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IMPACT OF URBANIZATION ON SPATIAL AND TEMPORAL VARIATION OF RAINFALL IN BEIJING OVER THE LAST 50 YEARS

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Rainfall is one of the key terms involved in many hydrological processes, and it is particularly important in the field of urban hydrology. In this study, the focus is set on the impact on the precipitation patterns in Beijing in term of spatial and temporal variation, from the urbanization over last 50 years in which time the fast and continuous expansion of the city at dramatic scales, the rapid growth of residents population as well as human activities especially building of ground constructions, collectively and inevitably bring changes to the local climatic characteristics of the urbanized areas. It has been found that the spatial distribution has demonstrated a clear pattern shift over the region; the temporal distribution, although shows insignificant (decreasing) trends on many average terms, gives a clear indication of stable, gradual increase in maximum 1-h rainfall intensity accompanying with the slow-urbanizing period and large fluctuations in the rapid development period.

INTRODUCTION

The Beijing metropolitan area is located in Northern China (Fig.1a) and is recognized as one of the ten largest mega cities in the world with a population of more than 10 million. It has experienced a rapid urbanization in the form of urban expansion in the last 30 years. Such urbanization, with increasing built-up areas and human activities, results in significant modifications to underlying surface properties and atmospheric circulations. Therefore, studies of temporal and spatial variations in the local climatic characteristics of Beijing are important to our understanding of the impacts of urbanization on local climate. Many researchers have studies the possible effects of urbanization on temperature and precipitation in Beijing and surrounding areas [1-2]. Miao et al. [3] modelled the impacts of urban land use on the characteristics of boundary layer structures, and revealed that urban-rural circulations induced by topographic differences are an important cause for the prevalence of mountain-valley flows in Beijing. Zhang et al. [4] used a mesoscale model to simulate rainfall events and found that urban expansion contributed to a reduction in precipitation over the Beijing area, particularly over the Miyun reservoir area. Moreover, Beijing has a varied and complex topography, with high mountains to the west (Taihang Mountains), north, and northeast (Yan Mountains), accounting for approximately three quarters of the Beijing metropolitan region, consequently, the terrain has an important effect on the location and distribution of precipitation in Beijing.

Sun and Yang [5] studied the summer meso-β scale rain in Beijing and found it was caused by the joint effects of topography and the urban heat island. They reported the formation of a strong temperature gradient that engendered a wind shear near windward slopes, because the terrain blocked the horizontal diffusion of heat generated by the heat island effect. The wind shear is important in developing and maintaining the convection, consequently, most of the mesoscale rain processes in Beijing occur at the margin of the urban area or in adjacent mountainous areas [5-7].

The rest of the paper presents a recent study in the vicinity of the Chinese capital Beijing to investigate: (1) spatial and temporal variations of precipitation in Beijing area based on annual mean precipitation during 1950-2012 and daily precipitation data from 22 rain-gauge stations; (2) possible effects of urbanization on rainfall variations and rainfall intensity distribution in Beijing.

