Flood Damage Assessment and Modelling in the Red River basin in Vietnam

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Abstract Flood damage is an important property in the evaluation of flood control and ecosystem upgrading measures in the decision support system for the Red River basin in Vietnam. Therefore, extreme water levels, flood damage and the relations between these variables are considered. It is found that annual, direct flood damage has a typical order of magnitude of 100-1000 million US$ and is highly uncertain. The uncertainty is caused by the lack of damage data, data on costs per unit damage and data on other damage categories, such as indirect damage and intangible damage. As a consequence relations between flood damage and water levels are uncertain as well. Comparison of the flood damage with the gross domestic product in the Red River delta emphasised the high importance of incorporating flood damage in decision support systems. Large floods may cause damages with a magnitude between 20-50 % of the gross domestic product.

Key words: floods; extreme water levels; damage assessment; spatial variability; uncertainty; Red River

1 Introduction

The FLOCODS DSS is a decision support system for evaluation of different flood control and ecosystem upgrading measures under different scenarios in the Red River basin in Vietnam and China (see e.g. Booij, 2003). In this DSS, cost-benefit analysis could be used as an evaluation tool and therein, flood damage is an important component. By comparing annual expected flood damage for different measures, a priority list of preferred measures can be made. It is therefore of crucial importance that a flood damage assessment module is incorporated in the FLOCODS DSS.

Flood damage can be broadly classified into two categories: tangible and intangible damages. Tangible flood damages, which can be expressed in monetary values, can be subdivided into two types: direct and indirect damage. These can be further subdivided into primary and secondary damages. Therefore four types of tangible flood damage can be distinguished (Dutta *et al.*, 2003): direct primary (e.g. structures, agriculture), direct secondary (land and environment recovery), indirect primary (business interruption) and indirect secondary (impact on regional and national economy). Intangible damages (e.g. health, psychological problems) have been occasionally investigated in literature (e.g. Lekuthai and Vongvisessomjai, 2001), but in general, research is limited to tangible damages. Here, flood damage is restricted to direct primary tangible damages because of the complexity of modelling other damage types. Intangible damage will only slightly be considered.

The most common approach for flood damage estimation employs the unit loss model, which is based on a property-by-property assessment of potential damage. In principal, such a model comprises a relationship between flood variables (inundation depth, duration, velocity) and damage for different damage categories. There are wide variations in the existing methodologies for flood loss estimation around the world and only a few countries have adopted standardized methodologies for this estimation (Dutta *et al.*, 2003). There are a few models available for flood damage assessment basically using relationships between flood variables and damage in a specific context (river basin, country etc.), examples are FDAP (USACE, 1988; 1994), ANUFLOOD (Greenaway and Smith, 1983) and ESTDAM (Chatterton and Penning-Rowsell, 1981). In the Red River basin, due to the specific context and the lack of data on flood variables (maps with inundation depths, durations) and damage (costs to convert to monetary units, spatial distribution), a situation specific model for flood damage assessment needs to be developed. This model is based on statistical relations between extreme water levels at different stations and the total damage lumped at the provincial level. The total damage is estimated from different direct primary damage categories converted to monetary units. The extreme water levels at different stations are aggregated to scaled extreme water levels per province in order to link with the damage data.

In section 2, the extreme water levels are estimated, section 3 considers the total damage and in section 4 relations between both variables are estimated. Additionally in section 5, an attempt is done to verify the estimated damage data using intangible flood damage data. Finally, in section 6 conclusions are drawn.

2 Extreme value estimation for water level

2.1 Observed water level data

Water level data from the Institute of Mechanics in Vietnam are employed in this analysis. These data have temporal resolutions of 6 hours (5 stations) and 24 hours (26 stations) for the period 1990-2001. Part of the stations is in the Red River delta and covers complete years (19 stations) and part is in the upstream Red River basin in Vietnam and covers the period June 1-October 15 (12 stations). It is assumed that the latter period represents the flood season and thus all important water level extremes. The 31 water level stations are in 15 of the 26 provinces in the Red River basin, in particular provinces with large annual flood damages.

2.2 Scaled values of annual water level extremes

Annual maximum water levels are used to represent annual floods. In order to obtain an average annual maximum for each province, scaled values of annual water level extremes $\tilde{h}_a$ are used

$$\tilde{h}_a = \frac{h_a - h_{\min}}{h_{\max} - h_{\min}}$$

where h_a is the annual maximum water level, $h_{\min}$ is the minimum of 12 (years of) annual maximum water levels and $h_{\max}$ is the maximum of 12 annual maximum water levels. The average annual maximum can then be obtained by averaging the scaled values of stations in a specific province for a specific year.

