9th INTERNATIONAL WORKSHOP on PRECIPITATION IN URBAN AREAS
Urban Challenges in Rainfall Analysis
6-9 December 2012, St. Moritz, Switzerland

TRENDS IN PRECIPITATION MEASUREMENT AND CLIMATE MODEL DATA AND THEIR INFLUENCE ON THE ASSESSMENT OF URBAN SYSTEMS

by
E. Freistühler(1), M. Quirmbach(1), I. Papadakis(1) and A. Pfister(2)
(1) *dr. papadakis GmbH, Werksstraße 15, D-45527 Hattingen, Germany* (efreistuehler@drpapadakis.de)
(2) *Emschergenossenschaft/Lippeverband, Kronprinzenstraße 24, D-45128 Essen, Germany* (pfister.angela@eglv.de)

ABSTRACT

Rainfall statistics are composed based on data gained by precipitation measurements and from climate models. These statistics are carried out for both periods in the past and the future. When analysing the time series, different trends can be seen in the measured data of the past and the model data for future periods. Influences on the statistically determined precipitation amounts caused by changes can be neglected for past periods. However, significant increases of the statistical precipitation amounts can be observed for the future. Here a pragmatic approach is presented, showing how to consider possible increases in the statistical precipitation amounts – due to the climate change signal – in the dimensioning of water management systems.

Keywords: trend analysis, regional climate model, CLM, *dynaklim*, rainfall statistics, dimensioning of water management systems

1 INTRODUCTION

Statistically determined precipitation amounts are needed as input parameter for the dimensioning and the verification of water management systems in urban areas such as sewer networks, rainwater retention basins and floodwater retention basins. During the statistical evaluation of measured precipitation data, e.g. in accordance with the DWA-A 531 (DWA, 2012), a stationary state is assumed, meaning trends that occurred during the observation period are not considered for the derivation of the statistically determined precipitation amounts. For the dimensioning of water management plants which are supposed to be operatively and sufficiently dimensioned beyond the year 2050, measurement data which often go back until the 1950s are used as a basis. Something that will therefore be examined within the framework of the networking and research project *dynaklim* is the degree of influence the climate change has on the precipitation patterns in the Emscher-Lippe region ELR (North-Rhine-Westphalia, Germany). The project *dynaklim* – Dynamic Adaptation of Regional Planning and Development Processes to the Effects of Climate Change in the ELR – carries out multi-disciplinary research on 'dynamic' adaption to the effects of climate change. The project focuses on the potential impacts on the regional water balance and the possible options to adapt for population, economy and environment.

Furthermore it will be investigated to what extent the assumption of stationary states remains admissible for the dimensioning of water management systems. Here, the relation of trends caused by the climate change to the natural temporal and spatial climate variability is examined. Additionally, the degree of influence these trends have on the dimensioning of water management systems will be analysed as well as which similarities and differences the trends feature with regard to measured precipitation and to precipitation data of regional climate models. While a previous publication (Quirmbach et al., 2012) focused on trends of hydrological principal values such as yearly rainfall totals this publication will mainly address trends for daily rainfall totals and shorter time intervals.

2 TREND ANALYSES OF PRECIPITATION DATA

2.1 Examining trends in the measured data

For the investigation of measured precipitation data time series of 14 rain gauges in the ELR covering the period of 1931 - 2010 were used. Initially, the frequency of heavy rainfall days (D = 1d) above defined threshold values was assessed per decade in order to be able to evaluate possible trend behaviour of heavy rainfall days that occurs with varying frequency (*Table I*).

Table I – Mean number of heavy rainfall days exceeding threshold values per decade and gauge.

Decade	N ≥ 20 mm/d	N ≥ 30 mm/d	N ≥ 40 mm/d	N ≥ 50 mm/d	N ≥ 60 mm/d	N ≥ 70 mm/d
1931 – 1940	39	12	4,4	0,6	0,0	0,0
1941 – 1950	32	11	2,7	0,7	0,4	0,2
1951 – 1960	39	9	3,0	1,1	0,6	0,4
1961 – 1970	38	9	2,8	1,4	0,6	0,3
1971 – 1980	27	6	2,1	0,5	0,1	0,0
1981 – 1990	35	8	2,4	1,4	1,2	1,0
1991 – 2000	**46**	**13**	**3,6**	0,9	0,2	0,0
2001 – 2010	**49**	**13**	**3,1**	1,2	0,3	0,2

Small heavy rainfall events with a return period of up to T ≈ 2 a (the classes up to N ≥ 40 mm/d) showed an increase of heavy rainfall events since 1991. On the other hand, no significant trend could be derived for extreme values of rainfall. The randomness of rare heavy rainfall events occurring within one of the samples had a significantly higher influence on the frequency estimation of heavy rainfall events than the climate change signal.

