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A method to construct flood damage map with an application to Huong River basin, in Central Vietnam

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Abstract. In recent years, under impacts of human activities and climate change, flood has been increased in both the frequency and magnitude, causing lots of damages to people. This study presents a method to evaluate the direct spatial damages of flooding based on inundation depth and land use data. Damage functions for different types of land use are selected and applied. Matlab strings and GIS are combined to calculate damage in monitery term. The method is applied for estimating loss caused by the flood event November 1999 for Huong river basin. The relative agreement between total damage of survey data and estimated results shown that the methodology provided in this study is applicable. The methodology can be used to determine the flood-induced economic loss for cost-benefit analysis in the flood control projects.

Keywords: Inundation map; Flood damage map; Huong river basin.

1. Introduction

Economic activities in flood-prone areas are being dentisified around the world. At the same time we face changing weather conditions and a rising sea level as a result of climatic change. If no measures are carried out, both probability and impact of floods will increase drastically [18]. In order to select effectively the mitigation measures, besides social concerns, the decision makers should be informed which measure brings more economic benefit to the area. In this sense, economic damage caused by flood must be estimated. This issue has been the interest of many studies. The FLOODsite's report (2006) provided a guideline for socio-economic flood damage evaluation [3]. The report bundled different approaches to flood damage estimation. Damages are divided into macro-, meso- and micro-scales and then damage is estimated by using the different damage functions based on the level of the flood event. Van der Veen and Logtmeijer (2004) extended the known concept about damage functions with the indirect economic effects on the rest of the regional and national economy [16]. They introduced the definition "vulnerability", a function of dependence, redundancy and susceptibility. Genovese (2006) carried out a damage assessment for the 2002 flood event in Prague, Czech Republic [5]. She used damage curves and maximum damage

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values proposed by Kok and Van der Sande [9, 14, 15] to determine the damage per square meter. These resources are of use to understand the foundations of the damage curve and the associated maximum damage value. Van der Sande [15] created detailed land cover maps using satellite images to implement for the damage functions collected from [9] and [11]. Huang went into the gap between scientific knowledge available and its implementation of decision support system, when river basin management applications were used [7]. Her thesis dealt with the difficulties related to the selection and performance evaluation of hydraulic models for Flood Risk Assessment (FRA). Among other FRA's, the FRA using depth-damage curves proposed by Kok, IKSR and Van der Sande [4, 9, 14] were listed. The U.S. Army Corps of Engineers developed HEC-FDA model to formulate and evaluate flood damage reduction plans using Risk-based Analysis Expected Annual Damage (EAD). EAD reduction was computed as the difference between EAD with and without alternative projects, a quantity used to aid in flood damage reduction project selection [8].

In taking the ability of Geographical Information System (GIS) in spatial analysis, this study attempts to suggest a method to combine the inundation depth and land use data to estimate flood damage map by adopting the damage functions and potential damage values for different types of land uses. With this method, the direct damage presented in monitery can be determined. However, due to lack of relavant data, other factors like flood duration and flow velocity of flood are not accounted for, although these factors may have important roles in flood damage analysis. An application of the method to simulation of the November 1999 flood at Huong river basin with inundation depth modelled by HEC-RAS and HEC-GeoRAS software is presented in this paper.

The paper is organized as follows. In Section 2, the methodology to construct damage map is explained. In Section 3, the application of the method to Huong river basin are presented. Section 4 is devoted to the dicussions on these results. Finally, in Section 5 conclusions on the methodology and the obtained results are presented.

2. Methodology

The construction of flood damage map requires huge amount of data related to flood and land. However, the available data normally only consists of inundation depth and land use map. Therefore damage functions should be applied based on these two characteristics. The procedure to develop damage map is presented in Figure 1. There are four types of land use considered in this study. For each type, a damage function including the depth-damage curves and the maximum damage values is selected or constructed. By uniting flood depth with land use maps, the land use and inundation depth at every grid cell can be determined. The damage functions, then, will be applied to these cells to estimate economic losses. Total damage is also computed as the summation of all grid cells in the studied area.