2.3 Analysis of annual water level extremes

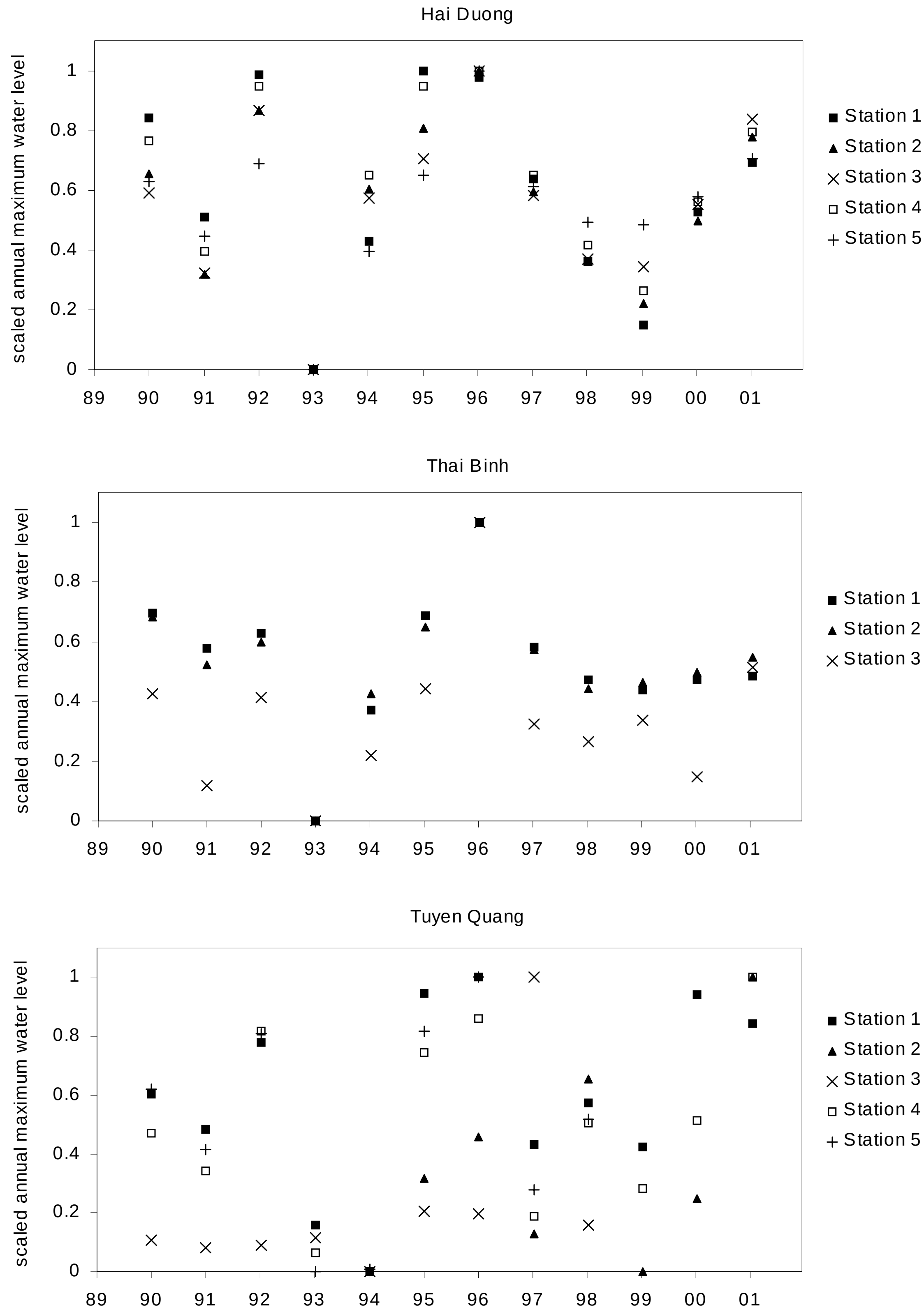

Figure 1 Scaled annual maximum water levels for 3-5 stations in three provinces for 1990-2001.

The individual and averaged scaled extremes will be presented and discussed in this section. Figure 1 shows the scaled annual maximum water levels for 3-5 stations in three provinces (Hai Duong, Thai Binh and Tuyen Quang) for the period 1990-2001.

Ideally, the scaled values for a particular year and within a particular province should be situated in the vicinity of each other. Then, water levels of different stations are highly correlated, which means that relatively large floods occur in the same year in each station. This situation can be identified in Figure 1 for Hai Duong province, where in particular 1993 characterises a relatively 'dry' year and 1996 a relatively 'wet' year. This picture is less evident for Thai Binh province, where only 3 stations have been used. But also here, 1993 and 1996 can be characterised as relatively dry and wet years. The results for Tuyen Quang province are less pronounced and the variability of the scaled values within a particular year can be rather high. This may obviously lead to less extreme averaged scaled water levels, i.e. $\tilde{h}_a$ will be away from 0 or 1. The other 12 provinces for which water level are available are represented by only 1 or 2 station(s) and will not be discussed here with respect to the individual scaled extremes.

Figure 2 presents the provincially averaged annual extremes for 15 provinces, also shown are the annual extremes averaged over Vietnam. The variability of scaled annual extremes within a specific year is rather high, in particular for 1991 and 1995. However, the 'dry' and 'wet' years 1993 and 1996 can still be identified being respectively the minimum and maximum of the average scaled extremes. Moreover, a slightly periodic trend could be derived for these average values, although it is unclear whether this may lead to a big flood in 2003 (see Figure 2). The scaled values for 2002 may already give some indication on this.

