Flood risk analysis in the Meuse river basin

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Abstract

This paper analyses the hydrological effects of climate change on flood risk along river Meuse with a focus on economic damage on the Belgian part of the basin (Wallonia). Nevertheless, the approach is developed in the scope of a transnational effort to achieve consistent flood risk management throughout the international basin of river Meuse.

We first review hydrological scenarios which have been developed at the scale of the Meuse basin. Next, we describe how hydraulic modeling has been conducted to produce the necessary flood maps for the subsequent exposure and vulnerability analyses.

The risk modeling employing a monetary approach, was performed at a meso-scale using European land use maps (CORINE) and regional geographic database (PLI), aggregated into a set of five damage categories.

For each damage category, appropriate damage functions and specific values have been used. In this paper, the focus is set on comparing several approaches to calculate the specific price of the residential land-use category in Wallonia. Through a sensitivity analysis, we show the influence on flood risk of using these different approaches as well as several damage functions and climate change scenarios.

Introduction

To investigate the effect of climate change on flood risk in the Meuse basin, hazard modeling has been conducted to obtain flood maps, accounting for various hydrological scenarios.

A wet scenario has been get up to evaluate flood risk while a dry one has been designed to assess the impacts of low flows on various economic sectors (energy, shipping, water supply and agriculture). The former corresponds to, respectively, an increase by 15% and 30% of the present Q_{100} for the time horizons 2020-2050 and 2070-2100 [1].

Next, accurate hydraulic simulations have been performed with the fully dynamic flow model WOLF2D developed at the University of Liege [2]-[3].

The outcomes of this inundation modeling including flood extent, water depth and flow velocity have been processed to constitute suitable inputs for the subsequent exposure analysis which has been performed at a meso-scale using the European land cover CORINE and the regional geographic database PLI. The latter covers the Walloon region and contains cadastral boundaries of regions, provinces, municipalities as well as characteristics about single buildings such as like their surface, nature…

Exposure analysis

From CORINE database, 44 land cover categories were selected and aggregated into a set of five damage categories: Settlement/Residential Area, Industrial/Manufacture, Traffic/Infrastructure, Agriculture and Forest. Furthermore, these information were completed

with cadastral boundaries from PLI. Each polygon of this combined land-use map was thus characterized by one damage category and a set of cadastral data.
The land-use map and the Q_{100} flood map in the base scenario have been combined to evaluate relative contribution of each damage category in the overall inundation extent (Figure 1).

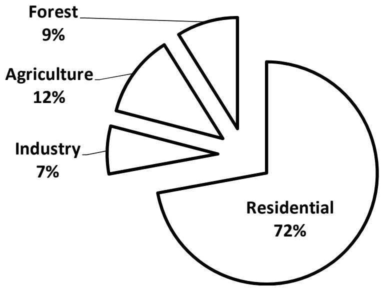

Figure 1: Flooded area distribution for Q_{100} in Wallonia

The average water depth being of the same order of magnitude in all these damage categories, the residential damage category will obviously be dominant in the overall damage. This has also been verified to remain valid for the other hydrological scenarios (Figure 2).

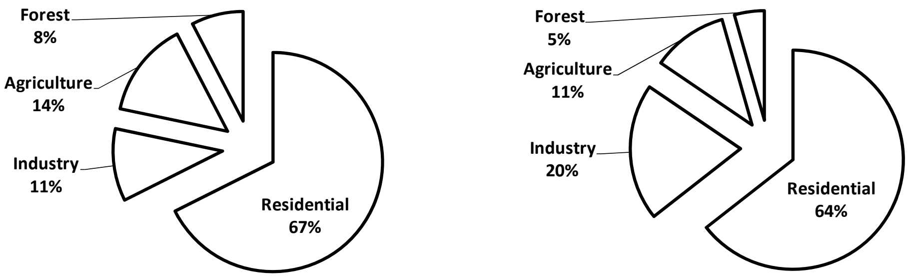

Figure 2: Flooded area distribution for $Q_{100+15\%}$ (left) and $Q_{100+30\%}$ (right) in Wallonia

Vulnerability analysis

Evaluating the monetary damage requires the knowledge of a specific price for each indentified damage category as well as corresponding damage functions translating the intensity of the damage encountered by the assets as a function of the inundation characteristics:

$$D_{€} = S_{CORINE} \times D_{\%} \times P_{spec} \quad (1)$$

with D the monetary damage [€]; S_{CORINE} the flooded surface [m²]; $D_{\%}$ the relative damage [-] ; P_{spec} the specific value [€/m²]. For the reason mentioned above, the focus was set on the residential damage category.

