Identification of intra-city variation of urban flash floods by statistical analysis of extreme rainfall events in Berlin, Germany

Identification de la variation intra-urbaine des crues éclair par l'analyse statistique des précipitations extrêmes à Berlin, Allemagne

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RÉSUMÉ

La Deutsche Wetterdienst (DWD) a fourni des données sur la hauteur des précipitations pour différents temps d'agrégation (basés sur une résolution temporelle de 1 minute) et les a analysées statistiquement sur une période maximale de 27 ans en se basant sur neuf stations météorologiques à Berlin et ses environs. Pour pouvoir caractériser un endroit donné en fonction de ses valeurs extrêmes de précipitations, il a fallu déterminer les valeurs extrêmes pour une gamme de temps d'agrégation différents, c'est-à-dire de quelques minutes à plusieurs heures. Dans cette étude, les extrêmes ont été définis par le 99e centile de chaque ensemble de données de temps d'agrégation. Ils ont été calculés pour la durée totale de chaque station météorologique afin de déterminer les cycles diurnes, saisonniers et annuels. Pour Berlin, les résultats montrent que les précipitations extrêmes ne sont pas également réparties dans le temps, ce qui indique une variabilité intra-urbaine. Dans la partie sud de la ville, les précipitations extrêmes sont uniformément réparties et il ne se dégage aucun schéma récurrent. En revanche, la partie nord présente la concentration la plus élevée le soir et une accumulation le matin. D'après les analyses saisonnières, nous pouvons conclure que les épisodes de précipitations extrêmes se produisent exclusivement en été, avec des précipitations croissantes de mai à septembre. La distribution annuelle montre une fluctuation des précipitations extrêmes au cours de la période analysée et illustre dans une certaine mesure une moyenne stable sur l'ensemble de la période.

ABSTRACT

Precipitation depth of different aggregation times (based on 1-min time resolution) were provided by the Deutsche Wetterdienst (DWD) and statistically analysed over a maximum time period of 27 years for nine meteorological stations in and around Berlin, Germany. To characterize a certain location with respect to its precipitation extremes required determining the extremes for a range of different aggregation times, i.e. from minutes to several hours. In this study, extremes were defined by the 99th percentile of each aggregation time dataset. They were calculated for the total time period of each meteorological station in order to determine diurnal, seasonal and annual cycles. For Berlin, the results show that extreme rainfall events are not equally distributed over time, indicating intra-city variability. In the southern part of the city extreme rainfall events are evenly distributed and no recognisable pattern is observed. In comparison, the northern part shows the highest concentration in the evening and an accumulation in the morning. From the seasonal analyses we can conclude, that extreme rainfall events occur exclusively in summer with increasing precipitation sums from May to September. The annual distribution shows a fluctuation of extreme rainfall events during the analysed period and illustrates to some extent a stable average throughout.

KEYWORDS

Climate change, extreme rainfall, intra-city variation, statistical analysis, urban flash flood

1 INTRODUCTION

Extreme rainfall events and the high variability of their occurrence have a significant effect on the urban water cycle and are commonly thought to increase in the future due to the impacts of climate change (Trenberth et al. 2003; Groisman et al. 2005). Several studies have suggested an amplification of rainfall extremes on hourly and sub-hourly timescales (Kendon et al. 2018). Here, especially short-duration extreme rainfall is responsible for urban flash flooding. In the last decades, rainfall measurement techniques and thus rainfall data resolution have improved significantly (see review of Einfalt et al. 2014). This enabled the analysis of the spatial and temporal variability of rainfall and the related effects on hydrological responses in urban areas (Emmanuel et al. 2012; Smith et al. 2013). An extended review is given by Cristiano et al. (2017).

For Germany the key focus of analysing precipitation extremes lies on the understanding of rainfall climatology. In detail, Eggert et al. (2015) and Weder et al. (2017), have addressed this issue in terms of the different formation types of precipitation, namely convective and stratiform. Malitz et al. (2011) investigated temporal changes in frequency and intensity of extreme precipitation within the 20th century in Germany using daily sums of precipitation. The results of these studies show a general increase in heavy precipitation. This signal is overprinted by a more pronounced regional and seasonal differentiation.

A new focus aspect in this topic is the examination of the diurnal, seasonal and annual occurrence and frequency of extreme rainfall events and their recurrence periods. These events may cause an overstraining of urban drainage systems and increase the risk of urban flash floods. This is an important step towards understanding how climate change will feed back to the risk of urban drainage system flooding (Arnbjerg-Nielsen et al. 2013).

