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Climate change impact assessment on urban rainfall extremes and urban drainage: Methods and shortcomings

P. Willems [a,b,*], K. Arnbjerg-Nielsen [c], J. Olsson [d], V.T.V. Nguyen [e]

[a] Katholieke Universiteit Leuven, Hydraulics Division, Kasteelpark Arenberg 40, BE-3001 Leuven, Belgium
[b] Vrije Universiteit Brussel, Dept. of Hydrology and Hydraulic Engineering, Pleinlaan 2, BE-1050 Brussels, Belgium
[c] Technical University of Denmark, Department of Environmental Engineering, DK-2800 Lyngby, Denmark
[d] Swedish Meteorological and Hydrological Institute, Research & Development (hydrology), SE-601 76 Norrkoping, Sweden
[e] Mc Gill University, Department of Civil Engineering and Applied Mechanics, Montreal, Quebec, Canada H3A 2K6

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ABSTRACT

Cities are becoming increasingly vulnerable to flooding because of rapid urbanization, installation of complex infrastructure, and changes in the precipitation patterns caused by anthropogenic climate change. The present paper provides a critical review of the current state-of-the-art methods for assessing the impacts of climate change on precipitation at the urban catchment scale. Downscaling of results from global circulation models or regional climate models to urban catchment scales are needed because these models are not able to describe accurately the rainfall process at suitable high temporal and spatial resolution for urban drainage studies. The downscaled rainfall results are however highly uncertain, depending on the models and downscaling methods considered. This uncertainty becomes more challenging for rainfall extremes since the properties of these extremes do not automatically reflect those of average precipitation.

In this paper, following an overview of some recent advances in the development of innovative methods for assessing the impacts of climate change on urban rainfall extremes as well as on urban hydrology and hydraulics, several existing difficulties and remaining challenges in dealing with this assessment are discussed and further research needs are described.

1. Introduction

For more than a century sewer systems have been constructed at large scale across cities worldwide. These sewer systems have reduced the vulnerability of the cities in general, but at the same time could make them more vulnerable to rainfall extremes, partly due to the lack of consideration to what occurs when the design criteria are exceeded. Next to this increase in the vulnerability, there is strong evidence that due to the global warming the probabilities and risks of sewer surcharge and flooding are changing. In their Fourth Assessment Report (AR4) the Intergovernmental Panel on Climate Change (IPCC, 2007) indeed reports for the late 20th century a worldwide increase in the frequency of extreme rain storms as a result of global warming. Based on climate model simulations with different future greenhouse gas emission scenarios, IPCC (2007) furthermore concluded that it is very likely (defined as more than 90% likelihood) that this trend will continue in the 21st century. Water managers therefore have to start accounting for these effects.

Consequently, the number of hydrological impact studies of climate change strongly increased in recent years. These studies, however, most often focus on risk of floods and droughts on river catchment scale. The number

* Corresponding author at: Katholieke Universiteit Leuven, Hydraulics Division, Kasteelpark Arenberg 40, BE-3001 Leuven, Belgium. Tel.: +32 16 321658; fax: +32 16 321989.
E-mail addresses: Patrick.Willems@bwk.kuleuven.be (P. Willems), karn@env.dtu.dk (K. Arnbjerg-Nielsen), jonas.olsson@smhi.se (J. Olsson), van.tv.nguyen@mcgill.ca (V.T.V. Nguyen).

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of climate change studies dealing with urban drainage impacts is still rather limited, partly because they require a specific focus on small urban catchment scales (usually less than 500 km^2) and short duration precipitation extremes (normally less than 1 day). Despite the significant increase in computational power in recent years, climate models still remain relatively coarse in space and time resolution and are unable to resolve significant features at the fine scales of urban drainage systems (Fig. 1). They also have limitations in the accuracy of describing precipitation extremes due to a poor description of the non-stationary phenomenon during a convective storm leading to the most extreme events on a local scale. To bridge the gaps between the climate model scales and the local urban drainage scales and to account for the inaccuracies in describing precipitation extremes, downscaling methods and bias-correction methods are commonly used in practice.