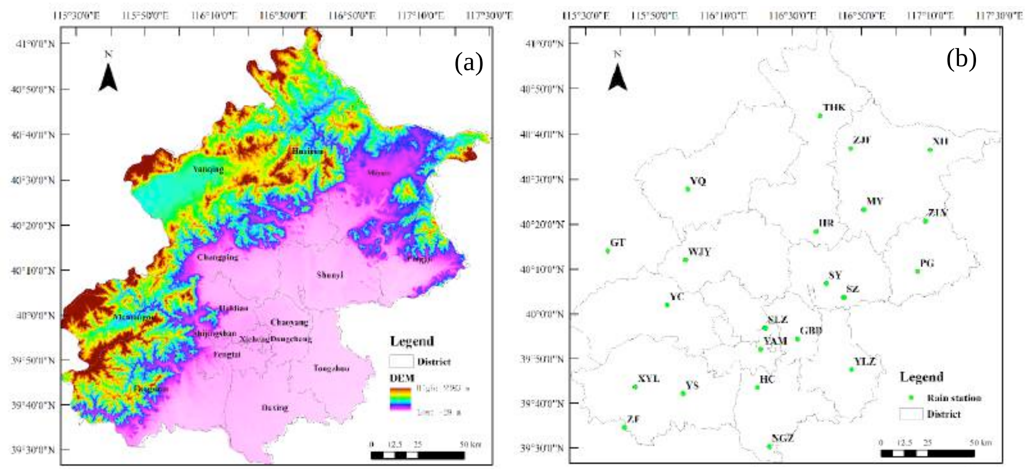


Figure 1. (a) Location and topography of Beijing and (b) the distribution of the 22 chosen stations

DATA AND METHODS

The monthly and annual mean precipitation of Beijing area from 1950 to 2012, and daily rain-gauge data of 22 rain gauge stations for the flood season (June-September) in 1961-2011 has been analyzed in this study. These data are provided by the Beijing Hydrological Stations (BHS) of the Beijing Water Authority (BWA). Note that most of the 22 observation stations within Beijing were established in the late 1950s and early 1960s, and formed the fixed network by the end of that decade due to China's reform policy. The 22 stations are as follows: Songlinzha (SLZ), Youanmen (YAM), Gaobeidian (GBD), Tanghekou (THK), Huairou (HR), Zhangjiafen (ZJF), Xiahui (XH), Miyun (MY), Huangcun (HC), Nangezhuang (NGZ), Zhangfang (ZF), Fangshan (FS), Xiayunlin (XYL), Pinggu (PG), Suzhuang (SZ), Tongxian (TX), Zhenluoying (ZLY), Guanting (GT), Yanchi (YC), Wangjiayuan (WJY), and Yanqing (YQ), and their location are shown in Fig.1(b). To divide the Beijing metropolitan region into different areas characterized of distinct topographic conditions, we first use an empirical method in terms of the distinct characteristic of urban and suburban, including urban central area (e.g., SLZ, YAM, and GBD), northern (e.g., THK, HR, ZJF, XH, and MY), southern (e.g., HC, NGZ, ZF, FS, and XYL), eastern (e.g., PG, SY, SZ, TX, and ZLY) and western area (GT, YC, WJY, and YQ). The annual and seasonal mean precipitation trend, and 1-hour precipitation intensity trend have been analyzed by applying the linear regression, Mann-Kendall trend test and moving average. The three methods has been widely used to discuss the long-term trend of precipitation distribution. The detailed information about these three methods can see some references.

RESULTS AND DISCUSSION

Temporal variability in Beijing area

The annual mean precipitation in Beijing area during 1950-2012 is from 383.9 mm (1965) to 1005.6 mm (1954) with an average of 584.7 mm. It can be seen from Figure 2 that the annual mean precipitation time series presents a slowly decreasing with significant trend during 1950-2012 analyzed by the linear regression method, the tendency of which is 28.5mm/10a, regardless of short-term fluctuations. 5-year moving average curve highlights trends and variability in the annual precipitation series on multiyear scales. In addition, trends of seasonal precipitation were also discussed. For the flood season (June, July, August, and September), the precipitation amount accounts for the annual precipitation about 83.5% (60.13%-91.53%) during 1950-2012. The slight decreasing trend of precipitation in the flood season is consistent with that of annual mean precipitation, and the tendency of which is 29.7 mm/10a. For the four seasons, seasonal precipitation in spring and autumn present a slowly increasing but non-significant trend analyzed by the linear regression (0.7 mm/10a and 0.9 mm/10a), while the seasonal precipitation in summer presents a visible decreasing with the tendency 32.8mm/10a, and the trend of mean precipitation in winter is almost flat, fluctuating within a narrow range. Therefore, the decreasing of precipitation in summer season is the most important reason for the decreasing of annual precipitation in Beijing area.

