are more sensitive to the effects of the inundation. For example, the maize yield would be reduced by 18%, 22%, and 32% if it were inundated for longer than 24, 48 or 72 h, respectively (Pioneer, 2010). It is also noted that the deeper inundated areas would probably take a longer time to dry out, thereby exacerbating the impact of the floods.

## Discussion

The geo-spatial modeling technique applied to generate the inundation maps in this study (see Fig. 6) produced similar results to maps created by the Institute of Geography (2010) using a hydraulic model (Fig. 9(a)). The spatial allocation of water depth from this study (as shown in Fig. 6) differed slightly from that of the Institute of

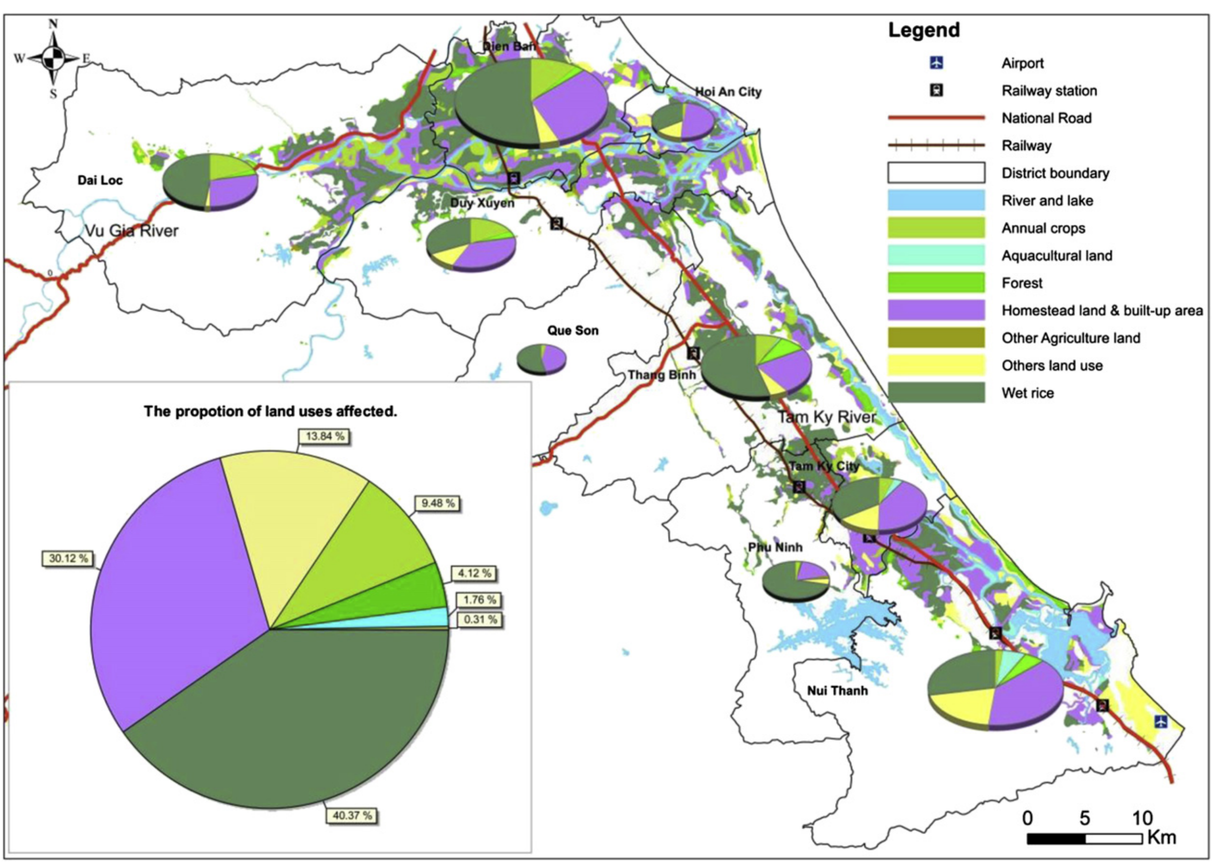


**Fig. 8.** Different land uses in Quang Nam province's districts affected by the 1:100-year flood.

**Table 2**
Estimated areas of agricultural land in Quang Nam province affected by flood scenarios.

| Flood scenario | Total area (ha) | Flooded area (ha) | | | Flooded area (%) | | | % of total provincial agricultural land | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1:10 | 1:20 | 1:100 | 1:10 | 1:20 | 1:100 | 1:10 | 1:20 | 1:100 |
| Annual crops[a] | 30,803 | 5263 | 6367 | 6999 | 9 | 9 | 9 | 17 | 21 | 23 |
| Wet rice | 56,445 | 24,496 | 27,275 | 29,815 | 42 | 41 | 40 | 43 | 48 | 53 |
| Other agriculture | 23,710 | 158 | 204 | 229 | 0 | 0 | 0 | 1 | 1 | 1 |
| Sub total | 110,958 | 29,917 | 33,846 | 37,043 | 50.8 | 50.3 | 50.2 | 27 | 30.5 | 33.4 |
| Total flooded area | | 58,905 | 67,267 | 73,835 | | | | | | |

[a] Annual crops are predominately by corn, beans, peanut, cassava, sweet potatoes and other vegetables.