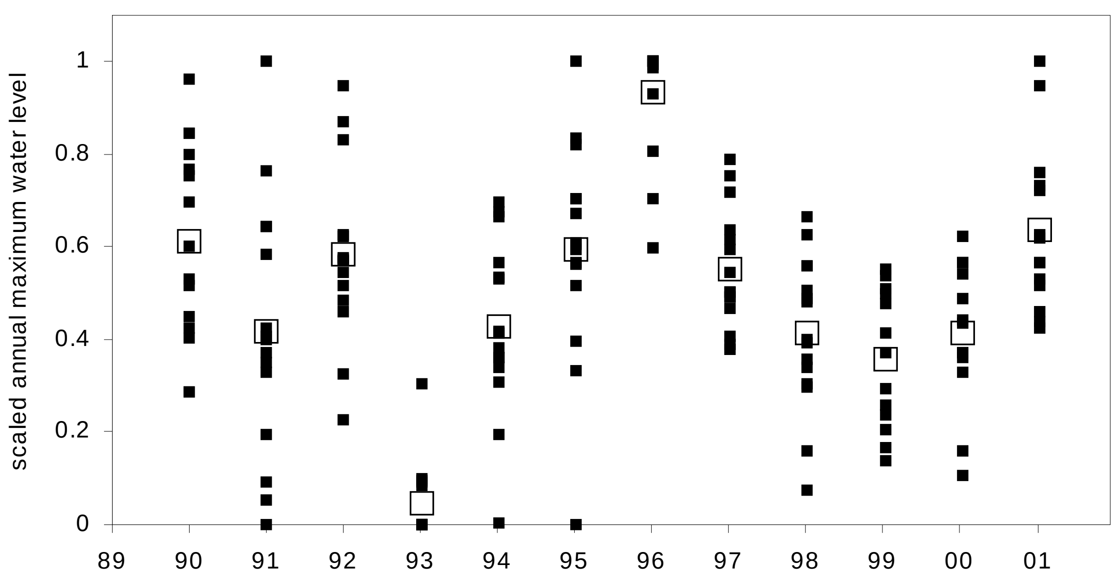

Figure 2 Scaled annual maximum water levels for 15 provinces for 1990-2001 (small black box) and average values for Vietnam (large white box).

3 Flood damage assessment

3.1 Observed flood damage data

Annual flood damage data from the Vietnamese Ministry of Agriculture and Rural Development and the Belgian Centre for Research on the Epidemiology of Disasters are used. The Vietnamese data are from 26 provinces in the Red River basin in Vietnam for the period 1990-2001. The data are subdivided into 13 main categories (people, houses, schools, hospitals, constructions, agriculture, irrigation system, traffic system, aquaculture, boats, communication system, energy, materials) and 108 sub-categories and are in non-monetary units (e.g. km, ha, kg). The monetary values of each unit (in e.g. US$/ ha) are hardly available, only some estimations can be used (Thuy, pers. comm.) to convert the non-monetary units into monetary ones enabling comparison and aggregation of the different categories.

The Belgian data are from an international, validated disaster database containing core data on the occurrence and effects of over 12,800 mass disasters in the world from 1900 to present (CRED, 2003). The database is compiled from various sources, including UN agencies, non-governmental organisations, insurance companies, research institutes and press agencies. A total number of 91 disasters (e.g. drought, flood, wind storm) in Vietnam are available of which 26 events are related to floods in Vietnam (5 occurred in the Red River basin). The complete set of 26 floods is analysed here. Features included for each flood are the spatial scale, rough location, date of occurrence, people affected (injured, killed, homeless) and estimated damage in monetary units. The Belgian data are primarily used for comparison with and verification of the Vietnamese data.

3.2 Variation of flood damage components

The spatial and temporal variation of some important flood damage components out of the 108 sub-categories will be discussed here for illustrative purposes. Figure 3 shows the spatial distribution of flooded rice area (in % of total rice area) for 1996 (the biggest flood, see section 2). In particular, the provinces Nam Dinh (about 75 %) and Bac Dinh (about 65 %) are heavily hit by the floods of 1996. In total, more than half a million ha of rice field has been flooded, far more than in other years during the period 1990-2001. Even more disastrous is the number of flooded houses in 1996 as shown in Figure 4. Again Nam Dinh province is most seriously hit with over 300 thousand flooded houses, but also Thai Binh and Vinh Phuc provinces seriously experienced damage to houses. Also here, the total number of flooded houses (more than 700 thousand) is far more than in other years. The extremity of 1996 is further illustrated by Figure 5, where the annual totals of some main sub-categories (scaled by their maxima in the period 1990-2001) are given.

Figure 3 Spatial distribution of flooded rice area as % of total rice area in the Vietnamese part of the Red River basin for 1996.

