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Research article

Effects of spatial planning on future flood risks in urban environments

Ahmed Mustafa[a,*], Martin Bruwier[b], Pierre Archambeau[b], Sébastian Erpicum[b], Michel Pirotton[b], Benjamin Dewals[b], Jacques Teller[a]

[a] *LEMA, Urban and Environmental Engineering Department, Liège University, Belgium*
[b] *HECE, Urban and Environmental Engineering Department, Liège University, Belgium*

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ABSTRACT

Urban development may increase the risk of future floods because of local changes in hydrological conditions and an increase in flood exposure that arises from an increasing population and expanding infrastructure within flood-prone zones. Existing urban land use change models generally consider the expansion process and do not consider the densification of existing urban areas. In this paper, we simulate 24 possible urbanization scenarios in Wallonia region (Belgium) until 2100. These scenarios are generated using an agent-based model that considers urban expansion and densification as well as development restrictions in flood-prone zones. The extents of inundation and water depths for each scenario are determined by the WOLF 2D hydraulic model for steady floods corresponding to return periods of 25, 50, and 100 years. Our results show that future flood damages and their spatial distributions vary remarkably from one urbanization scenario to another. A spatial planning policy oriented towards strict development control in flood-prone zones leads to a substantial mitigation of the increased flood damage. By contrast, a spatial planning policy exclusively oriented to infill development with no development restrictions in flood-prone zones would be the most detrimental in terms of exposure to flood risk. Our study enables the identification of the most sensitive locations for flood damage related to urban development, which can help in the design of more resilient spatial planning strategies and localize zones with high levels of flood risk for each scenario.

1. Introduction

The magnitude and frequency of floods, particularly river floods, are currently increasing in northwest Europe (Moel and Aerts, 2010). Climate change and urban development are key elements contributing to increased flood damage (Poelmans et al., 2011). Urbanization increases the damage due to flood exposure caused by the increasing population and infrastructure within flood-prone zones. In addition, transforming natural surfaces into artificial surfaces causes an increase in flooding frequency because of poor infiltration (Huong and Pathirana, 2013). Recent studies have shown different effects of climate change and urban development on flood risk (e.g., Löschner et al., 2017). The Intergovernmental Panel on Climate Change claimed, with low confidence, that climate change has affected the frequency and magnitude of flooding (IPCC, 2014). Poelmans et al. (2011) and Beckers et al. (2013) investigated the relative impact of both climate change and future urban expansion on floods. Poelmans et al. (2011) found that the potential flood-related damage was mainly influenced by urbanization on the floodplains. Similar results were obtained by Beckers et al. (2013) in a “dry” climate scenario, while climate change is more influential in a “wet” scenario. Hannaford (2015) found that changes in peak flows could not be directly attributed to climate change across the United Kingdom. Cammerer et al. (2013) analyzed potential changes in future flood exposure because of different land use developments and found that the range of potential changes in flood-exposed residential areas varies from no further change to 159% increase depending on the spatial planning scenarios.

Previous studies that coupled urban development scenarios with hydrological models using a spatial resolution between 50 m and 100 m (e.g., Beckers et al., 2013; Cammerer et al., 2013; Poelmans et al., 2010; Tang et al., 2005) considered only urban expansion processes, i.e., transitions from nonurban to urban land use. Such a binary process may fail to estimate the damage related to floods properly because it neglects the different densities of urban cells and the variation in density over time. Some studies used vector data for small urban areas (e.g., Achleitner et al., 2016). However, the drawback of using such a vector data is that it requires intensive computational resources to simulate future urbanization in larger study areas such as regions.

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* Corresponding author. Liège University, LEMA, Allée de la Découverte 9, Quartier Polytech 1, 4000, Liège, Belgium.
E-mail addresses: a.mustafa@uliege.be (A. Mustafa), mbruwier@uliege.be (M. Bruwier), pierre.archambeau@uliege.be (P. Archambeau), s.erpicum@uliege.be (S. Erpicum), michel.pirotton@uliege.be (M. Pirotton), b.dewals@uliege.be (B. Dewals), jacques.teller@uliege.be (J. Teller).