Geography (2010) (see Fig. 9(a)) whose DEM was constructed from a 1:25,000 scale contour map. However, the total inundation area corresponds well in both studies as shown in Fig. 9(b).

The inundation map for this study also compares well with Fig. 11, the flood hazard map, of Ho & Umitsu (2011), but seems to conflict in some part with Fig. 12 (The MODIS rapid response flood inundation maps provided by Dartmouth Flood Observatory (DFO)), in the Ho and Umitsu (2011) study. The 2009 flood in Vu Gia-Thu Bon started on 27th Sep and ended on 3rd Oct; the flood levels fluctuated day by day. Meanwhile the 2009 flood inundation map provided by the Dartmouth Flood Observatory (DFO) to Ho and Umitsu was derived from MODIS imagery, however, it is unclear at which stage or the exact date the flood inundation map refers to; it may have been before or after the flood peak which was used in this study. This outcome bears testimony to the usefulness of the flood mapping method used here, when meteorological and hydrological data are limited and where remote sensing images are unavailable to support decisions made during and immediately following extreme flood events. In emergency situations, the combination of interpolated flood depth markers and the DEM taken in short periods can be used to predict flood extended areas, which provides useful information for decision-makers to respond appropriately to real flood hazards. This study used 30 m DEM resolution, which was the best DEM resolution available in Quang Nam; the results could be more accurate if using higher DEM resolutions (Charrier & Li, 2012) and if a higher density of flood depth markers were available.

The results from this study highlight the areas susceptible to the flood scenarios. The reported loss and damage is consistent with reported data from the Quang Nam People's Committee (2005, 2008, 2010). Both present a similar trend in which the 2007 flood (1:100-year flood) caused the greatest damage on agriculture, followed by the 2009 flood (1:20-year flood). Despite the area inundated by a 1:100-year flood being less than 1:20 and 1:10-year floods at most of the inundation levels, 26% of the area affected by the 1:100-year flood would be submerged to more than 4 m and it results in the total area inundated being greater than the other two flood scenarios (Fig. 7). The area of rice production affected increased from 24,496 ha (1:10-year flood) to 27,275 ha (1:20-year flood) and 29,815 ha (1:100-year flood). The total area inundated may be under or overestimated, depending on the method employed. This is illustrated by Lastra, Fernández, Díez-Herrero, and Marquínez (2008), who used three different methods resulting in three different outcomes for the total flooded surface area.

Despite advice from government authorities and the huge effort from farmers, including shifting crops and modifying the planting season, agriculture in Quang Nam province is still highly vulnerable to floods. For example, storm No. 9 landed directly on Quang Nam