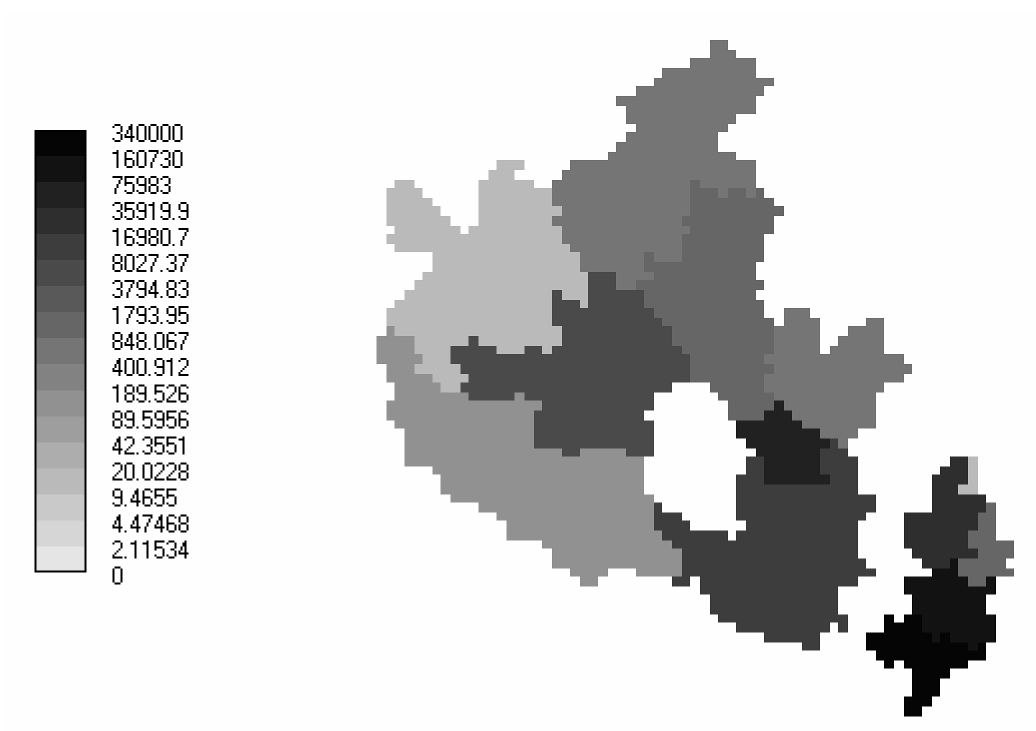

Figure 4 Spatial distribution of flooded houses in the Vietnamese part of the Red River basin for 1996.

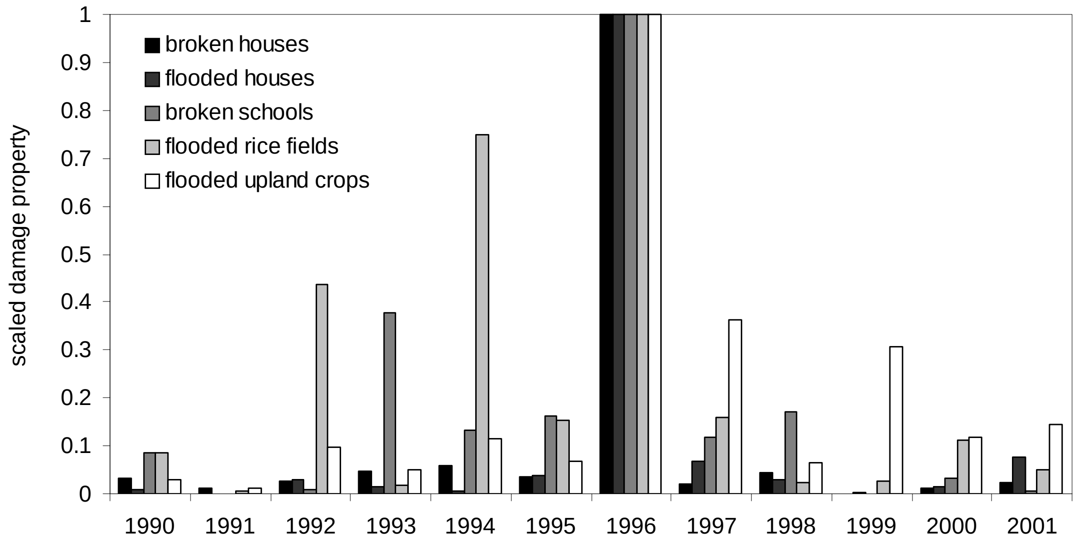

Figure 5 Scaled annual totals (with maximum value in 1990-2001 period) for sub-categories: broken houses (maximum: 45876), flooded houses (709136), broken schools (1997), flooded rice fields (519445 ha) and flooded upland crop fields (82645 ha).

3.3 Variation of total flood damage

The material damage components are aggregated and compared using the estimated costs per unit damage (e.g. US$/ ha, see 3.1). These costs are highly uncertain and are the most important uncertainty source in the estimation of flood damage. Obviously, the numbers associated with the separate flood damage components discussed in 3.2 are an important uncertainty source as well. The costs per unit damage for some important damage sub-categories are given in Table 1. Costs for several less important sub-categories have been derived from these values or have not been estimated at all, because relevant and reliable information was not available.

Table 1 Costs per unit damage for 9 most important sub-categories

Sub-category	Costs	Unit	Source
Broken house	2 500	US$/ unit	IMECH
Flooded house	1 000	US$/ unit	estimated
Broken school	25 000	US$/ unit	estimated
Broken hospital	125 000	US$/ unit	estimated
Drifted facility building	12 500	US$/ unit	estimated
Flooded rice field	396	US$/ ha	IMECH
Flooded upland crop field	230	US$/ ha	IMECH
Drifted dikes	625	US$/ m	IMECH
Failed roads	12 500	US$/ km	IMECH

The estimated costs can be used to determine the total flood damage per year (Figure 6), the total flood damage per province for a particular year (1996, Figure 7) and the composition of the total flood damage per year (Figure 8). Features already observed in 3.2 can be identified in these figures as well, such as the extremity of 1996 and enormous flood damage in Nam Dinh province. Furthermore, it seems that the order of magnitude of the total flood damage in 1995 and 1996 is in correspondence with the scarce information available (Nguyen *et al*., 2001), where only damage to houses and agriculture has been taken into account. The total damage in 1994 is highly underestimated compared to the figure given by Nguyen *et al*.. Houses and agriculture are the most important damage categories (see Figure 8), only in 1993 and 1995 other categories, respectively hospitals/ schools and traffic system, contributed significantly as well. Six main categories are not shown in Figure 8, because the costs per unit could not be obtained and/ or derived.