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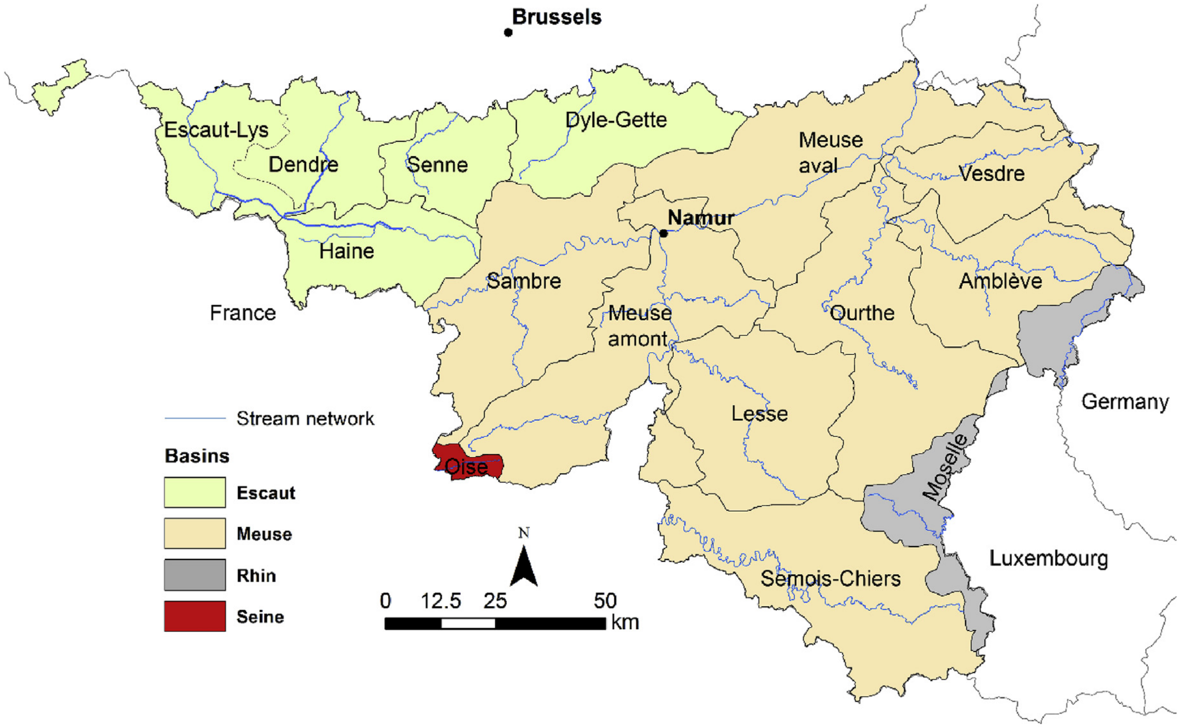

Fig. 1. The four hydrographic districts and 15 hydrographic subbasins in Wallonia (Belgium).

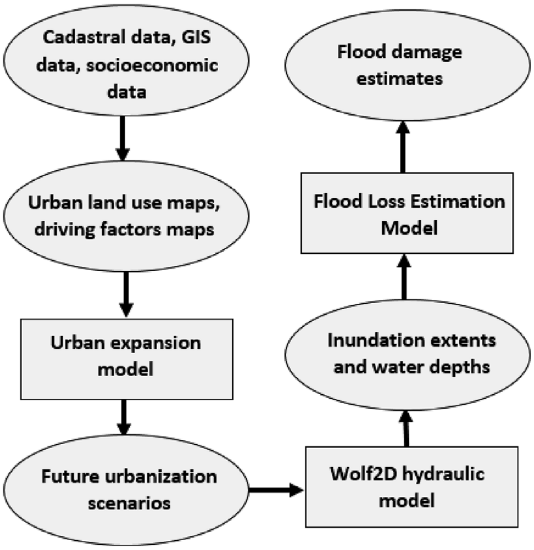

Fig. 2. Flowchart explaining the methodological structure.

This study investigates the possibility of flood damage related to different urban development scenarios in Wallonia region (Belgium) if there is no further climate change. The main contribution of our study is the evaluation of the impacts on flood damages from spatial planning policies that consider expansion versus densification processes compared with spatial planning policies oriented towards development restrictions in flood-prone zones.

2. Materials and methods

2.1. Study area

Wallonia covers an area of 16,844 km^2 in southern Belgium (Fig. 1). Its hydrographic network is structured along four hydrographic districts (Meuse, Rhine, Escaut Scheldt or Seine basin), 15 hydrographic subbasins and 6208 so-called PARIS sectors, each of which corresponds to a river stretch with relatively homogeneous characteristics in the main riverbed and in the floodplains. In this study, we only consider the two main districts of Meuse and Escaut, which cover 73% and 22% of Wallonia, respectively. The areas of most subbasins in the Meuse district are larger than in the Escaut district, while the population density is generally lower in the former. The Meuse aval subbasin is the largest in Wallonia and the most densely inhabited in the Meuse district. Four subbasins in the Meuse district have a population density lower than 100 inhabitants/km^2, while it is higher than 175 inhabitants/km^2 for all subbasins in the Escaut district (DGO3 2015a, 2015b). The Meuse district is mainly covered by agricultural uses and forests. The average annual precipitation ranges between 1000 and 1400 mm and snowmelt may influence flood discharges in some parts of the Meuse district. The Escaut district is mainly covered by agriculture and built-up uses. The average annual precipitation in the Escaut district is between 700 and 850 mm. In both districts, high flows generally occur in winter and low flows in summer, following the rainfall–evaporation regime.

2.2. Methodology

Our methodology to assess flood damage for different urbanization scenarios consists of three main steps (Fig. 2). Firstly, urban land use data for 1990, 2000 and 2010 were generated based on Belgian cadastral data. Thereafter, future urbanization scenarios were simulated for 2030, 2050, 2070, and 2100 by extrapolating the observed demand rates for urban development. New urban cells were then allocated using a spatial agent-based model (ABM). Secondly, inundation maps were computed for flood discharges with the WOLF 2D hydraulic model (Bruwier et al., 2015; Ernst et al., 2010). Thirdly, the future urbanization maps were combined with the computed inundations maps to evaluate the flood damage for each future urbanization scenario using a flood loss estimation model (FLEMO).

2.2.1. Future urbanization scenarios

2.2.1.1. Data. Urban land use data for 1990, 2000, and 2010 were