Assessment of damages caused by different flood types

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Abstract

Comprehensive risk assessments are essential to integrated, efficient flood management. However, investigations concentrate mainly on scenarios of slowly rising riverine floods and their loss assessment. The common loss models are focused on the water level as the primary factor determining damage, although, for example during flash floods, the velocity might be much more important. To improve the knowledge about flood losses and the loss-influencing factors, 1697 households affected by the Elbe and Danube flood in 2002 were interviewed. Cases affected by high groundwater levels, riverine floods, flash floods and dyke breaches were identified and separately analyzed. The four flood types show significantly different impact characteristics concerning the factors of water level, flood duration, flow velocity and contamination. In addition, the resulting losses differ significantly. Common loss models tested, i.e. stage-damage curves, were as such not suitable to estimate losses due to dyke breaches and high groundwater levels. Therefore, new loss models should be developed for these special flood situations.
Keywords: flash floods, flood loss, high groundwater levels, dyke breaches, riverine floods, impact, stage-damage curve.

1 Introduction

Comprehensive assessments that quantify the flood risk are essential for an efficient flood management [1–3]. Such analyses require the estimation of flood losses. A central idea in flood loss estimation is the concept of stage-damage curves, which have in common that direct monetary losses are mainly related to

www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/FRIAR100011

the type or use of the building and the inundation depth [3, 4]. This implies that slowly rising riverine floods are taken as the prototype for flooding [5], despite the fact that groundwater flooding, flash floods and dyke breaches also cause significant damage [6]. However, these flood types and differences in damaging processes have rarely been analysed. Exceptions are investigations of damage to the building structure, caused by physical pressure on the building due to high flow velocities in steep terrain or following dam or dyke breaches [7, 8].

The objective of the study is to analyse whether there are significant differences in the flood impact due to high groundwater levels, slowly rising riverine floods, flash floods and floods due to dyke breaches and whether these flood types cause significantly different flood losses in private households. It is analysed if common flood loss models, i.e. stage-damage curves are suitable to estimate losses due to these different flood situations.

2 Data and methods

The empirical data base resulted from computer-aided telephone interviews undertaken with 1697 households affected by the Elbe and Danube flood in 2002. With about 180 questions information about the flood impact, the losses, etc. were retrieved. Detailed descriptions of the survey, data processing and the development of indicators are published in [9, 10].

Interviews are identified as cases affected only by a high groundwater level, if people stated that 1) the water entered their building only from below and the water level was at maximum 50 cm (above the ground surface) or 2) the water entered their building from outside and below, but the main inundation source was groundwater and the water level was at most 50 cm (above the ground surface) [6]. According to these criteria, 264 interviewed households were identified as affected by high groundwater only. The differentiation between areas dominated by riverine floods and areas dominated by flash floods was undertaken on basis of topography and river morphology information as well as on basis of an analysis by Ulbrich et al. [11]. Thus, in total 594 interviewed households at the Elbe, the lower Mulde, the Danube, and the lower Regen were identified as riverine flood cases. And 577 interviewed households at the upper Mulde, in the Ore Mountains, at the upper Regen and the southern Danube tributaries were identified as flash flood cases. Areas close to dyke breaches (<500 m distance), and areas with many dyke breaches were characterised as "floods caused by dyke breaches" if flow direction, extent of the inundation area and the dyke location supported the decision. 262 interviews were selected as dyke breach cases.

A cluster analysis was performed with the four impact variables, i.e. water level, flood duration, flow velocity indicator and indicator for contamination to find groups with similar flood impact (Ward-Algorithm with squared Euclidian distance) [12]. To analyze the performance of stage-damage curves for flood loss modelling, a split sampling technique was applied [13]. The database with 1697 interviews was split into two equal parts as the datasets were put into the chronological order of undertaken interviews and every other was singled out. In a first step, loss models were developed on the basis of the first subset and were applied to the second subset, irrespective of the flood type. The second step was vice versa. Linear, square-root and polynomial stage-damage curves were applied for loss estimation as suggested by [14, 15]. For regressions between losses and the water level above ground surface, water levels below ground surface, i.e. if only the basement was affected, were set to zero. Additionally, stage-damage curves were calculated separated for the three classes of contamination. The performance of the loss models was evaluated by the ordinary bootstrap approach [16]. Confidence intervals for the mean loss ratios were calculated on the basis of 10000 simulated random samples of loss data which were drawn with replacement (bootstrap). The model performance was judged as sufficiently accurate, if the estimated mean loss ratios were within the 2.5%-97.5% confidence interval.