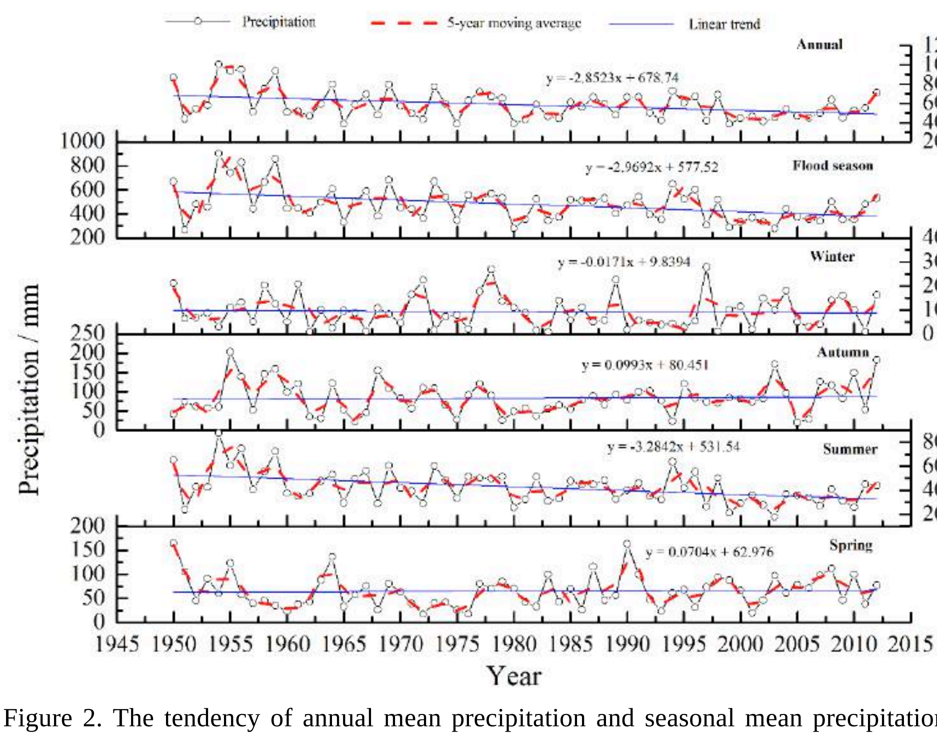


Figure 2. The tendency of annual mean precipitation and seasonal mean precipitation during 1950-2012 in Beijing area. The seasonal precipitation amount is the sum of precipitation for relevant months, e.g., flood season (June to September), spring (March to May), summer (June to August), autumn (September to November) and winter (December to February).

The Mann-Kendall test is applied to detect the mutation of the annual mean precipitation and seasonal mean precipitation during 1950-2012. The values calculated by M-K test algorithm are shown by the respective red solid line and blue solid line in Figure 3, and the horizontal dashed lines correspond to the confidence limits at the 0.05-significance level (±1.96) where the blue solid lines passing over the dashed line means there is a statistically significant trend of increasing or decreasing. For the spring and autumn season, the precipitation series present a slowly increasing but non-significant for most years. For the summer and flood season, the precipitation series present significant decreasing before 1970s, while it present a slowly increasing but non-significant. We also can see that the trend of annual mean precipitation is not significant, it becomes an increasing trend from the late 1980s but it is still insignificant.

From Figure 4, we can find that the annual mean precipitation series, and precipitation series in flood season and summer are still decreasing from 1950s, while the precipitation series in spring and autumn begin to be increasing since 1980s. However, the precipitation series in winter have no significant trend with conspicuous fluctuation. These results are consist with that of the other two methods.