2. methods

Evaluating regional impacts from possible climate change on urban drainage requires a methodology to estimate extreme and short-duration rainfall statistics for the time period and the geographical region of interest. For historical conditions, climate change effects can be investigated by analyzing trends in long-term historical records of rainfall. For future conditions, projected changes in rainfall statistics are based on future scenarios in greenhouse gas emissions simulated in climate models or statistical extrapolation based on historical observations. These changes need to be transferred to changes in the urban drainage model inputs.

The above methodology (graphically summarized in Fig. 2) describes the main impact of climate change to urban drainage. However, other drivers will also have a large impact on the performance of the sewer system, particularly urbanization, changes in the sewer system, and changes in the performance criteria (Arnbjerg-Nielsen, 2010). In the present work focus is on estimation of climate change impacts. However, in practical applications the other drivers are often as important as the climate change impacts (Semadeni-Davies et al., 2008).

2.1. Trend analysis for historical series of rainfall extremes

The general aim of statistical trend analysis is to investigate whether recent historical changes in the frequency and amplitude of the rainfall extremes can be detected, and whether these can be considered statistically significant in comparison with the natural temporal variability of rainfall intensities (as observed in long series) (Pagliara et al., 1998; Denault et al., 2006; Madsen et al., 2009). Most classical trend tests are the Mann–Kendall test (Verworn et al., 2008; Quirmbach et al., 2009), the Cox–Stuart sign test (Verworn et al., 2008), and non-parametric tests based on rank statistics (Arnbjerg-Nielsen, 2006), but other methods have also been employed.

Whatever method is applied for trend testing, the interpretation of the result is difficult because there is no objective way to discriminate trends among natural climatic trends, anthropogenic caused changes, and sampling variability. Due to the strong temporal variability of sub-daily precipitation intensities, time series indeed have to be of sufficient length (Rauch and de Toffol, 2006). In Denmark, for instance, Madsen et al. (2009) analyzed changes in extreme precipitation from 1979–1997 to 1979–2005, based on 1250 station years from 66 stations. They concluded that for the durations and return periods typical for most urban drainage designs (i.e. durations between 30 and 180 min and return periods of about 10 years) the increase in rainfall intensity is more than 15%. Given that their analysis was based on relatively short historical periods, these trends were not significant. An analysis of the same dataset including data until year 2009 indicated that the change in number of occurrences of precipitation extremes were significant with and without inclusion of variables to describe the multi-decadal variation due to the North Atlantic Oscillation, while

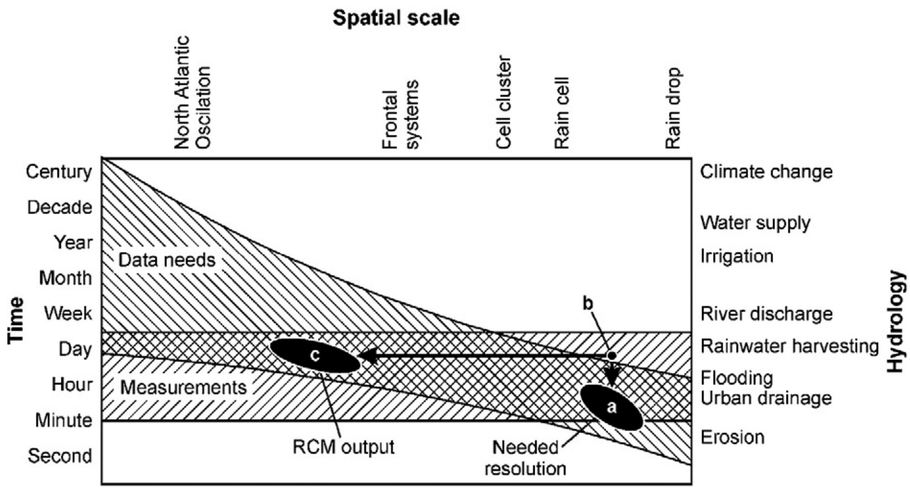

Fig. 1. Scale mismatch between the GCM/RCM outputs and the needs for urban hydrological impact studies (Adapted from Arnbjerg-Nielsen, 2008).