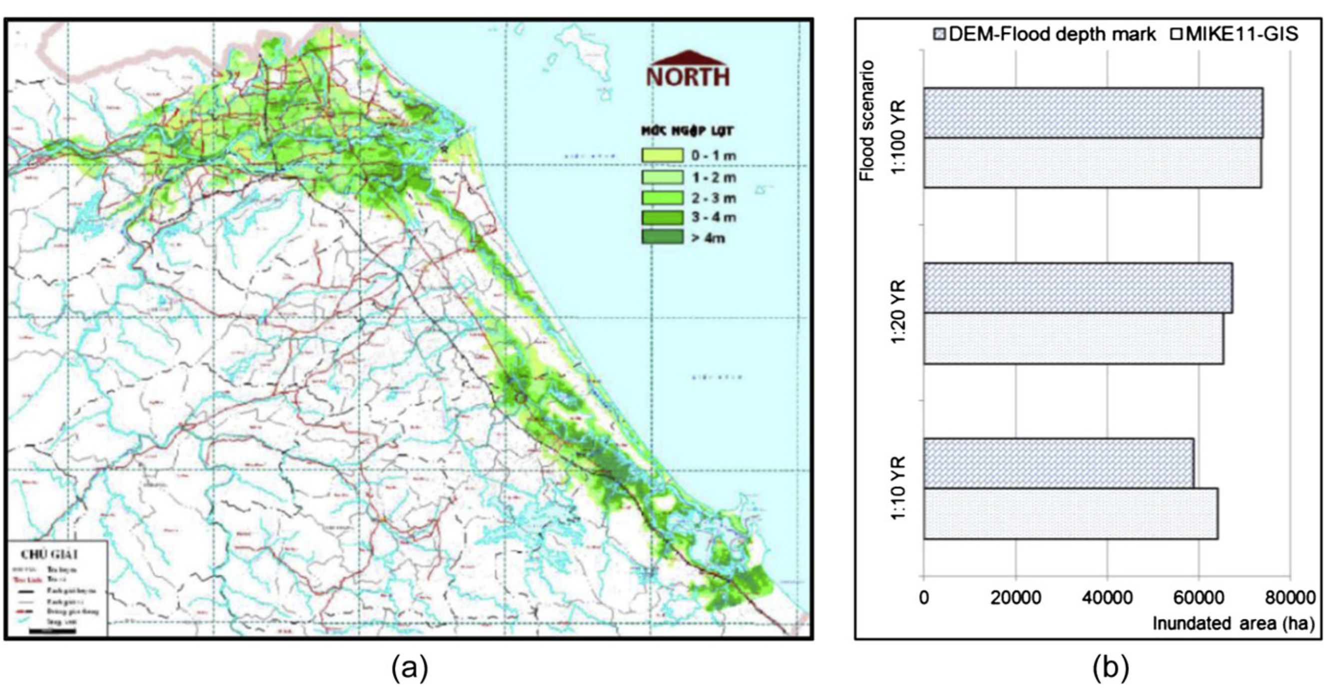


**Fig. 9.** (a) 1:100-Year flood map created by the Institute of Geography (2010) using hydraulic model MIKE11 GIS and (b) total areas of inundation in Quang Nam province.

in September 2009 followed by a flood, which resulted in the total destruction of approximately 3500 ha of the summer-autumn rice crop and more than 7600 ha of other annual crops. In addition, almost 350,000 poultry and 1500 cattle were destroyed and planting of the winter–spring crops was delayed for 15 days (Quang Nam People's Committee, 2010). Furthermore, during floods the yield and quality of harvested crops may be affected as a result of inadequate post-harvest processing, such as crop drying and storage. Farming in Quang Nam is characterized by small household farms where most of the harvest and post-harvest activities use manual labor and rely upon natural conditions, such as sunshine to dry the rice. The produce is then packaged and stored in households, which are also vulnerable to flooding. Post-harvest and storage measures need to be taken into consideration, particularly in the more deeply inundated areas.

Whilst Quang Nam's agriculture is slowly diversifying, it remains heavily reliant on crop production. Foot and mouth disease amongst cattle and avian influenza outbreaks amongst poultry in recent years have further emphasized the importance of crop production in the composition of Quang Nam's agriculture. Compounding this is the fact that production processes are heavily reliant on natural conditions, therefore, the ability to recover from natural disasters is low. This has made the agricultural sector more vulnerable to natural disasters than any other sector in Quang Nam province. The identified flood hazard zones will provide valuable information for farmers and decision makers to respond to flood hazards during the flood season and prioritize the livelihood of those living in the flooding zone.

## Conclusion

This study presented an overview of flood hazard mapping and GIS technology to measure the potential impact of extreme flood events on agricultural land in the Quang Nam province of Vietnam. The model used here demonstrated satisfactory performance in predicting flood inundation, compared to the result of the complex hydraulic model MIKE11-GIS and its impact on agricultural land, the results of which could enable more effective disaster planning, preparedness, mitigation and recovery processes. The methodology employed to map and estimate the agricultural land affected by flooding has demonstrated the simplicity and usefulness of the model, particularly when meteorological and hydrological data are limited and where remote sensing images are unavailable.

This study found that 27%, 31% and 33% respectively, of Quang Nam's arable area is estimated to be at risk from 1:10, 1:20 and 1:100-year flood scenarios. Wet rice would be the crop most affected, with more than 40% of Quang Nam's wet rice production land submerged in all three flood scenarios, with the Dien Ban district most affected. The actual percentage of production loss will depend on a number of factors, including crop variety, stage of plant development, and length of flooding period and level of inundation. Quantification and valuation of these impacts will provide further useful information for policy makers, investors and farmers. Further research will be undertaken to extend the results of this study to estimate the likely economic losses incurred by the agricultural sector in Quang Nam province as a result of extreme flood events.

Using these results in conjunction with field observations, statistics and flood legislation in the Quang Nam province, a number of recommendations can be made. First, there needs to be a review of short and long term corrective procedures which address appropriate non-structural measures, as current flood prevention and mitigation are based heavily on structural measures alone. Second, the lack of appropriate mining and forest management to date has caused large quantities of suspended sediment to flow downstream reducing the drainage capacity of the Vu Gia-Thu Bon River. This has contributed to increased flooding of valuable agricultural land, therefore, it is recommended that effort be directed toward achieving sustainable natural resource management, particularly in forestry and mining. Third, in the flood risk areas there is a need for risk classification based on flood inundation levels, coupled with provision of appropriate action guidelines at each risk level. Of particular importance is the need to increase both the number of technical staff and other resourcing to respond to the flood hazards. Finally, data on hydrology, agricultural land use and infrastructure needs to be regularly upgraded and free access to information provided, with the aim of improving awareness of likely flood impacts and the action that needs to be taken, prior to, during and immediately following flood events.

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