For short time intervals (D ≤ 1d) the frequency of heavy rainfall was additionally examined by series of rainfall over threshold and the precipitation amount of heavy rainfall by annual series. Here it became apparent that for all short time intervals, on average both the frequency as well as the precipitation amount of heavy rainfall increased significantly across all 14 time series. *Figure 1* shows both the development of the number of heavy rainfall events per year (series of rainfall over threshold) and the development of the mean level of yearly maximum rainfall totals (annual series) for the duration D = 60 min.

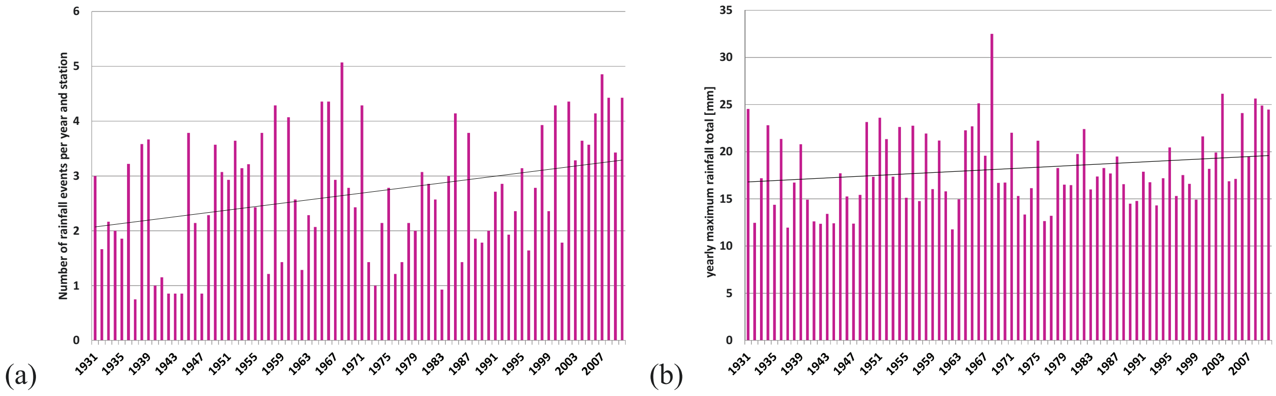


Figure 1 – (a) Mean number of heavy rainfall events per year for D = 60 min in the ELR
(b) Mean level of yearly maximum rainfall totals for D = 60 min in the ELR

At first, the number of heavy rainfall events per year increases only slightly (by 5%) between the periods 1931 - 1960 (2.42 events per year) and 1961 - 1990 (2.53 events per year). The number of events measured from 1991 - 2010 (3.30 events per year) then shows a significant increase of 36% (when compared to the period 1931 - 1960). This increase is similar to that in the assessment of the daily totals in the same period. The significance level is 99.5%. The significance was examined using the Mann-Kendall Test (Hipel and

McLeod, 1994; Douglas et al., 2000). The evaluation of the mean levels of yearly maximum rainfall totals showed analogous results. After a minor increase between 1931 - 1960 (17.53 mm/h) and 1961 - 1990 (18.00 mm/h) of 3% the average amounts of the period 1991 - 2010 (19.47 mm/h) turned out to be 11% higher than those from 1931 - 1960. The significance level is 95.7%.

Similarly to the threshold value examination for the daily totals, these results also show a general increase of small heavy rainfall events and do not allow any statement about the trend of rare heavy rainfall events, since a relatively high number of events with return periods of T ≤ 1a are considered for the series of rainfall over threshold and the annual series.

Furthermore, no general increase of the statistically determined precipitation amounts can be found considering the results of the statistical analysis on basis of the series over threshold in a next step (*Figure 2*). Here, sliding time windows of 30 years between 1931 - 2010 were evaluated for different time intervals and return periods. Since the statistical method is disproportionately highly affected by extreme rainfall events, no increase of rare heavy rainfall events can be proven using these statistics.

