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Study on the Change of Rainfall Characteristics in Hangzhou's Urbanization Process

Shi Zheng^{1,2}, Hu Lin-lin^{1,2}, Chen Huan-Bao^{1,2} and Tang Hong-xia^{1,2}

¹Zhejiang Institute of Hydraulics & Estuary, Hangzhou 310020, Zhejiang Province, China

²Zhejiang key laboratory of disaster prevention and mitigation for hydraulics, Hangzhou 310020, Zhejiang Province, China

E-mail: 13858051984@126.com

Abstract. With the development of the economy and expansion of the city size, urbanization has more important effects on rainfall characteristics. This paper takes Hangzhou for example, uses measured data of rainfall stations, and analyses the influence of urbanization on rainfall characteristics. The results show that the urbanization has changed the Hangzhou's rainfall characteristics, and the heavy rain occurred probability increases, the flood disaster is more and more frequent.

1. Introduction

With the concentration of people in urban areas, the process of expanding cities is called urbanization[1]. In the course of urbanization, human activities have more influences on nature, affecting the temperature and precipitation conditions in the city, and creating a different climate situation in the countryside. Usually the rainfall in the urban area is larger than the countryside, and the thunderstorm rainfall of the downtown also increases during flood season, which leads to urban flood disaster when serious[2].

Hangzhou is one of the most rapidly urbanized cities in China, but also has prominent flood disaster problems. Hangzhou is located in the north of Zhejiang Province, which belongs to the transitional zone from Zhejiang west hill to north plain. Due to geographical conditions, storage capacity and historical reasons, its flood control situation has been serious. Since the 1990s, Hangzhou has developed rapidly and its urbanization process has accelerated. The urban land area of the downtown has increased from 99.21 km² to 368.72 km², with a net increase of 269.51 km². The average growth rate is 14.18km²·a⁻¹, with an annual growth rate of 7.2%. The percentage of urban land area in the Hangzhou's total area has also increased from 14.03% to 52.13%. With the continuous expansion of urban area, the characteristics of rainfall have also changed. Based on Zhakou and Linping rainfall station, this paper analyses the possible impact of urbanization on the rainfall characteristics of Hangzhou, and provides some references for the study of urban flood disasters in the process of urbanization construction.

2. Mechanism of Urbanization Affecting Rainfall

The emergence and development of cities have dramatically changed the original natural landforms of the region, affected the local climate conditions of the urban areas in a certain extent, and further changed the characteristics of urban rainfall. In the process of urban construction, the change of the surface makes the radiation balance changed, and the change of aerodynamic roughness affects the movement of air. The heating and cooling systems, and motor vehicles increase the heat in the atmosphere, and



combustion sends water vapor into the atmosphere along with a variety of chemicals. Buildings can cause mechanical turbulence, and cities as heat sources can also cause thermal turbulence. Therefore, urban buildings have a considerable impact on air movement. Generally speaking, breezes can be strengthened in urban areas, and there are few windy days in cities compared with suburbs. Condensation nodules, thermal turbulence and mechanical turbulence over cities can affect local cloud and rainfall[4]. There are three physical mechanisms that urbanization influences rainfall formation process:(1) Urban heat island effect. Due to the change of urban underlying surface, the increase of artificial heat sources and the decrease of water body and greenbelt, the temperature of the city is obviously higher than the nearby suburbs. This temperature anomaly is known as the urban heat island effect. Thermal energy makes the structure of urban atmosphere unstable and causes thermal convection. When water vapor is sufficient in the city, it is easy to form convective rainfall;(2) Urban retarding effect. The urban special underlying surface and densely buildings result in a much greater degree of roughness than suburb plains, not only causing turbulence, but also hindering the effect of retarding the dewatering system (static front, static cut and slow cooling, etc.) making the movement speed slowly, prolonging the time of stagnation in the city, which cause the increase of precipitation intensity and precipitation time in the urban area;(3) Urban condensation effect. Urban air pollution is easy to form condensation nodules, which is conducive to the formation of intracloud colloidal instability, and thus play a role in promoting rainfall. Under the combined action of the above factors, the probability of rainstorm occurrence increases with the increase of total rainfall in urban[5].

3. Impact Analysis of Urbanization on Rainfall

Several sudden rainstorms occurred in Hangzhou, such as typhoon "Rosa" rainstorm disaster in 2007. The 3-hour rainfall reached 117 mm, causing 533 roads to fill with large puddles, blocking More than 40 intersections by deep water, trapping more than 150 cars in the water, and resulting in a direct economic loss of 1.063 billion yuan. This paper use the methods of moving average curve, cumulative curve, precipitation coefficient and rainy days frequency analysis, and take the data of Precipitation stations in urban and suburban areas of Hangzhou as the object of analysis. The interannual variation of rainfall in urbanization process is analyzed longitudinally, and the changes of rainfall characteristics in urban and suburban areas are compared horizontally. At the same time, the rainfall data in main flood season is analyzed emphatically.

(1) Data selection and representative analysis

Rainfall data of urban rainfall station called Zhakou and suburban rainfall station called Linping were selected as the analysis basis. The linear distance between the two stations was 27.3km. Linping Station is located in the northeastern part of Hangzhou, which is in the suburbs. Its urbanization development is relatively slow, and its rainfall is less affected by hilly landform. It can be used as a suburban station; Zhakou station is located in the main urban area of Hangzhou and close to the city center, which can reflect the impact of urbanization development of Hangzhou on rainfall in the sub-region, and can be used as a representative station in the urban area. The two stations are located in the same plain landform, with low elevation and consistent large-scale climate change. The influence of topographic fluctuation on precipitation can be ignored. According to the urbanization process of Hangzhou, it can be considered that 1991-2009 is a period of rapid urban development. In order to analyze the impact of urbanization on rainfall, the daily precipitation data of Zhakou and Linping station from 1991 to 2009 were selected for analysis.

