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Pluvial, urban flood mechanisms and characteristics – Assessment based on insurance claims

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ABSTRACT

Pluvial flooding is a problem in many cities and for city planning purpose the mechanisms behind pluvial flooding are of interest. Previous studies seldom use insurance claim data to analyse city scale characteristics that lead to flooding. In the present study, two long time series (~20 years) of flood claims from property owners have been collected and analysed in detail to investigate the mechanisms and characteristics leading to urban flooding. The flood claim data come from the municipal water utility company and property owners with insurance that covers property loss from overland flooding, groundwater intrusion through basement walls and flooding from the drainage system. These data are used as a proxy for flood severity for several events in the Swedish city of Malmö. It is discussed which rainfall characteristics give most flooding and why some rainfall events do not lead to severe flooding, how city scale topography and sewerage system type influence spatial distribution of flood claims, and which impact high sea level has on flooding in Malmö. Three severe flood events are described in detail and compared with a number of smaller flood events. It was found that the main mechanisms and characteristics of flood extent and its spatial distribution in Malmö are intensity and spatial distribution of rainfall, distance to the main sewer system as well as overland flow paths, and type of drainage system, while high sea level has little impact on the flood extent. Finally, measures that could be taken to lower the flood risk in Malmö, and other cities with similar characteristics, are discussed.

1. Introduction

Extreme rainfall leads to pluvial flooding in many cities, affecting many people (Houston et al., 2011). Extensive urban and suburban growth in combination with insufficient sewer systems (Swan, 2010) as well as climate change (Semadeni-Davies et al., 2008a,b) aggravates the problem. Pluvial flooding is becoming less accepted as society is becoming more reliant on highly developed, power supply dependent technology and as cities are becoming more densely populated. Property owners pay service fees and expect that the drainage system shall work properly (Schmitt et al., 2004). Where flooding earlier was seen as an unforeseen event that cities could not afford to prevent from happening, awareness is rising that cities can be better prepared for flooding by using flood warning systems, by implementing measures that can lower peak runoff through retention, and by leading excess flow to less vulnerable places. It is however expensive to increase the drainage capacity in cities, even when multiple-purpose solutions, e.g. blue-green infrastructure, are used. For strategic reasons, it is therefore necessary to identify in which environments rains of different characters, or combinations of rain and high receiving water levels, contribute to flooding and what the characteristics of flood-threatened areas are. Thus, it is our objective to investigate the mechanisms and characteristics of urban, pluvial flooding.

Several studies have sought mechanisms behind urban flooding. Akukwe (2014) collected data from questionnaires and interviews. Two thirds of the flooding in Port Harcourt Metropolis, Nigeria, could be explained by human-induced factors like unplanned urban development and poor drainage capacity, which can be influenced by city planners, while the biggest factor, rainfall, cannot. While information from the public can be used to identify problems in the drainage system, the physical drivers behind pluvial flooding can barely be understood by questionnaires and interviews solely. ten Veldhuis et al. (2009) analysed data from a complaint register, which might give a better understanding of the mechanisms. They found that the most important contribution to flooding in Haarlem, the Netherlands, was gully pot blockage (79% of reported complaints), while the contribution of heavy storm events were much lower (5%). Torgersen et al. (2015) used insurance data to study the relation between extreme rainfall and urban flooding and found that long-lasting, but less intensive,

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rainfall lead to more flooding than shorter, intensive rainfall in Fredrikstad, Norway.

Studies on causality of fluvial flooding are more prevalent, as there are more data available from rivers and more methods of analysis developed than for urban, pluvial flooding. There are interesting lessons to learn both about climatological (Glaser et al., 2010) and hydrological (Berghuijs et al., 2016) drivers as well as the effect of human activities (Zhang et al., 2014). Every river catchment is unique and flood frequency patterns must be understood independently (Glaser et al., 2010). Pluvial flooding acts on a different scale than fluvial flooding, where mechanisms and characteristics are functioning differently. Consequently, research is needed to investigate mechanisms and characteristics also for pluvial flooding.

In the present study of pluvial, urban flooding, two long time series (∼20 years) of flood claims in Malmö, Sweden, have been collected and analysed. The data come from a municipal water utility company and from an insurance company that covers property loss from overland flooding, groundwater intrusion through basement walls and flooding from the drainage system. The flood claims are used as a proxy for flood severity for different events. As the addresses for all claims are included in the datasets, they are suitable for spatial analysis. The flood claim data give a good measure of flood extent during both minor flood events and more severe flood events, and in combination with climatic data and characteristics of urban drainage, topography, etc., the mechanisms of urban, pluvial flooding are analysed and discussed.