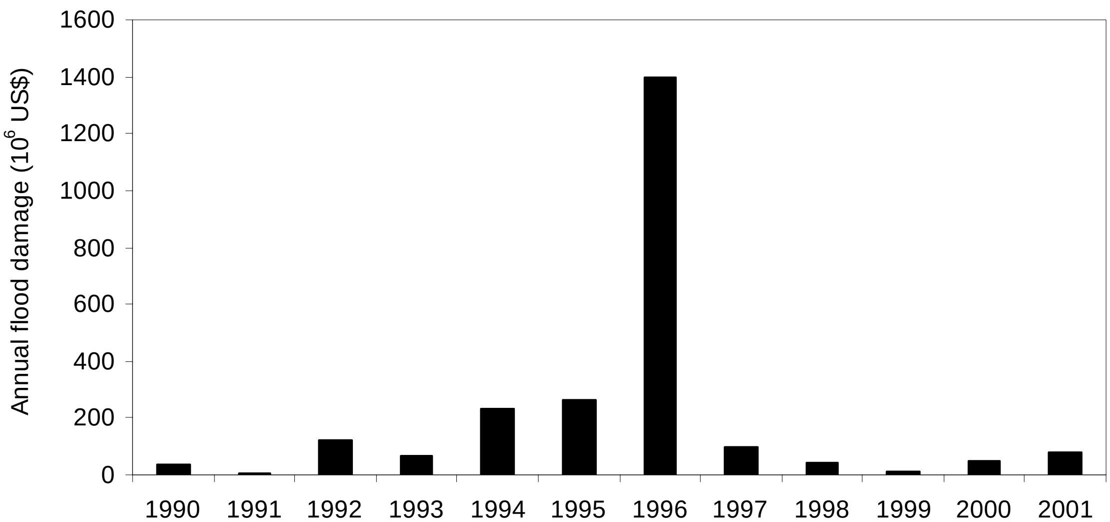

Figure 6 Total annual flood damage in the Vietnamese part of Red River basin for the period 1990-2001.

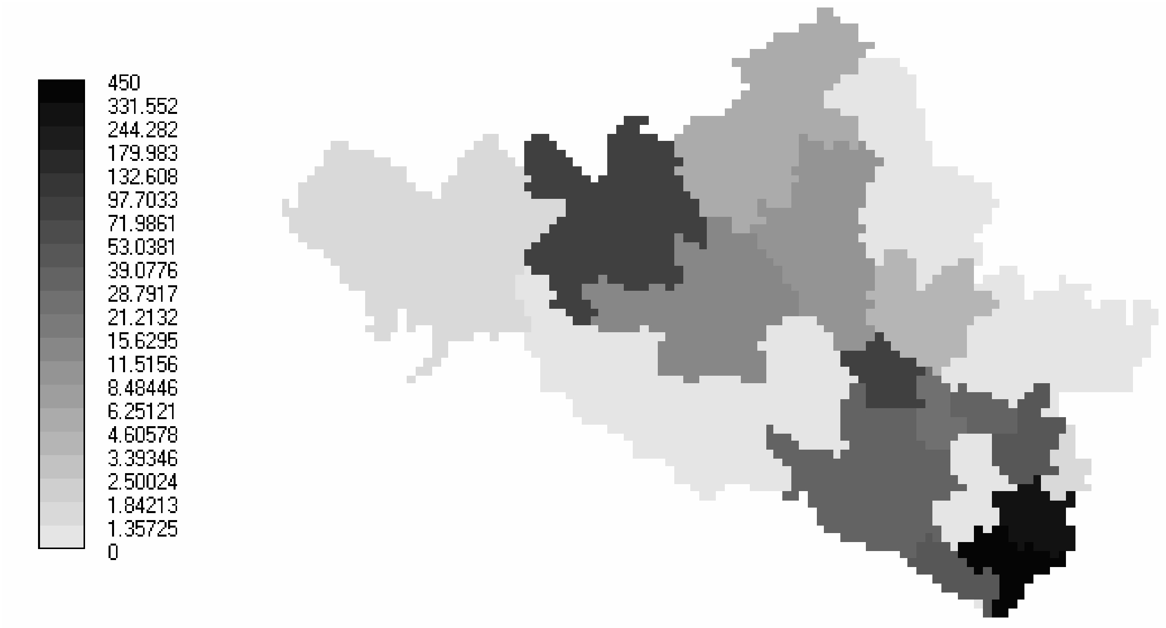

Figure 7 Spatial distribution of total flood damage in 10^6 US$ in the Vietnamese part of the Red River basin for 1996.