2.1. Damage function

The function consists of a damage curve and the maximum damage value. The depth-damage curve represents the vulnerability of the concerning object or asset when it is flooded. The maximum damage value is identified by the loss value in case the object or asset is fully flooded. Many relative depth-damage functions exist in the literature. However, because the depth-damage curve and the maximum damage value depend strongly on the characteristics of the object or asset, a damage function should not be simply taken over from a preliminary research. Therefore, in this study, damage functions that have been done in the Vietnam area or constructed in the areas with similar conditions to Huong river basin are selected.

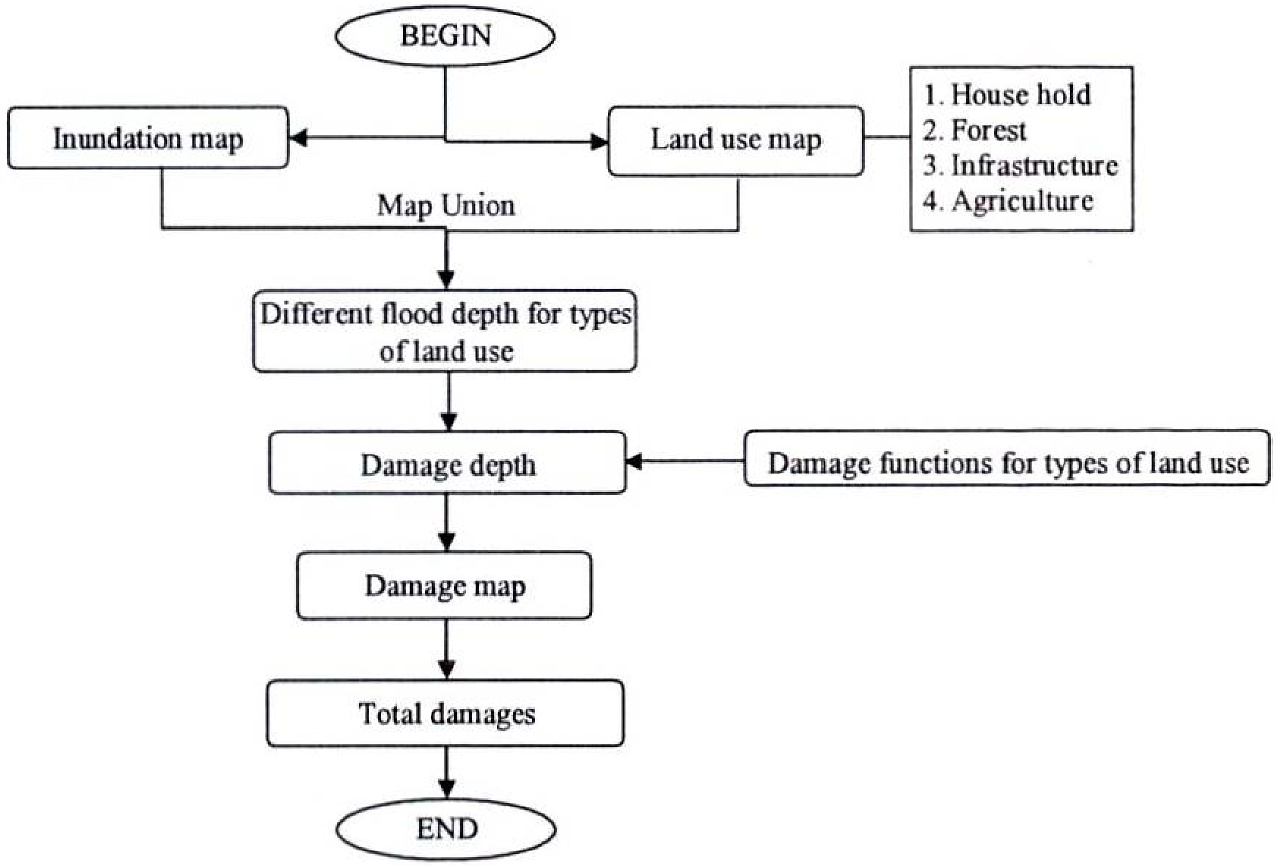

Fig. 1. Flowchart for constructing damage map.