The study presented here considers a maximum time period of 27 years due to limited data availability. Therefore, only short recurrence periods are included, and results should only be seen as a trend indication of climate change. In more detail, this statistical approach focuses on four objectives: I) During which time of the day and year is an extreme rainfall event likely to occur? II) In which years (within last 27 years) did extreme events occur? III) What are the recurrence periods of certain events? IV) Can we identify intra-city variability?

2 METHOD

Our investigations are based on a dataset of precipitation measurements with time periods between 11 and 27 years with a high temporal resolution, which can be obtained from the DWD (Deutscher Wetterdienst: German weather service) for numerous meteorological stations across Germany. The DWD provides precipitation depths for a range of aggregation times, starting from a resolution of one minute up to one day for all German cities with a coverage of at least ten years. In this study we focused on Berlin, the capital of Germany, and analysed precipitation data of seven spatially well distributed meteorological stations within the city area and two stations in direct vicinity, which have been added for more comprehensible results.

To select common precipitation extremes in this location required determining the extremes for a range of aggregation times. Therefore, the focus of interest was limited on precipitation durations of 10min and 1h periods. These limits were chosen to include short duration as well as medium duration extreme rainfall events.

Extremes were defined here after Weder et al. (2017) by the 99th percentile of each aggregation time dataset. For this calculation only events with precipitation depths greater than or equal to 1mm have been taken into account. They were calculated for the total time period of each meteorological station in order to determine diurnal, seasonal and annual cycles. For the selection of extreme events of 10min and 1h duration, we ensured that two events are clearly separated by at least 10min and 1h, respectively.

To investigate different recurrence periods for events with 10min and 1h aggregation time, a special catalogue requiring return intervals of extreme rainfall events, called KOSTRA (Koordinierte Starkniederschlagsregionalisierung und -auswertung: Coordinated extreme precipitation regionalisation and evaluation, Malitz and Ertel (2015)) has been used. This catalogue was primarily developed by the DWD for the design of water management facilities and includes calculated regionalized precipitation levels emerging from analysis of historical rainfall events and statistical calculations. Data processing including all statistical calculations has been done using the programming language R (R Core Team, 2018).

3 RESULTS AND DISCUSSION

We exemplify the results of our study via the meteorological station Tegel, which is located in the central west of Berlin. The diurnal, seasonal and annual distribution of 10min and 1h extreme rainfall events are shown in Fig. 1. Using the method of the 99th percentile of each dataset, leads to a total number of 15 10min and 36 1h events. Here, precipitation depths range between 10.5 - 29.2 mm for 10min events and 12.2 – 67.3 mm for 1h events.

The analysis of diurnal extreme rainfall events (Fig.1a) shows an accumulation of both events in the morning (10.8 - 28.8 mm) and afternoon with a precipitation peak of both events in the early evening. A small gap of no precipitation of three hours is evident in the time between 7 and 9 am. This distribution pattern is also recognised in three other meteorological stations in Berlin, all of them located in the northern part of the city. A similar diurnal cycle was found by Weder et al. (2017) and Blenkinsop et al. (2016) for the summer season in the United Kingdom. The stations located in the southern part show an even distribution throughout the day with no major clustering.

Figure 1b illustrates the occurrence of extreme rainfall events within one year. The data show that all rainfall events exclusively occur in summer between May and September except for two rainfall events of short duration in January. A remarkable trend of increasing precipitation towards the end of summer (September) can be observed. This observation correlates with observations made by Weder et al. (2017) for short aggregation times at the Hamburg weather station in northeast Germany, which have been explained by annual cycles of convective processes contributing to the generation of precipitation. Furthermore, increasing precipitation amounts can be caused by increasing temperature and moisture in the atmosphere, which leads to increases in heavy rainfall intensity (Trenberth et al. 2003).

