Past, present and future variations of extreme rainfall in Denmark

A well-functioning drainage system is of utmost importance to ensure safe and liveable cities. The cost of urban flooding is high and in worst case fatal. Denmark has a long tradition for providing guidelines for urban drainage design, including recommendations on design rainfall. A regional model for estimation of urban design intensities has been applied since 1999. The main motivation is that the uncertainty of the estimated design intensities can be reduced by including regional information. The model has been updated several times, but its basic assumptions are now challenged by several indications of non-stationary extreme rainfall behaviour, in Denmark as well as worldwide.

To provide recommendations on future design intensities it is necessary to explore and understand patterns of temporal variation in urban design rainfall and identify potential drivers behind past, present and future changes. In addition, there is a need for an extreme value model that can include both regional and temporal explanatory variables, evaluate their significance and on this basis estimate the design rainfall. Both topics are addressed in this thesis. The analysed data material includes 137 years of observed daily rainfall, and 34 years of high-resolution observations from a regional tipping-bucket network. To evaluate future design intensities climate model simulations from the ENSEMBLES project is applied, in combination with two high-end simulations. The number of extreme rainfall events and the mean intensity of sub-daily extreme rainfall have increased over the last 34 years. Analysis of the long daily rainfall series show that the number of extreme rainfall events, smoothed by a 10-year moving average, fluctuates between periods of relative high and periods of relatively low number of extremes. The increase observed over the last 34 years fits well into this pattern. Sea level pressure differences over the North Atlantic are found to be a potential driver of this multi-decadal variability. Specific constellations of high and low pressure zones favour a high number of extreme rainfall events in Denmark, and these form more frequently in some decades. In relation to the increase in mean intensity of sub-daily extreme rainfall, sea surface temperature of the Danish waters is a strong candidate among the potential drivers. The correlation between the two is not studied in detail in this thesis. In relation to projections of future rainfall extremes anthropogenic climate change plays an important role. At higher temperatures the air can hold more water and therefore release more rainfall. Climate change can also affect the variability of the extreme rainfall indirectly by a modification or intensification of the large scale drivers. Climate models are the most important tool for assessing the magnitude of the change, but their output should be critically assessed especially in regard to extreme rainfall. The thesis shows that the spatial correlation structure of observed hourly extreme rainfall is not reproduced well by the two climate models assessed. The thesis also presents a framework in which regional and temporal variability of extreme rainfall statistics can be modelled simultaneously. The framework is an extension of the regional model presently used for estimation of urban design intensities. It applies a threshold value for extreme rainfall that varies in both time and space. This eliminates the issue of having a nonuniform distribution of extremes events over the observation period. Furthermore, the model is capable of taking the spatial correlation structure of the rainfall extremes into account. The model can compare the relative importance of the temporal and regional variation. For several of the analysed rainfall durations regional variation is identified, but temporal variability explains a larger percentage of the total variability. The presented model only includes ‘time’ as a temporal variable. It can be modified to contain physical explanatory variable, like the two large scale drivers discussed above, when their present and future influence is confirmed. The analysed climate model simulations show that over the next 100 years the most likely increase of a 2-year event with a rainfall duration of 1 hour is 20 %. This almost corresponds to the change observed over the last 34 years, which emphasises the importance of understanding the large scale drivers behind. It is very important to quantify and communicate the uncertainty of the design rainfall both in relation to the natural variability, the expected impacts of climate change and their interplay. A large part of the uncertainty is inherent and cannot be reduced. On top of this come the many unknown features in the climate system. The irrational behaviour of mankind contributes to the uncertainty, as it both affects the greenhouse gas emissions, and the requirements to cities of the future. Simple case studies based on different decision making frameworks show that the uncertainty of the future is not a hindrance for adaptation.

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