Households Damage: Kok [10] developed the Standard Method to estimate flood damage for various land uses including houses. He made different functions for different housing types from low-rise buildings (two main floors), middle-rise buildings (four main floors) and high-rise buildings (six main floors). A visit to the city of Hue and its surroundings made clear that the urban area nowadays is filled with mostly three or four level buildings, while in the rural residential area houses with one or two main floors are more common. So for the urban residential area the middle-rise building curve will be used and for the rural residential area the low-rise building curve will be adopted as the depth-damage curve.

The used curves are shown in Figure 3. In these curves, the economic damage is the damage of the building plus the loss of assets. In the implementation of the Standard Method of the damage curve for houses, the factor between the concerning maximum damage values is 0.41.

Extra factors: The used curves also provide the damage factor for the sum of the direct damage, direct damage due to production loss and indirect damage. Due to the substitution effects in the surroundings of the flooded area, the damage function for the households must be given a factor of 0.75. Moreover, the area for urban residents and rural residents is not completely filled with houses. A surface factor is used to correct this information. Factor of 0.4

is used for the urban area while factor of 0.2 is used for the rural area. These two factors are implemented by using the following function, in which EED is the economic damage, d is damage corresponding to the inundation depth in meters, α is the damage factor for the households, γ is the reduction factor and β is the surface factor.

$$EED = \alpha_{DF\_household} \times d \times \gamma_{Reductionfactor} \times \beta_{Surfacefactor} \quad (1)$$

Maximum damage value: Since the damage curve of the Standard Method of Kok [10] is used, the maximum damage value can be developed with the foundations from this method. The maximum damage values for a household are defined as the rebuilding cost for houses and the replacement value for the assets inside the house. According to Table 1, a value of 29 USD/m^2 is used as maximum damage value for houses in the urban area while a value of 22 USD/m^2 is used for rural area.

Infrastructure damage: In this study, infrastructure is concentrated on damages cause for roads. De Bruijn [2] constructed a damage curve for the roads and railways in the Mekong Delta. The curve is similar for different types of roads but the maximum damage values are different for the highways, provincial roads and railroads. The damage to rural roads is neglected since no maximum damage value for this type of road is known.

Extra factor: The resource data of the infrastructure exists in USD/m. However, since the damage function needs its input in square meter, a conversion factor is used to correct the conversion from a USD/m unit into a USD/m^2 unit. This factor is calculated using the average length of a road through a cell and the area of this cell. The formula for this factor is given in Figure 2. This factor is then implemented in the following damage formula:

$$\text{EED} = \alpha_{conversion}\, f_{\text{infrastructure}}\, d \quad (2)$$

in which EED is the economic damage in USD/m^2; $f_{infrastructure}$ is the damage factor for the specific infrastructure, d is the economic damage corresponding to the inundation depth in meter, which defined from damage function and $\alpha_{conversion}$ is the conversion factor from USD/m to USD/m^2.

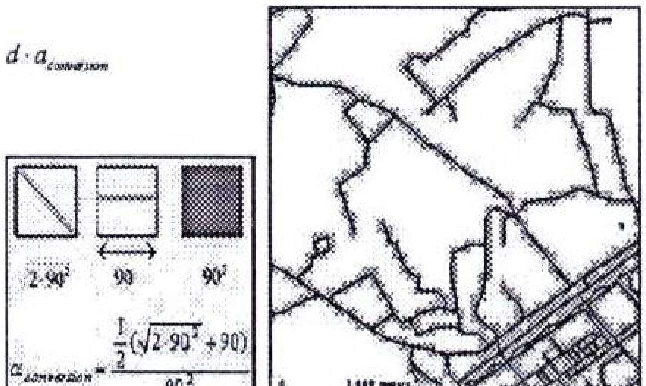

Fig. 2. Calculation of surface factor and infrastructure cells (The length of one cell is 90 meter).

Maximum damage value: The maximum damage value of the provincial road is 80 USD/m while this value for the national road is 400 USD/m and for the railway the maximum damage value is 1000 USD/m.