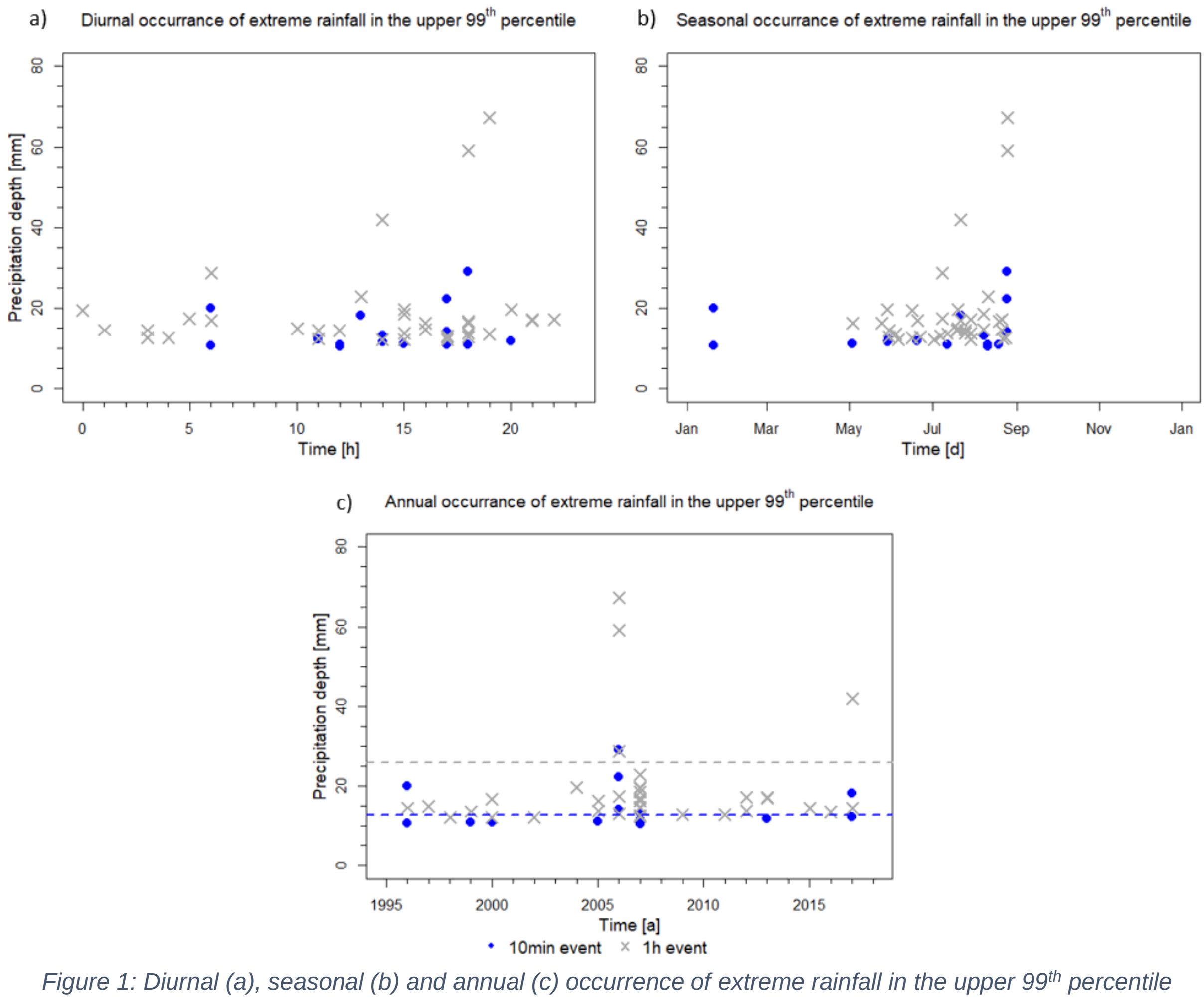

Figure 1: Diurnal (a), seasonal (b) and annual (c) occurrence of extreme rainfall in the upper 99th percentile plotted for the meteorological station Tegel in Berlin. Blue points represent 10min rainfall events and grey crosses represent 1h rainfall events. Lines mark limit values derived by KOSTRA (blue = 10min, grey = 1h).

In a final step we analysed the occurrence of extreme rainfall events at Tegel station for the period from 1995 to 2018 (Fig.1c). Here, a constant fluctuation between years with particularly high precipitation and low precipitation can be observed. Especially the years 2006, 2007 and 2017 were affected by recurring extreme precipitation. Two limit values (12.7 mm for 10min events and 26 mm for 1h events) were derived by KOSTRA and used to mark the precipitation depth with a recurrence period of five years. Values below the limits potentially occur at a frequency of three years or less.

4 CONCLUSIONS

The statistical analyses of precipitation data clearly show that intra-variability of rainfall can be observed in the area of Berlin. Striking differences in the diurnal distribution of extreme rainfall events were observed between the northern and southern part of Berlin. In this context, the temporal distribution in other cities and inter-city variation of extreme rainfall events would be of further interest. The annual distribution shows a fluctuation of extreme rainfall events during the analysed period and illustrates to some extent a stable average throughout. Despite strong evidence for climate change in rising average temperatures the analysed data show no observable change in distribution of extreme events.

In addition, these results can be used to identify urban catchment areas affected by especially high precipitation events which is of major relevance for rainwater management purposes.

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