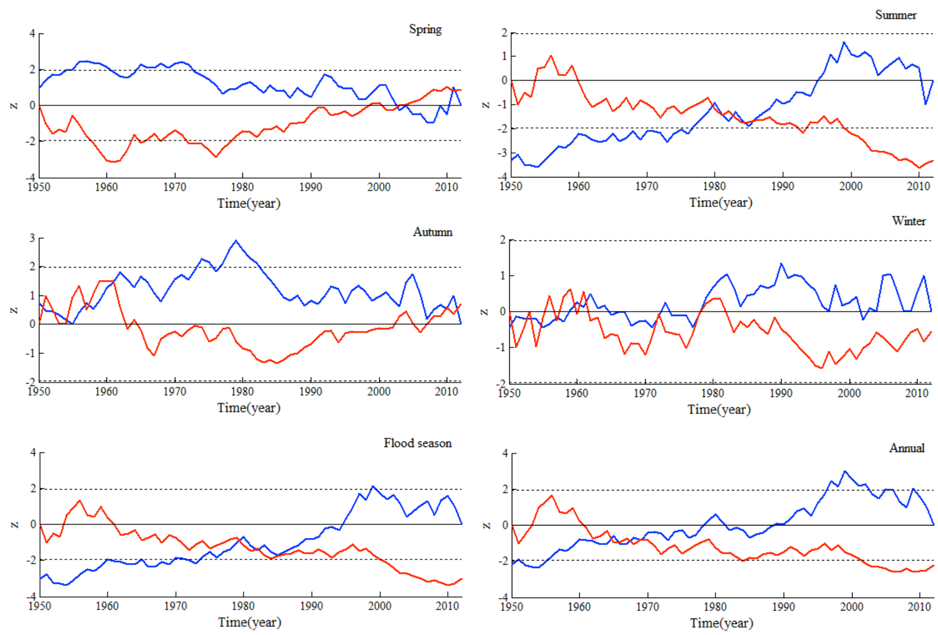


Figure 3. Mutation results of the annual mean precipitation and seasonal mean precipitation during 1950-2012 tested by the M-K method.