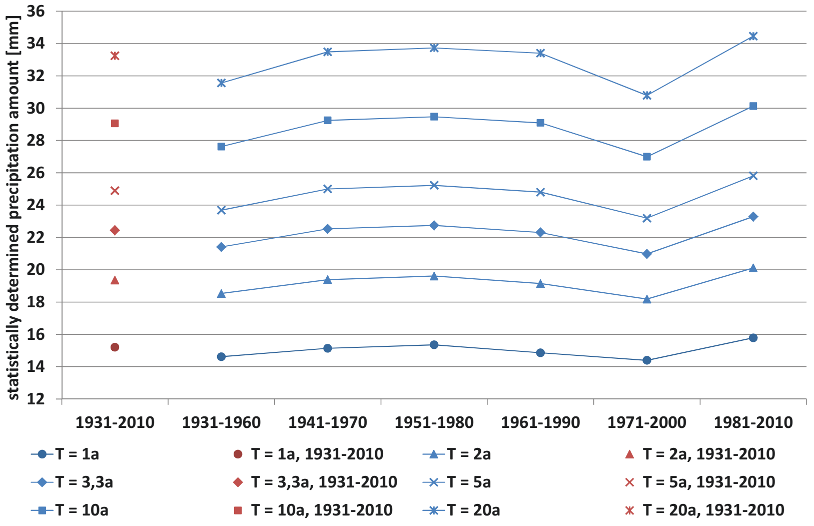


Figure 2 – Development of the statistically determined precipitation amounts for the duration D = 60 min and the examined return periods T in the ELR.