Specific prices

The formula applied to calculate the specific price P_{spec} is:

$$P_{spec} = \frac{P \times N}{S} \quad (2)$$

with P the price per house [€]; N the number of houses [-]; S the considered surface [m²].

P was calculated using statistics from *SPF Economie*. This governmental body delivers annually and for each municipality, the number and value of real estate transactions and the associated surface. A ten-year sample (from 2000 to 2009) has been considered. All the values have been updated to 2009, the reference year, using the ABEX index, which reflects the cost of housing construction in Belgium. Applying that methodology, an average price of 111 000 € per house has been obtained for the flooded municipalities.

The surface associated to the aggregated residential damage category has been calculated from CORINE database.

In addition, the number and characteristics (nature, surface…) of buildings being contained in the PLI database, N and S could be extracted from PLI as well.

Nevertheless, when using PLI database to get N or S, two possibilities exist, depending on which buildings natures are taken into account.

In the first case, N and S are both associated to the same housing category, being thus consistent with the definition of P. In the second case, they designate buildings which natures correspond to the definition of the aggregated CORINE residential damage category. In the latter approach, the number of building associated to a PLI category must be adapted to correspond to P which is a price per house. Therefore, N_i, the number of buildings in PLI category i, is multiplied by S_i/S_h, with

- S_i the average surface of considered buildings surface ;
- S_h the average houses surface.

That approach is consistent with the global risk analysis process.

A last methodology proposed consisted in using only SPF Economie database to calculate all component of P_{spec}.

That analysis finally leads to five options for assessing the specific value of the residential damage category, depending on the methodology employed to calculate the surface and the number of buildings.

Table 1: Specific values of the residential damage category

N°	Surface	Number of buildings	Type of buildings	Specific value [€/m²]	Relation to n°4
1	PLI	PLI	Houses	167	149%
2	SPF	SPF	Houses	187	167%
3	CORINE	PLI	Houses	75	67%
4	CORINE	PLI	All urban buildings	112	100%
5	CORINE	PLI	All urban buildings	per municipality	[48% - 260 %]

The damage calculated with (1) refers to CORINE surface. Consequently, the method which seems the most consistent is the 4th one, associating the housing price from *SPF* Economie database, surface from *CORINE* and a house-equivalent number of buildings from *PLI,* corresponding to CORINE damage category definition. According to that methodology, we have also considered a spatial distribution for P_{spec} in each municipality.

The specific prices for the other damage categories are based on the results of the Rhine Atlas, a similar transnational study concerning the Rhine Basin. In that study, the specific values of the agriculture and forest damage categories were identical for all involved countries, respectively 7€ and 1€. The specific prices for Industrial and Traffic damage categories had the same order of magnitude as the residential one. Their mean ratio with respect to the residential damage categories have been calculated and applied to the five different specific prices contained in Table 1.

Damage functions

Damage functions link the relative damage to hydraulic parameters, mainly water depth. The state-of-the-art FLEMO [4-5] damage functions have been used for the residential damage category. An upper and a lower bound of values have been considered for the relative damage. For the other damage categories, appropriate damage functions have been chosen in literature.

Sensitivity analysis

A sensitivity analyses has been carried out in order to study the impact on the overall damage of the specific price, the residential damage function and the climate change scenarios.