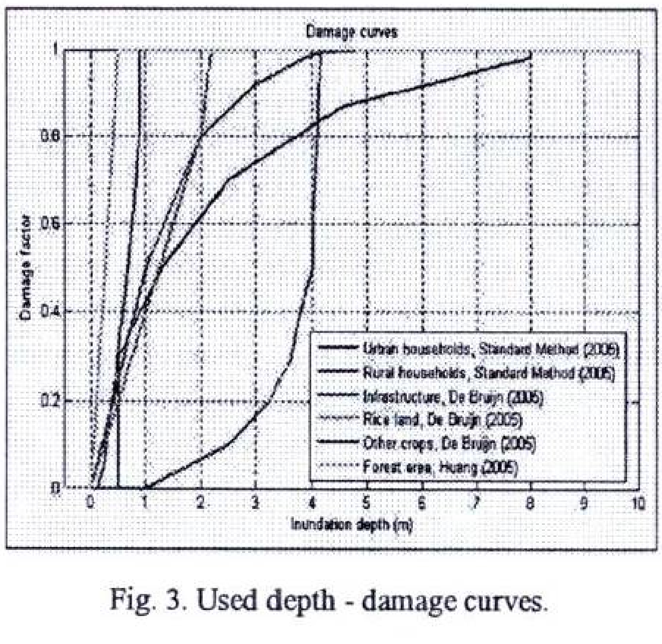

Fig. 3. Used depth - damage curves.

Agriculture damage: Due to the similarity in conditions, the De Bruijn's damage curve for rice in the area of Mekong Delta is used for rice land as well as other crop in this assessment. As regard to the maximum damage values for the crop, she uses a maximum damage value of 440 USD per hectare for the other crops than rice and 200 USD per hectare for rice.

Damage for forest: The thesis of Huang [7] provides the damage curve as shown in Figure 3. Report of CRUEIP [1] provided the replacement value for forest area in the Thua Thien Hue Province which is equal to 0.84 USD/m^2. This value is adopted as the maximum damage value.

Table 1. Used maximum damage values per land use type

	Used maximum damage value	Resource characteristic	Extra factors
Urban area	29 USD/m2	Construction costs & Asset value	Surface factor: 0.4 Reduction factor 0.75
Rural area	22 USD/m2	Construction costs & Asset value	Surface factor: 0.2 Reduction factor 0.75
Provincial road	80 USD/m	Construction costs	Conversion factor: 1/75
National road	400 USD/m	Construction costs	Conversion factor: 1/75
Railway	1000 USD/m	Construction costs	Conversion factor: 1/75
Rice	0.044 USD/m2	Maximum damage value	
Other crops	0.02 USD/ m2	Maximum damage value	
Forest	0.84 USD/m2	Replacement value	

3. Application of the method to construction of damage map for Huong river basin

3.1. Study area

The Huong River Basin is located in Thua Thien Hue, a central province of Vietnam, bordered on the east by the East Sea, on the west by the Laos. The Huong River originates in the mountainous area around the border with Laos and flows in the North-Eastern direction to the coast. The Huong River Basin and its adjacent area embrace an area of 3760 km^2, of which 2960 km^2 belongs to the main Huong River Basin, and the remaining of 800 km^2 belongs to contiguous basins. The Huong River flows into a concatenation of lagoons near Hue, from which it leads to the East Sea. Much of this province's infrastructure and industry lies in the coastal plain and most of the populations live within 25 km of the coast. This area has a small slope and the Huong River and its tributary streams meander through population and agriculture area.

The Thua Thien Hue Province has a tropical monsoon climate and is affected by annual tropical storms. These typhoons usually develop in the Northwest Pacific and follow a path over the Philippines, cross the East Sea. When landing on the Vietnamese coast they loose force, they release their water over the coastal zone [17]. Because the Huong River Basin is very flat in the coastal area and the basin has no sufficient hydraulic structures to handle this amount of rainfall, it is under the high risk of flood.

In November 1999 a disasterous floods struck eight provinces in Central Vietnam. Thua Thien Hue is one of the provinces that were affected the most severely. Approximately 90% lowland is under water. The flood lasted for one week, broke five new floodgates and created a new river mouth near the lagoon. Nearly a million homes were damaged, of which more than 40 thousand were destroyed. The flooding caused 265 million USD of damage plus almost 500 million USD of economic losses [12].

3.2. Data available

Land use map: The land use data is obtained by the Vietnam National University, Hanoi from the government of the Thua Thien Hue Province. Although the data covers the whole province, only the data of the flooded area is displayed since the data outside the flooded area is not used. The data has been converted to ESRI files to view the data in ArcView software and to convert it to ASCII-files with a 90 meter grid. In Figure 4, the 90-meter grid is displayed with all the land uses that are used for the damage mapping. The location of the left lower corner of the land use figure is longitude: 758.628.434 and latitude: 1.804.480.528.