3 Results and discussion

3.1 Flood impact characteristic

All impact parameters, i.e. water level, flood duration, flow velocity indicator and contamination indicator, differ significantly between the four flood types (Table 1). High groundwater levels are characterised by a very low flood impact, i.e. lowest average water level, flow velocity indicator and contamination indicator and second lowest average flood duration. Riverine floods are characterised by the second highest average water level, flood duration and contamination indicator and a medium flow velocity indicator. Flash floods are characterised by the lowest average flood duration, the highest average flow velocity indicator and medium water levels and contaminations. Floods due to dyke breaches are characterised by a very high flood impact, i.e. highest average water level, flood duration and contamination indicator and a medium flow velocity indicator.

However, the variability of impact parameters within the flood type groups is high. The groundwater and flash flood cases are most heterogeneous, the dyke breach cases most homogenous. Due to this high data variability, nearly all seven impact clusters contain cases of all flood types. Exceptions are cluster 1 without groundwater cases and cluster 4 without dyke breach cases (Table 2). Cluster one is characterized by very high water levels, high flow velocity, medium flood duration and contamination. Cluster 4 is characterized by very low water levels and flow velocity as well as low flood duration and contamination. Most groundwater cases (58%) fall into the impact cluster 4. Most riverine flood cases fall into cluster 3 (26%) and 6 (26%). Cluster 3 is characterised by medium water levels and flood durations, low flow velocities and contamination. Cluster 6 is characterised by high water levels, medium flood durations, low flow velocities and high contamination. Most dyke breach cases fall into cluster 5 (32%) and 6 (29%). Cluster 5 is characterised by very high flood durations and medium water levels, velocities and contamination. Most flash flood cases fall into clusters 2

Table 1: Descriptive statistics of the flood impact parameters.

	water level* [cm]	duration [h]	flow velocity (indicator)	contaminatio n (indicator)
High groundwater level				
number of cases	257	258	264	263
25%-percentile	-170	12	stagnant	no
median	-108	48	moderate	no
mean	-102	116	0.8	0.3
75%-percentile	-32	120	moderate	medium
CV [%]	-82	180	104	175
Riverine flood				
number of cases	589	578	585	581
25%-percentile	40	48	moderate	no
median	112	96	moderate	medium
mean	124	167	1.3	0.8
75%-percentile	190	168	high	medium
CV [%]	116	116	40	91
Flash flood				
number of cases	566	568	576	567
25%-percentile	-60	10	moderate	no
median	41	24	high	medium
mean	37	54	1.7	0.6
75%-percentile	112	48	high	medium
CV [%]	394	219	35	107
Dyke breach				
number of cases	260	253	242	260
25%-percentile	110	120	moderate	medium
median	150	288	moderate	medium
mean	154	312	1.4	1.0
75%-percentile	189	357	high	medium
CV [%]	64	82	39	69

(26%) and 7 (25%). Cluster 2 is characterised by low water levels, flood durations and contamination and high flow velocities. Cluster 7 is characterised by high water levels, flow velocities and contamination, and low flood duration.

3.2 Loss characteristics

The different flood impact characteristics lead to significantly different flood losses for buildings and contents affected by the four different flood types (Fig. 1). Expectedly, high groundwater levels result in the lowest absolute and relative losses to buildings and contents. Floods due to dyke breaches lead to the highest losses (Fig. 1). Median losses due to riverine floods are higher than those caused by flash floods.

Table 2: Mean values of flood impact variables in seven clusters and the total data set as well as the fractions of the flood type cases (GW = high groundwater level; RF = riverine flood; FF = flash flood; DB = dyke breach) within each cluster.

	flood impact variables				fractions of flood type cases			
cluster	water level* [cm]	dura -tion [h]	velo-city (ind.)	cont. (ind.)	GW cases [%]	RF cases [%]	FF cases [%]	DB cases [%]
1	306	89	2.0	0.7	0	11	10	5
2	-28	54	2.0	0.2	18	6	26	6
3	99	92	1.0	0.2	9	26	14	15
4	-124	59	0.6	0.2	58	8	15	0
5	93	590	1.3	0.9	7	13	2	32
6	119	141	1.0	1.3	4	26	8	29
7	105	71	2.1	1.4	4	10	25	13
total	64	143	1.4	0.7	100	100	100	100