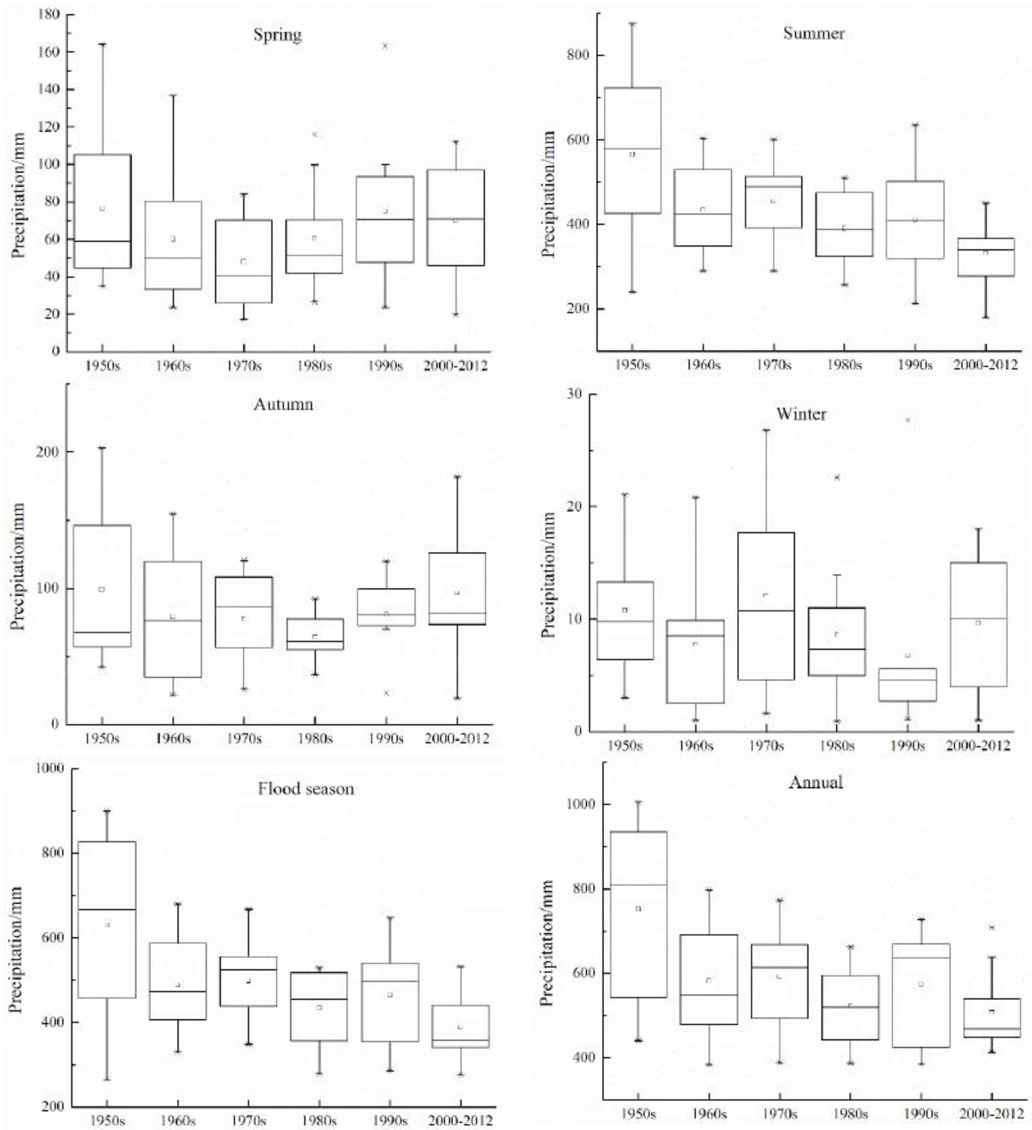
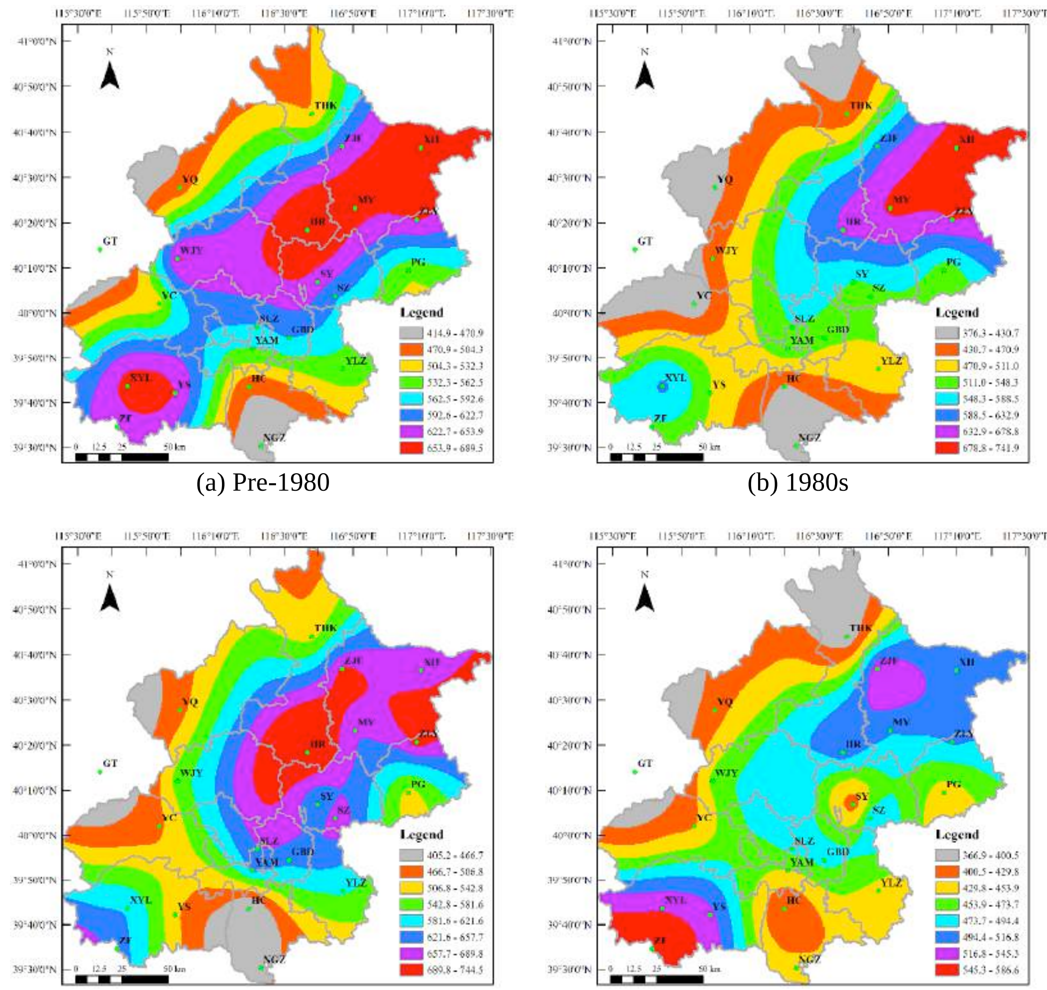