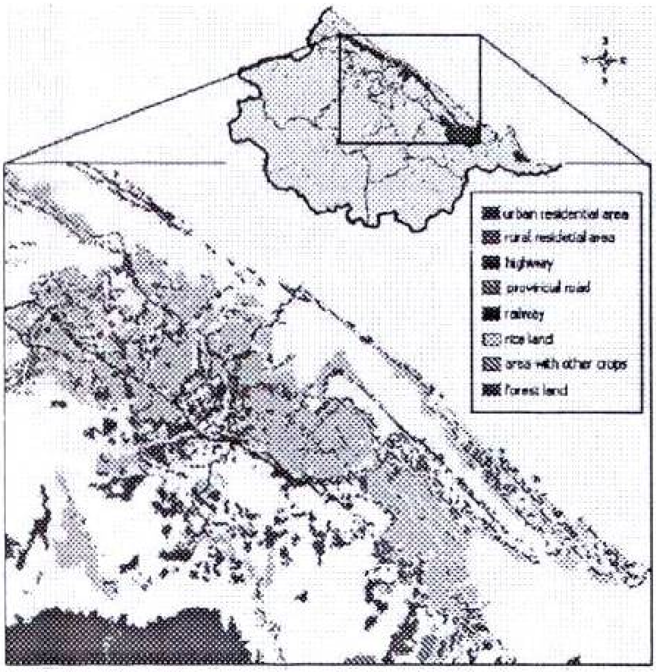

Fig. 4. Land use map of the study area.

As shown in Figure 4, the urban area is mostly in Hue city that can be recognized by the square shape of the channels around old Hue Citadel. Another urban area is located at the Bo River in the North West of the figure near the highway. The rural area is mostly located near the riverside and around the lagoons. It is surrounded by rice land that can be found in the whole flat area of the Thua Thien Hue Province. The forest land is located more uphill. The area that is defined 'with other crops' is the land used for agriculture that is not rice. Because in the flooded area there are not many other crops grown, these are not defined in more detail. The railroad and highway 1A run from the North West to the South East. These roads are not drawn in the figure from the moment that they leave the urban area, due to lack of data.

Inundation map: The inundation depth map with respect to the maximum water level at Kim Long station developed by Giang and Phuong [6] was used. In Figure 5, the spatial data of the inundation depth is drawn, with the location of the left lower corner, the grid size and the length from top till bottom that is similar to the figure of the land use. As can be seen in Figure 5, the study area was inundated from the minimum of 10 mm to maximum of 6078 mm.

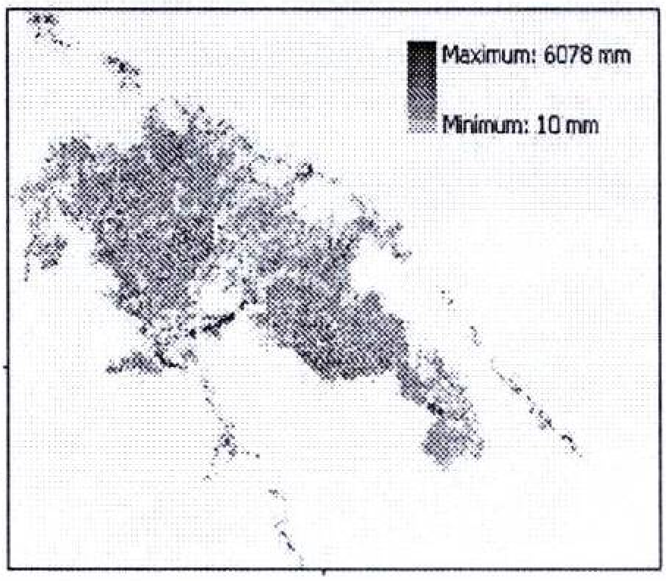

Fig. 5. Inundation map [6].