Specific prices

In this analysis, the specific values of the industrial and traffic damage categories have been assumed proportional to the residential specific value. In addition, the specific values for agriculture and forest damage categories are small in comparison with the others. Therefore, given equation (1), the resulting damages vary almost linearly with the specific value of residential damage category. This has been verified and validated through complete flood damage evaluations. Consequently, the potential damage is found very sensitive to the selected specific prices; nevertheless, we focus the rest of the analysis on the fourth approach in Table 1.

Flemo Dammage functions

The three FLEMO damage functions have been compared for Q_{100} and a set of specific prices based on the fourth approach in Table 1. The left side of Figure 3 shows the influence of the damage function on overall damage.

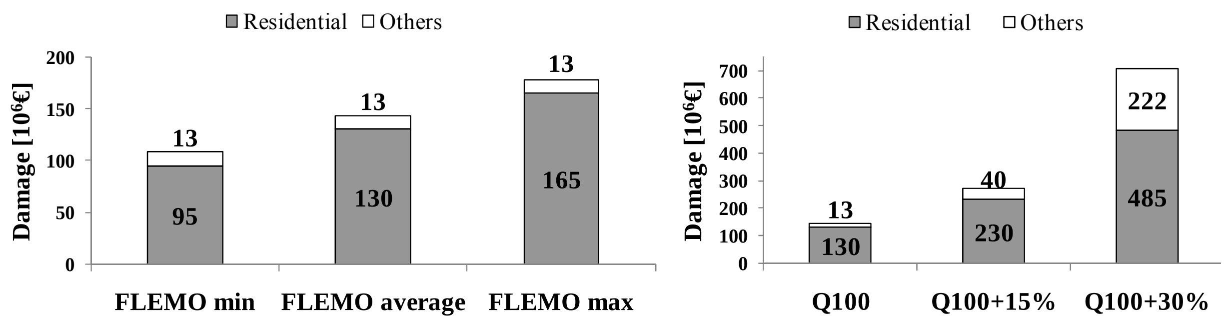

Figure 3: Comparison of total damage considering different FLEMO damage functions for Q_{100} (left) and different hydrological scenarios with the mean FLEMO function (right).

In the case study, the total damage evolves almost proportionally with the change in the relative damage given by the residential damage function. As for the specific price, this results from the dominant proportion of residential flooded areas and the low specific prices for agriculture and forest damage categories.

Hydrological scenarios

The two hydrological scenarios $Q_{100+15\%}$ and $Q_{100+30\%}$ have been compared to the base scenario to evaluate the impact of climate change on the potential economic damage. The fourth set of specific values (Table 1) and the mean FLEMO damage function have been employed. As can be seen on the right side of Figure 3, beyond the severe increase of the total damage, the relative contributions to damage and inundated areas (Figures 1 and 2) considerably change. The industrial damage category, for which the specific price is of the same order of magnitude as for the residential one, also undergoes considerable increases which have a significant impact on the total damage value and distribution.
Table 2 summarizes the total damage obtained for all the considered cases.

Table 2: Comparison of the total damage

	Damage [millions €]			
Residential Specific Price [€/m²]	112		Distributed	
Q_{100}	108	143	179	109
$Q_{100+15\%}$	209	270	332	216
$Q_{100+30\%}$	580	707	835	888
$Q_{100+15\%}/ Q_{100}$	1,89	1,93	1,86	1,98
$Q_{100+30\%}/ Q_{100}$	5,36	4,94	4,68	8,15

The ratio on the last two lines reflects the increase of the total damage for the two hydrological scenarios. For the same damage function (FLEMO average) and hydrological scenario ($Q_{100+30\%}$), using a single or a set of spatially distributed specific values highly modifies the damage obtained. As shown in Figure 4, the two main municipalities, Liège and Namur, are both highly affected by the inundation.