Figure 4. Box chart of the annual mean precipitation and seasonal mean precipitation during 1950-2012. Small squares represent the mean value of precipitation data. The top, middle and bottom horizontal line represent maximum value, medium value and minimum value. The top and bottom oblique cross-shaped represent the 99th percentile and the 1st percentile value.

Spatial variability

The spatial distribution of the annual precipitation is shown in Figure 5. The annual precipitation of the plain area is greater than that of the mountainous area, both of which are generally less than that along the front belt of the windward slopes of the mountains surrounding the plain. Figure 5 further show the relationship of spatio-temporal distribution of rainfall and urban expansion in Beijing. For the period of pre-1980 (Figure 5a), there are two centers of precipitation with the annual maximum precipitation value of 650mm. One is located in the vicinity of the Huairou and Miyun reservoir in the northeastern section of Beijing, and the other is centered in the Fangshan district in the southwestern part of Beijing. For the period of

1980s, the center of annual maximum precipitation moves to the northern part of Miyun reservoir (Figure 5(b)). For the period of 1990-1999, the center moves to the southern part, with the maximum value located in the vicinity of the Huairou reservoir (Figure 5c). For the period of 2000-2011, it is clear from Figure 5(d) that the annual precipitation in Beijing has been declining since 1990s, with the largest decrease in the northeastern are. These results are in good agreement with the results obtained from Zhang et al. [4].



(a) Pre-1980 (b) 1980s

(c) 1990s (d) 2000s

Figure 5. The spatial distribution of the decadal average precipitation in Beijing area

Impact of urbanization on spatial and temporal variation of precipitation

It is understandably difficult to estabilish a compresensive picture as to how urbanisation can have and has had impact on precipitation. In this preliminary study, the annal maxima of 1-h rainfall intentisity was chosen to meaure the possible change due to urbanisation. The study area is divided into five sub-areas in this case: the western (WA), the estern (EA), the southern (SA), the northern (NA) and the central yet fully urbanised area (UA). Figure 6 shows the trend analysis of the annumal maxima from the five sub-areas. Out of the five sub-areas, there are four demonstrating increasing trends in annual maxima, where the central urbanised area as well the north part present stronger trend. The south part of the reagion does not show any trend at all. Notably, however, a stabilised trend can be found over the period of 1960s-late 1990s.

This can be potenitally linked to the slow yet stable urbanisation over that period. It is also interesting to observe that, for the central part, the large fluctuations over from 1990s-2000s, which may be conincidience with the unparalelled speed of urbanisation over that perod.