Population density: The data of the population density were obtained from the government of the Thua Thien Hue Province. It consists of the total amount of residents per district, together with the area of each district. This data, then, is used to calculate the average density of the population per district. The data are converted to ESRI files to view the data in ArcView software and to convert it to ASCII-files with a 90-meter grid.

3.3. Estimation of economic damage

Damage map: Based on given data, the damage map obtained for the Huong River Basin is shown in Figure 6. The data is drawn in the cells of 90x90 m^2. Economic damage is presented in USD/m^2. The spatial damage data in Figure 6 shows that the infrastructure causes the highest damage per square meter (17-24 USD/m^2) while rice fields have the least damage per square meter with damage below 0.5 USD/m^2. Remarkable point is that Hue City has several locations with a high predicted damage, but in general it has only little damage. This is probably caused by the higher inundation depth due to the conventional irrigating system around the old Citadel of Hue.

Figure 7 presents the inundated area and damage for different types of land use. The rural area covers the second largest inundated area and is subject to 53 percent of the total damage. The railways and the urban land use are the next land use types that suffer large damages. The damage to the forest area and to the area with other crops is marginal, the damage to the rice fields which is not proportional to its inundated surface are also negligible. In Table 2, the average damage per land use type is calculated and compared with the used maximum damage. This shows that the rice land, the forest area and area with other crops have average damages most close to its maximum damage values. After these land use types, the rural and urban areas have the highest damages in comparison to its maximum damage values.

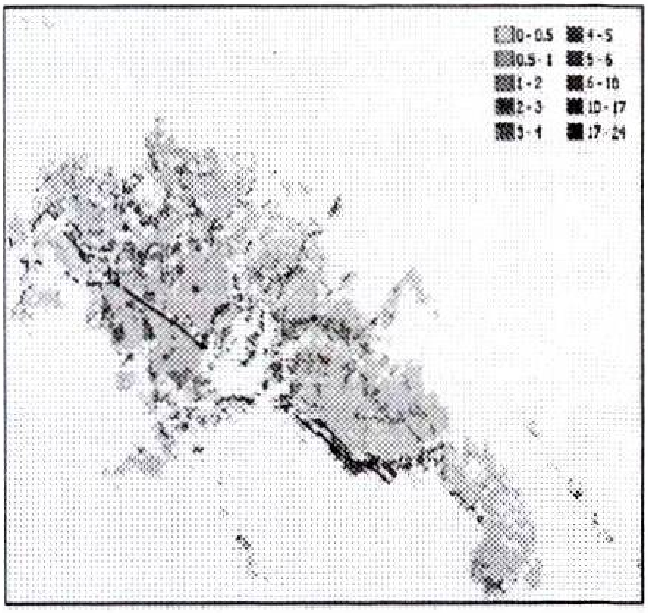

Fig. 6. Damage in USD/m^2 using inundated constructed by HEC-RAS and HEC-GeoRAS.