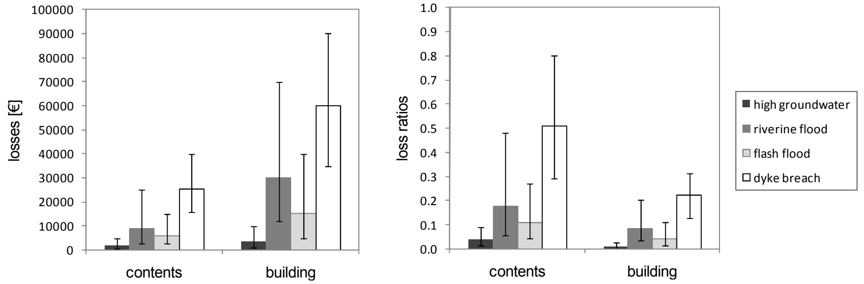

Figure 1: Absolute losses and loss ratios of buildings and contents separated for the four flood types (median, 25%-, 75%-percentiles).

A correlation analysis reveals that water levels and contaminations are significantly correlated with the losses for all four flood types (Table 3). Water levels and losses show the highest correlation coefficients, confirming it to be the main loss influencing factor. Correlations between flood duration and losses are not significant for high groundwater levels, and only partly significant for the other flood types. Correlations between flow velocity and losses are only significant for flash floods. This is in accordance with a study [17] which concluded that a general consideration of flow velocity in flood loss modelling cannot be recommended. More detailed information about impact and resistance factors influencing the losses in respect to this database were published in [10].

3.3 Modelling of losses

Assuming that only loss models whose estimates fall within the 95% confidence interval of the resampled loss ratios are acceptable, the simulations reveal that

Table 3: Correlations between impact factors and resulting losses divided for the four flood types: Sperman-Rho (pair-wise data exclusion; * correlation is significant).

	water level [cm]	duration [h]	flow velocity (indicator)	conta-mination (indicator)
High groundwater level				
absolute building losses [€]	0.41*	0.13	0.09	0.22*
absolute contents losses [€]	0.31*	0.07	0.06	0.23*
building loss ratios	0.35*	0.11	0.03	0.19*
contents loss ratios	0.38*	0.14	0.04	0.25*
Riverine flood				
absolute building losses [€]	0.52*	0.19*	0.12*	0.26*
absolute contents losses [€]	0.34*	0.06	-0.03	0.16*
building loss ratios	0.54*	0.16*	0.09	0.28*
contents loss ratios	0.35*	0.09	-0.02	0.16*
Flash flood				
absolute building losses [€]	0.58*	0.34*	0.37*	0.41*
absolute contents losses [€]	0.39*	0.04	0.14*	0.22*
building loss ratios	0.56*	0.35*	0.35*	0.40*
contents loss ratios	0.45*	0.13*	0.22*	0.24*
Dyke breach				
absolute building losses [€]	0.30*	0.17*	-0.04	0.30*
absolute contents losses [€]	0.33*	0.15*	-0.13	0.21*
building loss ratios	0.33*	0.12	-0.07	0.18*
contents loss ratios	0.32*	0.12	-0.09	0.19*

stage-damage curves fail to estimate the loss ratios due to high groundwater levels and due to dyke breaches with sufficient accuracy (Fig. 2). The consideration of the two impact factors water level and contamination in the loss models lead to marginal improvements only (Fig. 2). Most stage-damage curves overestimate the observed loss ratios of buildings and contents caused by high groundwater levels. This is in accordance with previous findings [6]. Results are even worse for dyke breaches. All stage-damage curves by far underestimate the observed loss ratios of buildings and contents caused by floods due to dyke breaches (Fig. 2). In contrast, stage-damage curves were relatively well able to estimate the building and contents loss ratios caused by riverine and flash floods. Some problems of overestimation existed concerning the building loss ratios of part 2 and the contents loss ratio of part 1 for both flood types (Fig. 2).