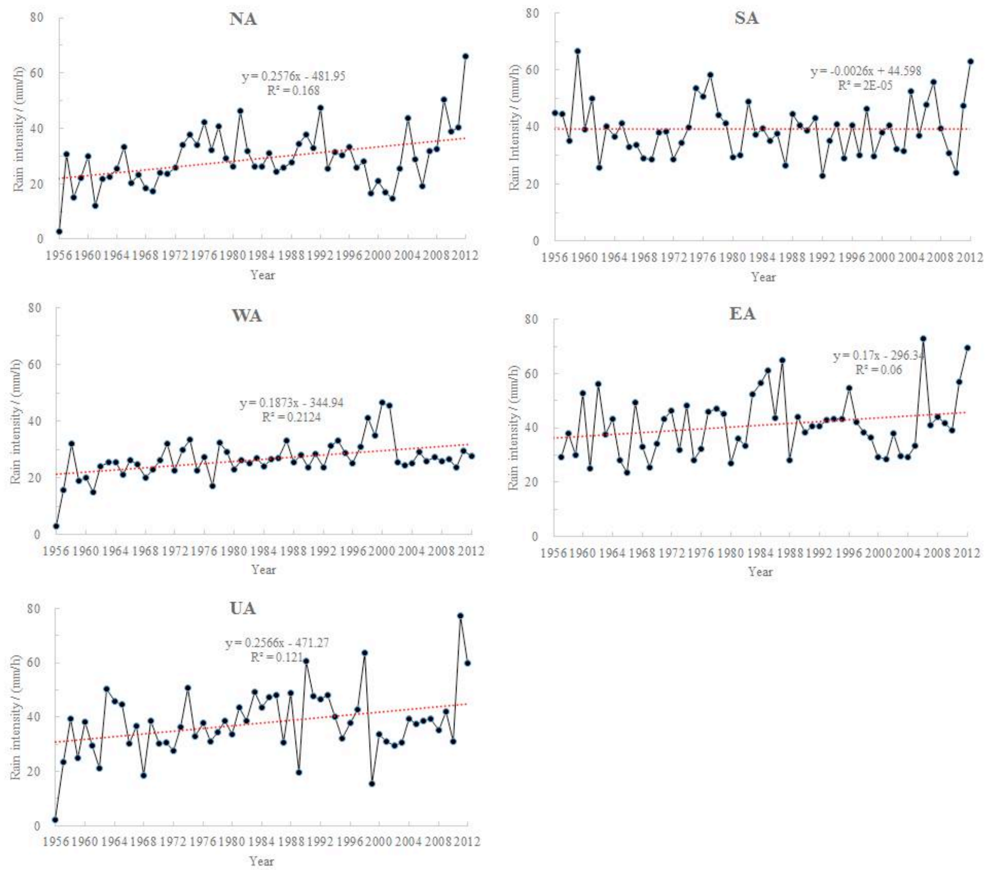


Figure 6. The trends of annual maximum 1-hour precipitation intensity for different parts in Beijing area during 1956-2012

CONCLUSIONS

This paper presents a preliminary study on the impact of urbanization to the spatial and temporal distribution of precipitation in Beijing area. The annual and seasonal mean precipitation in Beijing area during 1950-2012 and the annual precipitation from 20 rain-gauge stations covering Beijing during 1956-2012 are analyzed by several methods, and some conclusions are subsequently obtained. Firstly, the annual mean precipitation has a clear decreasing trend, and the decreasing trend of precipitation in summer and flood season is the main contribution to the decrease of annual precipitation. The tendency of precipitation changes from decreasing to increasing in spring and autumn between the two urbanization period, and the precipitation in the winter has a slight increasing trend since 1990s. Secondly, in the slow urbanization period, the precipitation in the southern part of Beijing is more than that in the northern part. However, in the fast urbanization period, the precipitation distribution pattern is reverse, and the precipitation center locates in the northeastern part (in the vicinity of Miyun and Huairou reservoir). Finally, the annual maximum 1-hour precipitation has an increasing trend apart from the south part during 1956-2012. For the spatial variation of precipitation intensity, the east, south and the urban area become the main storm centers with the relatively larger precipitation intensity. It is easy for the urban center area to suffer from extreme rainstorms due to the impact of urbanization, especially in the fast urbanization period.

Acknowledgments
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