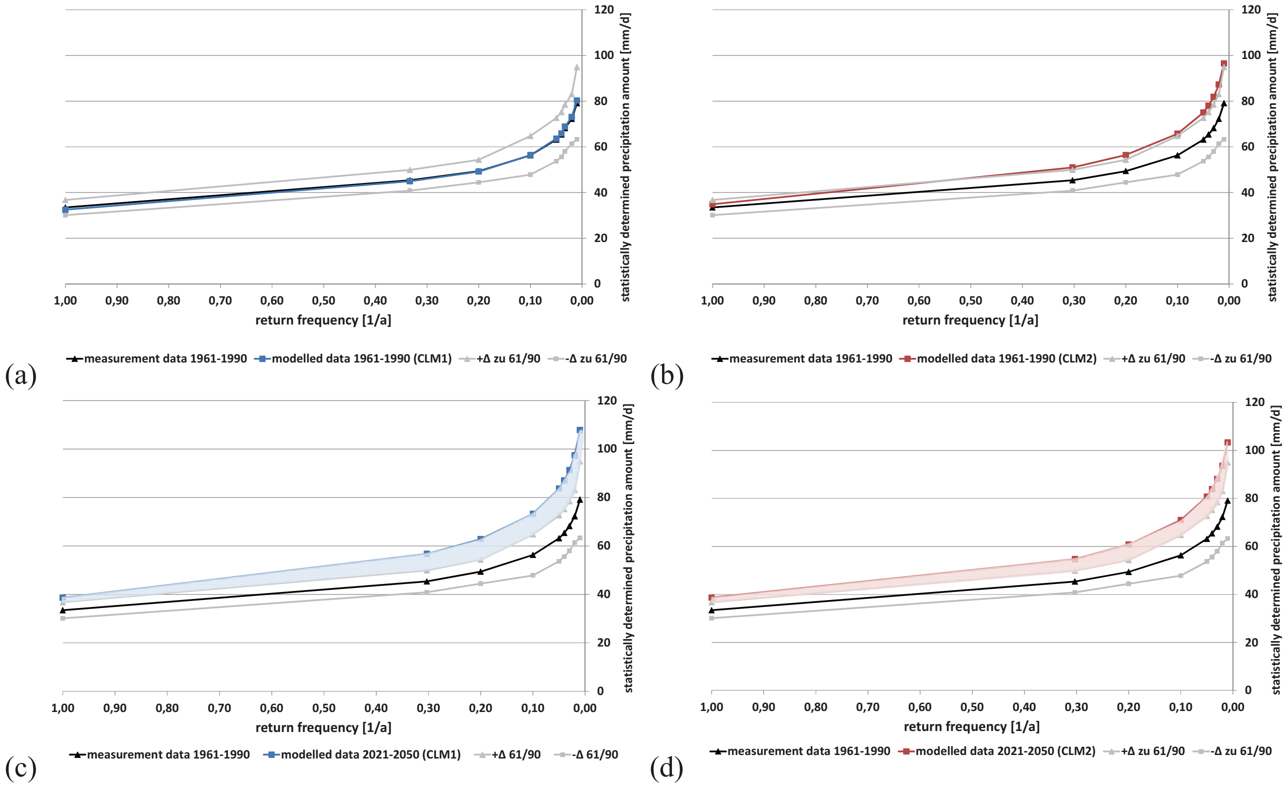
2.2 Examining trends in the model data

Apart from the measured precipitation data, there are also bias corrected precipitation data available from the regional climate model CLM (Quirmbach et al., 2012). The two CLM runs CLM_C20_1_D3 (CLM1) and CLM_C20_2_D3 (CLM2) (Hollweg et al., 2008; Lautenschlager et al., 2009) are considered for the trend analysis and only differ slightly in their starting conditions. The CLM model data only regard the daily rainfall totals for two reasons. Firstly, the hourly totals of the CLM Regional Climate Model do not reflect the natural rainfall patterns and secondly, the downscaling (Tessendorf et al., 2012) was only applied to small catchment areas. Analyses of the measured data have shown that the daily totals tend to show a similar trend as the shorter durations (D < 1d). Therefore the assumption was made that this will also apply for model data in the future.

The increase in heavy rainfall events already visible in the measured data can also be found in the data provided by the climate model and continues into the future. The measured data showed an increase only for the heavy rainfall events in the classes up to R ≥ 40 mm/d and featuring small return periods of up to T ≈ 2a. The model data, however, also displayed an increase in the medium heavy rainfall events. In the near future (2021 - 2050) the number of events in the class R ≥ 50 mm/d will increase to 0.24 (CLM1) / 0.19 (CLM2) events per year and in the class R ≥ 60 mm/d to 0.10 (CLM1 and CLM2). Thus also the number of heavy rainfall events which are currently counted in the statistics at return periods of T = 5a - 20a increases. However, a further increase of heavy rainfall events in the far future (2071 - 2100) cannot be seen. For this period, the number of heavy rainfall events remains constant (CLM1) or even shows a slight decrease (CLM2) when compared to the near future.

Figure 3a shows that the statistical evaluation of the measured data and the CLM1 model data are almost identical for the time period 1961 - 1990. However, the statistically determined precipitation amounts shown in the CLM2 model exceed them by 10% - 20% (*Figure 3b)*. This puts the CLM2 values at the upper margin of the range of tolerance as given in the KOSTRA DWD-2000 statistical evaluations (DWD, 2005). The range of tolerance is marked in grey in *Figure 3*. Thus the results of the heavy rainfall evaluation for the CLM2 time series (1961 - 1990) also lie within the tolerance range.

In comparison, the statistically determined precipitation amounts for the near future, from both the CLM1 and the CLM2 time series are above the tolerance range (*Figures 3c and 3d*). What needs to be considered here is that similarly to the measurement data, natural precipitation variability and possible climate change signals overlap. It is therefore impossible to make an unambiguous conclusion about whether the changes in the precipitation amounts are a result of either the natural variability or the climate change signal. Changes in precipitation amounts within the tolerance zone between ±10% and ±20% according to the return period are therefore interpreted as natural variability. Only changes above this tolerance zone are assigned to the climate change (light blue area in *Figure 3c* and light red area in *Figure 3d*).



(a) (b) (c) (d)

Figure 3 – Comparison of the statistically determined precipitation amounts for varying return frequencies allowing for a tolerance zone for natural precipitation variability, (a) CLM1 (1961 - 1990) vs. measured data (1961 - 1990); (b) CLM2 (1961 - 1990) vs. measured data (1961 - 1990); (c) CLM1 (2021 - 2050) vs. measured data (1961 - 1990); (d) CLM2 (2021 - 2050) vs. measured data (1961 - 1990)

3 CONCLUSIONS FOR THE DIMENSIONING OF WATER MANAGEMENT SYSTEMS

No significant influence of the increase of heavy rainfall on the statistically determined precipitation amount can be detected in the historical records yet, since up to now only smaller and not the extreme rainfall events have increased. The development in the climate model data indicates, however, that in future also the extreme events will increase and will affect the results of the rainfall statistics.