Insurance claim data have recently been used for various other studies, e.g. statistical analysis to determine distribution of extreme events (Smith and Goodman, 2000), and to explain flood variability related to sewer flooding with rainfall data in Aarhus, Denmark (Spekkers et al., 2013b). Spekkers et al. (2013a) analysed the relation between flood claims and rainfall extremes for the Netherlands. They were able to explain some of the spatial variance in flood magnitude with spatial distribution of the rainfall, while a considerable fraction could not be explained. Zhou et al. (2013) tried to find a relation between hourly and daily rainfall and flood related costs, but could only explain some of the flood related costs variance by rainfall intensities. Spekkers et al. (2013b) suggest that further research is needed where factors that may potentially influence the severity of flooding, such as topography, building and household characteristics, urban drainage characteristics and spatial distribution of rainfall are evaluated. Some of these parameters, i.e. topography, urban drainage and spatial distribution of rainfall, are analysed and discussed in the present article together with other parameters, such as sea level and historical existence of watercourses in the urban landscape.

The main objective of the present study is to analyse mechanisms and characteristics of urban, pluvial flooding on city-scale. It is discussed which rainfall characteristics result in most flooding and why some extreme rainfall events do not lead to severe flooding. The relation between topography and flood extent under different rainfall characteristics are analysed, and the influence of high sea level is also discussed.

The detailed research questions are

- Which are the most important mechanisms and characteristics that influence flood extent and its spatial distribution?
- Can any spatial patterns of flooding be identified?
- Is the spatial pattern consistent for different rainfall events with similar distribution?
- What are the consequences of extreme rainfall with different spatial and temporary patterns?

In the following sections, we first introduce the study site, Malmö, Sweden, and the data used in the study. Second, we present the methodology by which the data are analysed. Then, the relation between flooding and different mechanisms and characteristics, i.e. rainfall, sea level, topography, and drainage system type, are analysed and discussed. After these sections, three severe and recent flood events are described and discussed. A flood hazard map from City of Malmö is discussed. Finally, after a summary of the most important results, potential strategies for Malmö and data reliability are discussed.

2. Study site and data

The city of Malmö, Sweden, was selected as study site since, in the Scandinavian context, Malmö is a large city, where there have been several flood events in recent years. Like in many other cities, the more densely built areas have sewer systems where stormwater and sewerage are drained with one single pipe (combined system), leading to high risk of basement flooding. The sewer system in Malmö is representative for Scandinavian cities, with a mix of combined and separate sewers. Good quality data on flood extent, precipitation, topography, sewerage system, etc. are available. Malmö is also well known within the field of urban hydrology, as the city was an early starter in the work with integrated water management (Niemczynowicz, 1999; Stahre, 2008).

As the focus is urban, pluvial flooding, only urbanised areas of Malmö were included in the study. A boundary of the study area was drawn, restricted by the outer ring road in south and east, by the municipal border in northeast and by the coastline in north and west (Figs. 1 and 3).

In the following section, data are described that relates to urban, pluvial flooding, including meteorological factors (e.g. rainfall depth and duration), hydrological factors (e.g. topography and watercourses) and factors related to the drainage system (e.g. type of system).

2.1. The urban landscape

Malmö is the third biggest city of Sweden with a population of 320,000 (SCB, 2015), situated in the very south of the country (Fig. 1). The city of Malmö went through a rapid urbanisation from mid-19th century until the 1970s and again after the 1990s. Land between smaller villages that were located outside Malmö in 1940, during the first period of urbanisation, is today (2017) urbanised. Places like Limhamn, Bunkeflo, Fosie and V. Skrävlinge are now well-integrated parts of Malmö and the population has doubled since 1940. The urban part of Malmö has an area of 7681 hectares, where approximately half of it is impermeable (SCB, 2016).

2.2. Geology and watercourses

Malmö is situated in a flat landscape where the highest elevation is 37 m above sea level. The bedrock consists of limestone, which generally is covered with clayey till (Länsstyrelsen Skåne, 2016). The Riseberga Brook runs from south to north in the eastern part of the city connecting to the Sege Brook short before it reaches the sea north of Malmö. The two brooks can be seen in some of the oldest maps of Malmö (Provincial map, late 1600s; Biurman, 1752). In addition to these, presently open brooks, a watercourse in western Malmö is shown on the old maps, reaching from Bunkeflo in southwest to Slottsstaden. A map from 1940 shows that (probably) the same watercourse was still noticeable at this time, as well as a watercourse reaching from Mariedal/Kulladal in south to Pildammsstaden. None of these watercourses is visible in the urban landscape anymore, as they have been drained in pipes. A canal surrounding the inner part of the city tracks back in history to at least late 17th century and is culturally an important landscape feature in the city. Many combined sewerage overflows (CSOs) pollute the canal during rainfall. There are no lakes in Malmö.