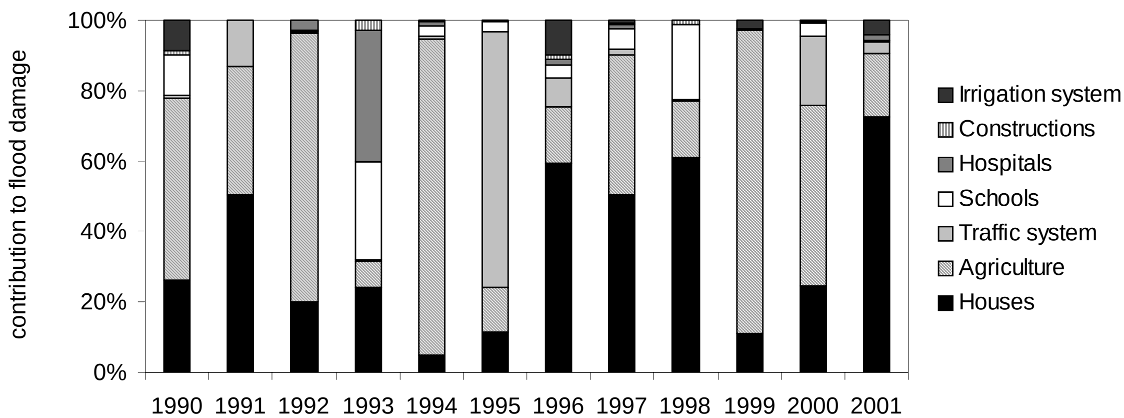

Figure 8 Contribution of seven main categories to total flood damage for 1990-2001.

The influence of the uncertainty in the costs per unit on the results will be illustrated by varying the costs per unit (between –50% and +50%) and showing the effects on the total annual damage (Figure 9). As expected, the total damage varies between –50 % and +50 %, because it is a linear combination of the various damage components. However, this figure illustrates the large uncertainty in flood damage estimation, which will have considerable impacts on flood damage modelling and consequently on the evaluation of different flood control measures under different scenarios.

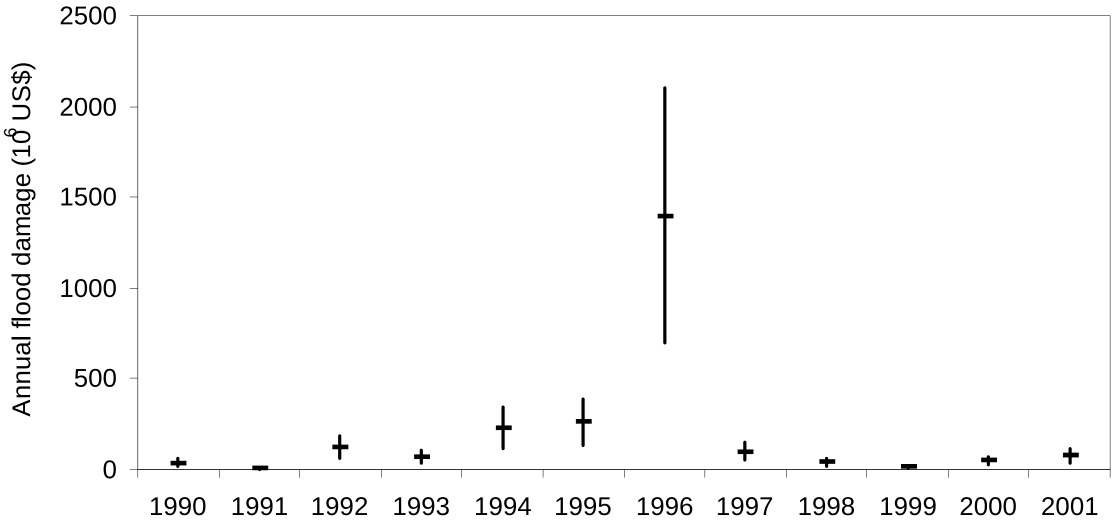

Figure 9 Uncertainty in total annual flood damage for the period 1990-2001 as a result of uncertainties in costs per unit.

4 Relations between extreme water level and flood damage

This section considers possible relations between extreme water levels from section 2 and flood damage from section 3. These relations can be used to predict damage as a result of future/ historic floods for decision support in flood and ecosystem control. The scaled annual maximum water levels for 15 provinces from Figure 2 and the total flood damages from 3.3 will be used for this purpose.

The correlation between the scaled annual maximum water levels and the total damage varies between none (r = correlation coefficient < 0.3; 4 provinces), weak ($0.3 < r < 0.6$; 6 provinces) and reasonable ($r > 0.6$; 5 provinces). Although for some provinces correlation coefficients seems to be promising, they may only be based on a few years for which flood damage data were available. Therefore, by taking into account the number of flood damage observations (more than 5), for only 4 provinces with reasonable correlations and 2 provinces with weak correlations relationships could be established. Figure 10 shows the relations as semi-logarithmic plots for the 4 provinces (Ninh Binh, Yen Bai, Nam Dinh and Tuyen Quang) with reasonable correlations.