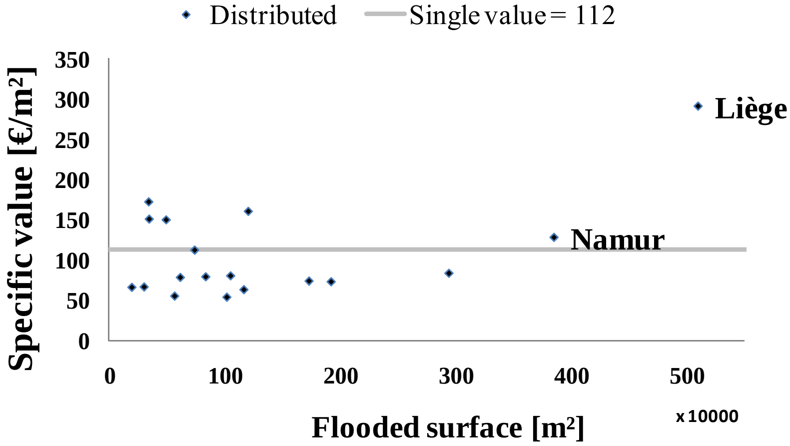

Figure 4: Specific values and flooded area for the residential damage category in the flooded municipalities of Wallonia for $Q_{100+30\%}$

In addition, their specific values are higher than the single value used in the compared analysis. Figure 5 clearly illustrates the consequences of that double effect which also explains the difference observed in Table 2 between the two methods.

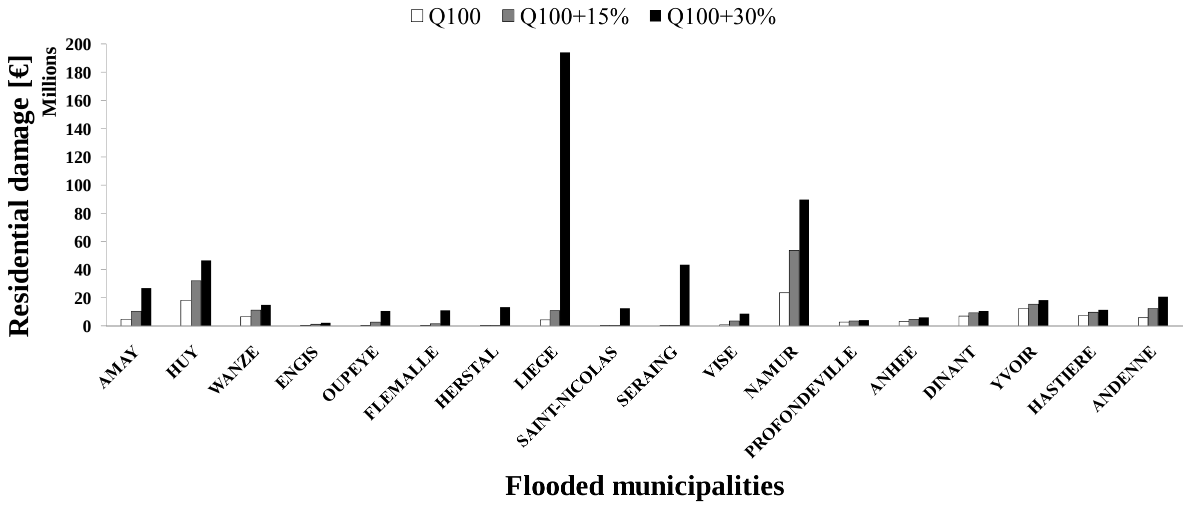

Figure 5: Spatial distribution of the residential damage for Q_{100}, $Q_{100+15\%}$, $Q_{100+30\%}$

Conclusion

In this paper, we have first shown the importance of focusing on the residential sector in the Walloon region when leading a flood risk analysis of the Meuse river basin. A corresponding relative damage function has been selected and its influence on final results studied.

We have also described different approaches to evaluate specific values for the residential economic sector. Given the scattering of the values obtained, these alternatives have been compared, studying their impacts on the total damage.

In addition, for a given methodology, it has been demonstrated that distributing spatially the specific value has a huge influence on final results.

Finally, two hydrological scenarios $Q_{100+15\%}$ and $Q_{100+30\%}$ have been compared to the base scenario in order to understand the climate change impact on the economic damage. In particular, the difference between the single value and distributed value methods has been explained by the dominant contribution of a limited number of heavily inundated towns and cities such as Namur and Liège.

Acknowledgements

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