4 Conclusions

The four flood types of high groundwater levels, riverine floods, flash floods and floods due to dyke breaches show significantly different impact characteristics

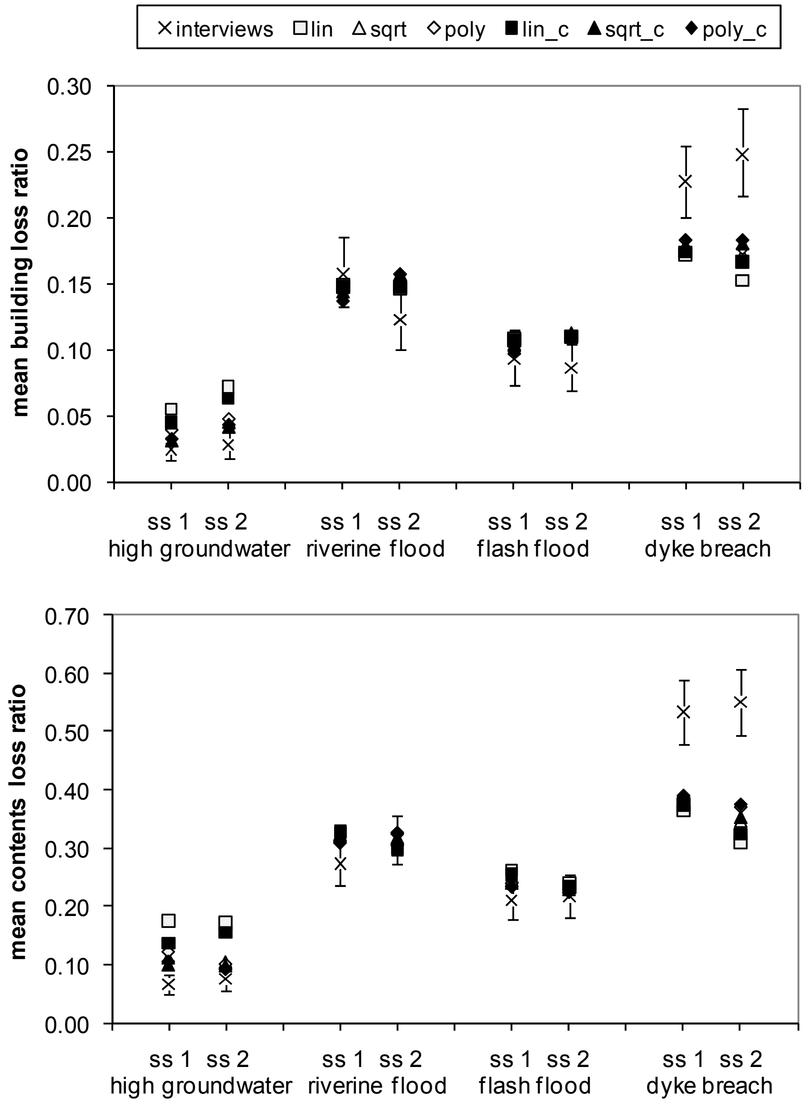

Figure 2: Surveyed and estimated mean ratios of losses to buildings and contents caused by the four flood types. For the surveyed data the mean and the 2.5% to 97.5% confidence intervals, calculated by bootstrap, are shown.

concerning the factors water level, flood duration, flow velocity and contamination. High groundwater levels are characterised by a very low flood impact. Floods due to dyke breaches are characterised by a very high flood impact. The resulting losses differ significantly, with lowest losses for cases affected by high groundwater levels followed by cases affected by flash floods, cases affected by riverine floods and highest losses for cases affected by floods due to dyke breaches. Still, impact factors as well as damage data are highly variable within the flood type groups. The factors water level and contamination are significantly correlated with the losses for all four flood types. However, common loss models tested, i.e. stage-damage curves with and without taking contamination into account, were as such not suitable to estimate losses due to dyke breaches and high groundwater levels. Therefore, new loss models should be developed for these special flood situations. For instance, in [6] it is suggested to develop loss models for high groundwater levels just on basis of loss data from cases affected by high groundwater levels and to take more predictive variables besides the water level into account.

Acknowledgements

The telephone interviews were undertaken within the German Research Network Natural Disasters (DFNK) in cooperation between the Section Hydrology at the GFZ and the Deutsche Rückversicherung AG. We thank the Deutsche Rückversicherung AG and the German Ministry for Education and Research (BMBF) (no. 01SFR9969/5) for the financial support.

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