The resulting climate-based increases of the precipitation amounts (percentage over the tolerance zone) lie in the range of up to +10%. Such an increase of 10%, however, already leads to a considerable shift of the return periods in the rainfall statistics. Precipitation amounts that possessed a return period of T = 100a in the past will occur with a frequency of T = 50a in the future. Even for smaller recurrence intervals, these intervals decrease while maintaining the same rainfall total (e.g. from T = 5a to T = 3a).

The dimensioning of water management systems should always consider an increase in heavy rainfall events, in order to avoid an increase in system failures in the future. An increase in the statistically determined precipitation amounts occurring due to natural variability should, however, not be overestimated or may even be neglected - this could otherwise lead to an uneconomic over-dimensioning of the structure. A more pragmatic approach should be chosen for the daily dimensioning routine. Continued usage of statistical evaluation with historical measured data is therefore recommended as the basis for the dimensioning. After this first step, possible future precipitation amounts need to be assessed from climate model data. These amounts have to be decreased by a tolerance value attributed to natural variability. It would be best to use several runs or even different climate models for this process. This would help to achieve a wide range of possible developments. Lastly, sensitivity analyses need to be carried out for the water management systems using the newly gained future precipitation amounts. This step is necessary for the quantification of possible system failure. A sustainable development of urban water resources management needs to develop solutions for any weak spots discovered in the process.

4 ACKNOWLEDGEMENTS

The *dynaklim* – project is part of the development programme KLIMZUG (climate change in regions) and is supported by the German Federal Ministry of Education and Research (BMBF).

5 REFERENCES

Douglas, E.M., R.M. Vogel and C.N. Kroll, (2000) Trends in floods and low flows in the United States: impact of spatial correlation, *Journal of Hydrology*, 240: 90-105.

DWA, (2012) Starkregen in Abhängigkeit von Wiederkehrzeit und Dauer*, Arbeitsblatt A 531*, DWA, Germany.

DWD, (2005) *KOSTRA-DWD-2000 Starkniederschlagshöhen für Deutschland (1951-2000) – Grundlagenbericht*, Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main, Germany.

Hipel, K.W. and I. McLoad, (1994) *Time series modelling of water resources and environmental systems*, Elsevier, Amsterdam, The Netherlands.

Hollweg, H.-D., U. Böhm, I. Fast, B. Hennemuth, K. Keuler, E. Keup-Thiel, M. Lautenschlager, S. Legutke, K. Radtke, B. Rockel, M. Schubert, A. Will, M. Woldt and C. Wunram, (2008) *Ensemble Simulations over Europe with the Regional Climate Model CLM forced with IPCC AR4 Global Scenarios*, Technical Report No. 3, Gruppe Modelle & Daten (M & D), Max Planck Institute for Meteorology, Hamburg.

Lautenschlager, M., K. Keuler, C. Wunram, E. Keup-Thiel, M. Schubert, A. Will, B. Rockel and U. Boehm, (2009) Climate Simulation with CLM, Climate of the 20th Century run no.1 / no.2, Scenario A1B run no.1 / no.2, Data Stream 3: European region MPI-M/MaD. World Data Center for Climate.

Quirmbach, M., T. Einfalt and G. Langstädtler, (2012) Climate Change Analysis of Precipitation Data for North Rhine-Westphalia, *Atmospheric Research*, 109-110, June 2012, 1-13.

Quirmbach, M., E. Freistühler, I. Papadakis and A. Pfister, (2012) Bias Correction of Precipitation Data from the CLM Regional Climate Model for Water Management Model Applications. *Proceedings of the 9th International Workshop on Precipitation in Urban Areas*. December 2012, St. Moritz, Switzerland.

Tessendorf, A., M. Quirmbach, T. Einfalt, E. Freistühler and M. Jessen, (2012) *Statistical downscaling of CLM precipitation using adjusted radar data and objective weather types*. Abstract for 9th International Workshop on Precipitation in Urban Areas. December 2012, St. Moritz, Switzerland.