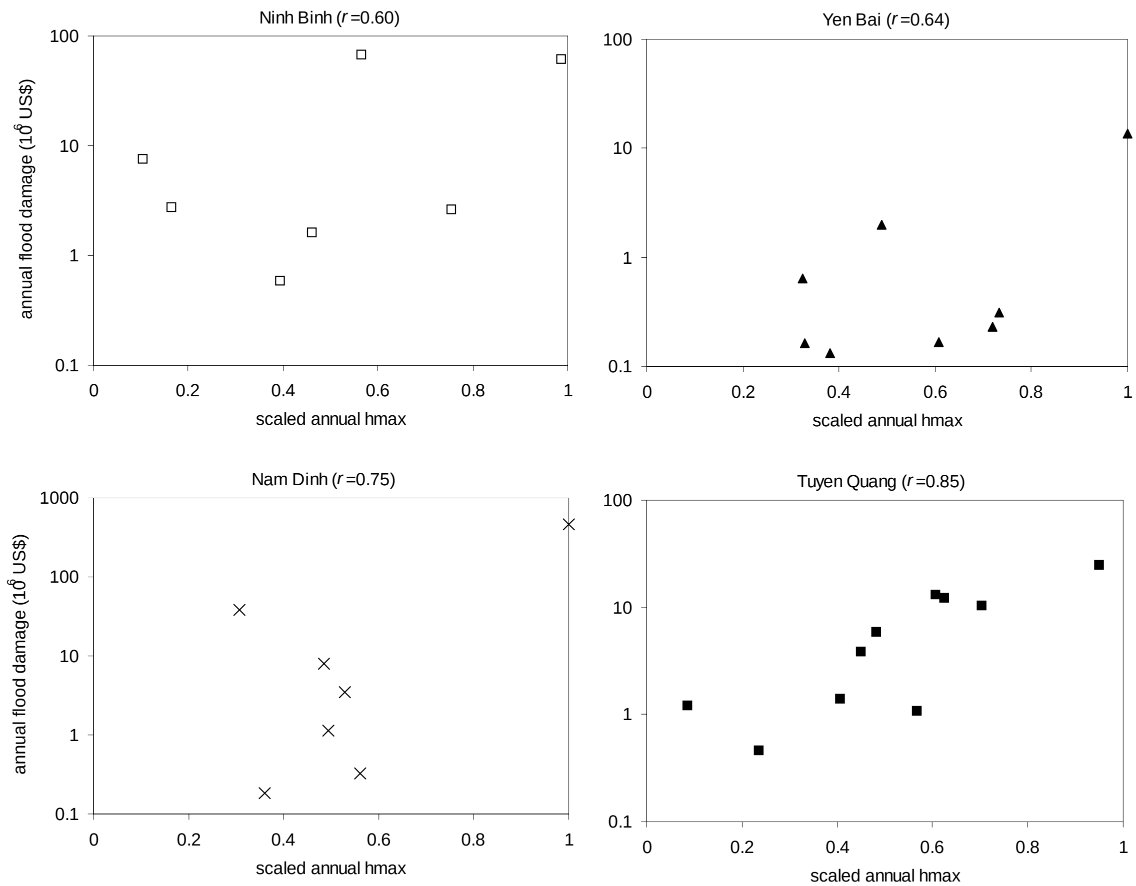

Figure 10 Total annual flood damage as a function of scaled annual maximum water level (hmax) for provinces Ninh Binh, Yen Bai, Nam Dinh and Tuyen Quang.

The relation for Tuyen Quang is explored in more detail in Figure 11, where two functions are fitted to the point pairs: an exponential and a stepwise function. The stepwise function expresses the discontinuous flood damage behaviour, i.e. damage abruptly increases as the water level reaches field level, then increases again as base floors of buildings are inundated etc.. The number of point pairs are insufficient to determine which of these or other relations should be used to describe the relation between water level and flood damage. Preferably spatially distributed *inundation depths* should be used together with more spatially distributed damage maps to derive more detailed damage functions (dependent on land use type, better determined functions). Moreover, more data on costs per unit used to convert damage components from non-monetary to monetary units need to become available to reduce one of the most important uncertainty sources.

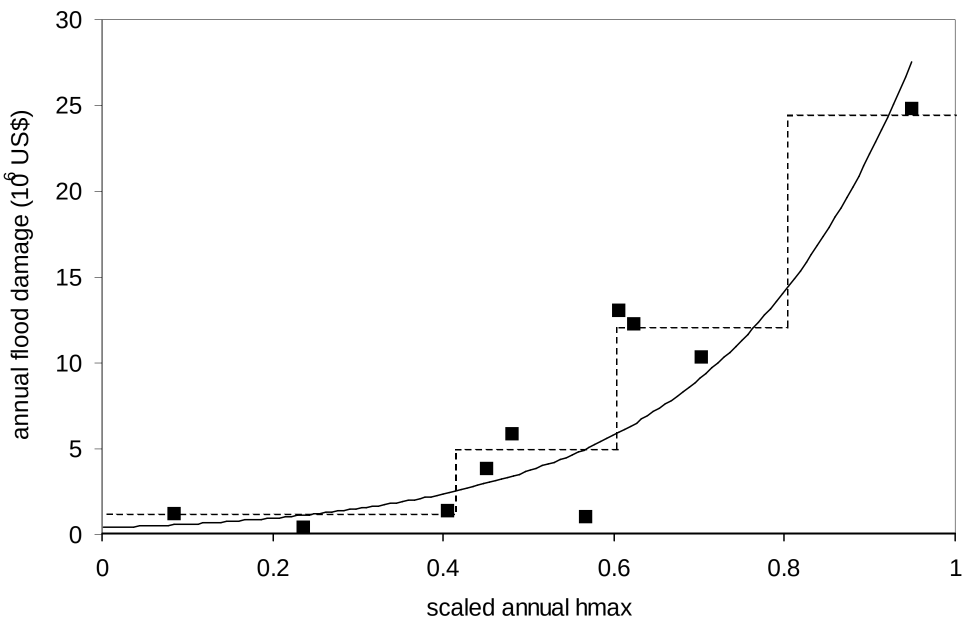

Figure 11 Total annual flood damage as a function of scaled annual maximum water level Tuyen Quang and fitted exponential and stepwise function.