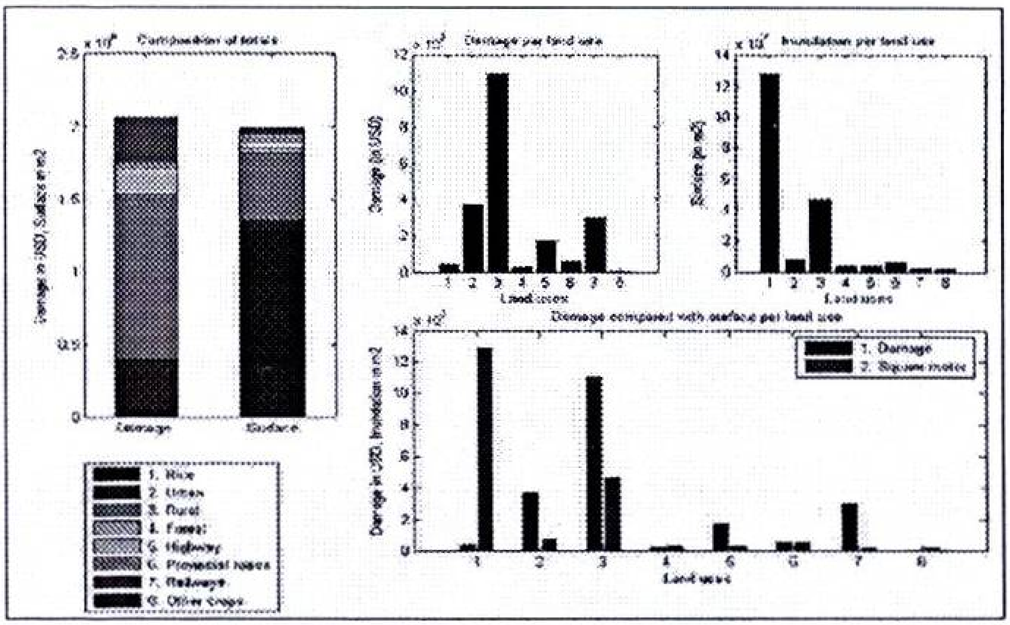

Fig. 7. Damage and inundated area with respect to types of land use.

Table 2. Average calculated damage and maximum damage value per land use

	Average damage	Maximum damage value	Percentage
Rice	0,0403	0,044	92
Urban	5,53	29	19
Rural	2,67	22	12
Forest	0,84	0,84	100
Highway	5,05	400	1,2
Provincial roads	1,05	80	13
Railways	12,2	1000	1,2
Other crops	0,0053	0,02	27

3.4. Validation of damage map

The total damage according to the damage map with the HEC-RAS inundation map in this assessment is about more than 200 million USD (see Table 3). Using the observed inundation map for a validation, the total damage is calculated to 285 million. Comparing this number with the damage reported by international resources [13] which is equal to 265 million USD, the used damage functions seem to be quite accurate. However, when incorporating the error caused by inundation map then the difference between losses becomes larger (207 millions compared to 285 millions).

Table 3. Total calculated damage and reported damages in USD

	HEC-RAS inundation map	Observed inundation map
Urban area	36.679.000	66.589.000
Rural area	110.220.000	154.590.000
Rice fields	4.096.000	6.383.800
Forest area	2.633.400	2.612.700
Highway	17.207.000	20.627.000
Railroads	30.227.000	23.535.000
Provincial roads	5.746.100	10.859.000
Other Crops	5.143	15.525
Total damage:	207 millions	285 millions

4. Discussions

There is no doubt that flood damage assessment contains many uncertainties coming from both the method and its inputs. Regarding to input, this assessment assumes that the inundation depth data is true. However, in the previous study, the simplified network without consideration of small channels and storages, the higher level of roads and railways in the study area reduces the accuracy of inundation map. Moreover, other information like flood intensity and duration which affect considerably on the damage have not been provided. As a result, damage related to these data is neglected.

Regarding to the land use data, only a small amount of land use types is used and they can not represent all the existing land use types in the Huong River Basin. This means that not all the possible economic damage that the Huong River Basin suffers is taken into account. For example, industry, commerce, tourism, fishery, recreational areas and temples would be subject to damage. These land use types as well as the used land use types can cause economic losses due to failure. Since this is not taken into account in this assessment, this damage map may create an incomplete image of the reality. Moreover, the accuracy of the validation is affected by the age of the data of the land use which is obtained recently and flood event which dates back to 1999.

The uncertainty of damage functions is another source of error. All of the damage curves used in this study coming from different locations not Huong river basin. As a result, in some cases, these functions can not reflect the relationship between inundated depth and economic losses. Detailed consideration of the damage map is not validated although the total damage of the damage map is validated. The spatial damage results within the map actually are in a black box.

5. Conclusions

In this paper, a method to calculate the damage of flood is proposed. Based on inundation and land use data, the method can constructs the damage map by using damage functions. Spatial analysis techniques of GIS and codes of Matlab are two main tools to quantify the damage. The relative agreement between the accumulations of the damage of several land use types for observed inundation depth with the survey damage proved that the consequences of flooding on the Huong River basin can be predicted by the suggested method.

For the economic damage in case of a flood like the November 1999 flood, the area around rivers in the Huong River Basin is also subject to the largest consequences. This is mostly caused by the settlement near the rivers and its large vulnerability to flooding. The rural area has the largest share in the total damage and the second largest area of inundation, after the rice fields. Determining the damage per square meter, it appears that the railroad and the highways suffer the most extreme damage, followed by the urban settlement. When forest area or rice fields are struck by inundation, its maximum damage is reached with only a small water depth.

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