5 Relations between immaterial and material flood damage

So far, only material flood damage has been considered, which can be expressed in monetary terms after some conversion. This is not the case for immaterial damage, such as the number of killed and injured people due to floods. However, these and other immaterial damage categories should obviously taken into account when considering and planning flood control measures (total number of killed people in Red River basin between 1990-2001 more than 1200). It is anything but clear how this should be done.

Here, the Belgian immaterial damage data and related total material damage data (see 3.1) are used to verify the total material damage (and related immaterial damage) as derived from the Vietnamese data. In total, material damage data are available for 16 out of 26 events in the Belgian data set in the period 1991-2001. It should be noted that these data are for the complete country of Vietnam, not only for the Red River basin. Figure 12 shows the relation between total flood damage and the number of killed people as derived from the Vietnamese data set (12 points) and the Belgian data set (16 points). There exists a reasonable relation between the two properties ($r > 0.9$ for both data sets). Moreover, point pairs from both data sets are in the same range, although the estimated total damage from the Vietnamese data is generally larger than the estimated damage from the Belgian data. This is also illustrated by the regression lines for both data sets. On the basis of these relations, data on the number of victims could be used as an indicator for the total flood damage, but obviously care should be taken in doing this.

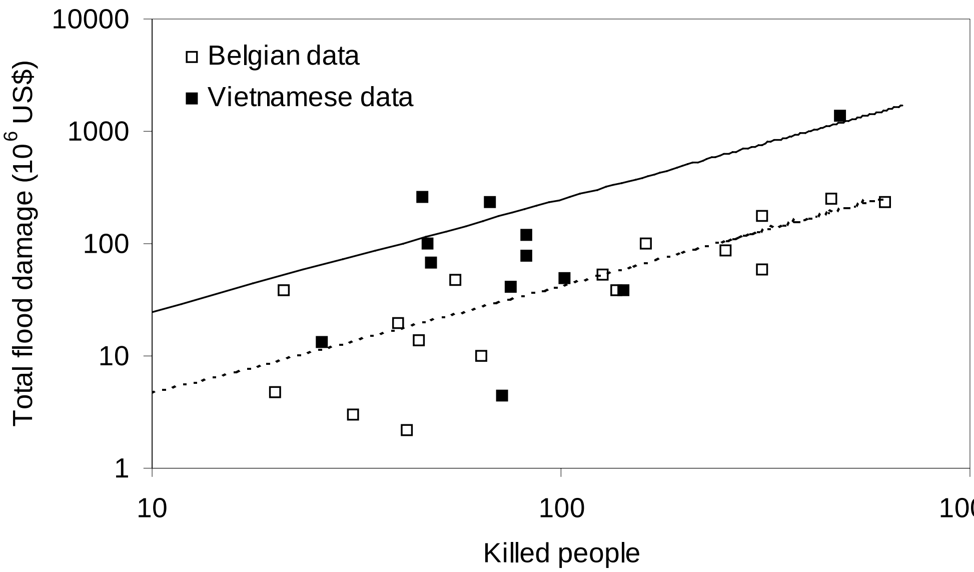

Figure 12 Total flood damage as a function of the number of killed people as derived from the Belgian and Vietnamese data set on a log-log scale. The solid line represents the linear regression to the Vietnamese data and the dashed line represents the linear regression to the Belgian data.

6 Conclusions

This paper has considered extreme water levels, flood damage and the relations between these variables for the Red River basin in Vietnam. It has been found that annual flood damage has a typical order of magnitude of 100-1000 million US$ and is highly uncertain. This uncertainty is caused by the lack of damage data, data on costs per unit damage and data on other damage categories, such as indirect damage and intangible damage. Therefore, flood damage functions, i.e. relations between flood damage and water levels, are uncertain as well. These functions can be improved by using, besides more damage data and data on costs per unit, maps with spatially distributed inundation depths.

Comparison of the typical order of magnitude of annual flood damage of 100-1000 million US$ with the Gross Domestic Product (GDP) of several economic sectors may reveal the importance of flood damage. The GDP for agriculture, industry, construction, services and all four sectors together in the Red River delta in 1997 was respectively 1000, 800, 300, 1700 and 3800 million US$ (MARD, 2002). As can be seen, minor floods constitute 1-5 % of the total GDP of the Red River delta and a major flood as in 1996 could cause flood damage with a magnitude of 20-50 % of the total GDP. This latter amount is comparable with the GDP of the biggest sectors agriculture and services. This emphasises again the importance of incorporating flood damage in the evaluation of flood control and ecosystem upgrading measures in a decision support system.

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