Table 1. Summary of hydrological stations

Station name	Year of establishment	Observation project	Remarks
Zhakou	1922	Tidal Water level, precipitation	Tidal water level observation began in 1950
Linping	1957	Water level, precipitation	water level observation began in 1957

(2) Impact of Urbanization on Total Rainfall

The annual precipitation process lines of Zhakou and Linping Station from 1991 to 2009 are plotted, and the whole precipitation series are respectively processed by moving average for 3a and 5a. The results are shown in Fig. 1 and 2.

Comparing Fig. 1 and Fig. 2, although the urbanization effect is increasing with time, but the Zhakou and Linping station sliding curves show that the precipitation changing trend is basically stable. It means that urbanization does not have a significant impact on the periodic precipitation characteristics For long time scales, and long-term scale precipitation is still mainly affected by atmospheric circulation. Urbanization only increases the fluctuation of short-term precipitation sequence, and the fluctuation amplitude changes more and more.

Further, the double cumulative curves of annual precipitation and annual rainfall in main flood season (July to September) of 1991-2009 at Zhakou and Linping station are plotted, as shown in figure 3, 4. It can be seen that the slope of annual precipitation double cumulative curve is increasing, especially in the main flood season. This shows that in the process of urbanization, compared with suburbs, the annual precipitation in Hangzhou has an increasing trend. This shows that the urbanization process has changed the microclimate of some regions to a certain extent.

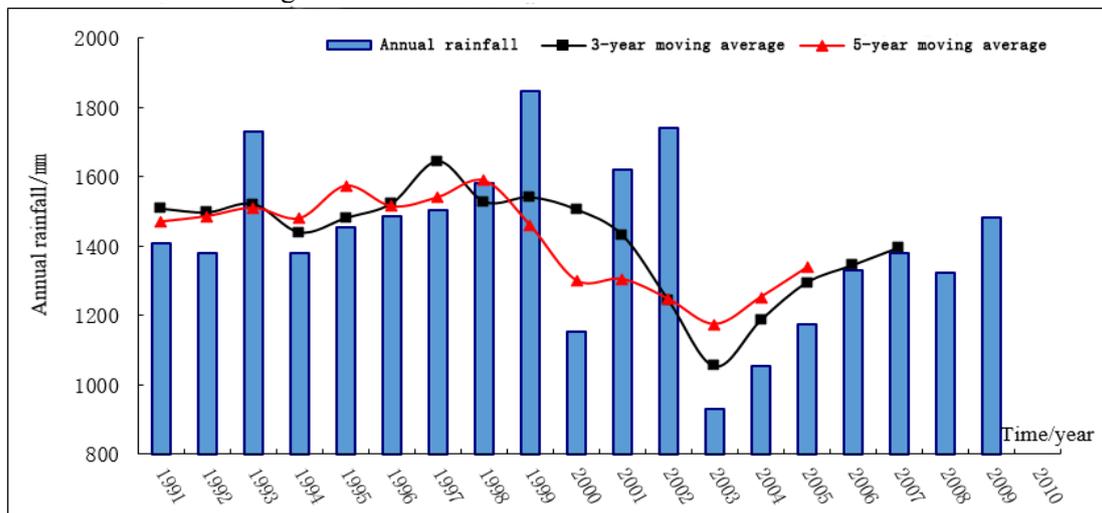


Figure 1. Annual precipitation process line and sliding average curve of Zhakou station

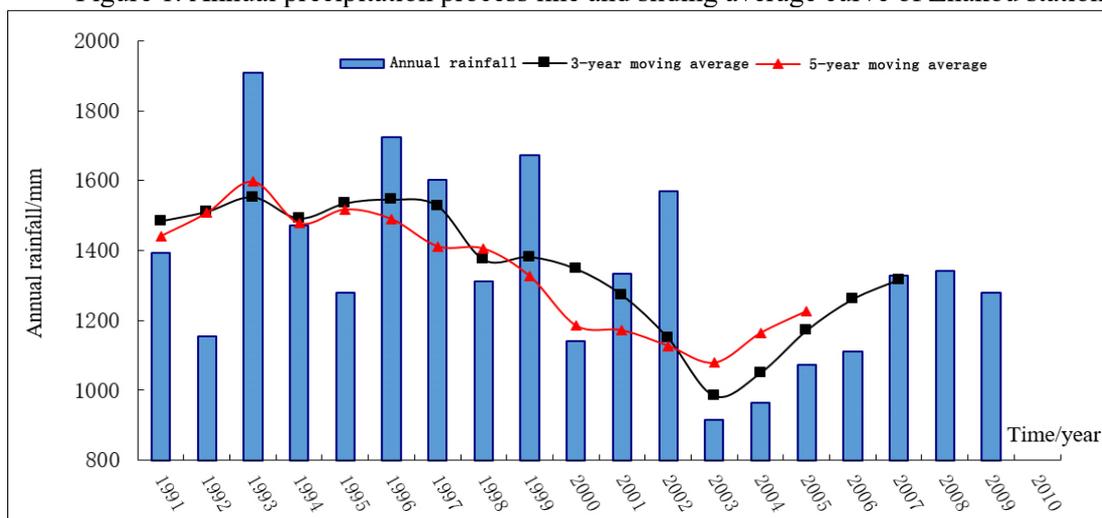


Figure 2. Annual precipitation process line and sliding average curve of Linping station

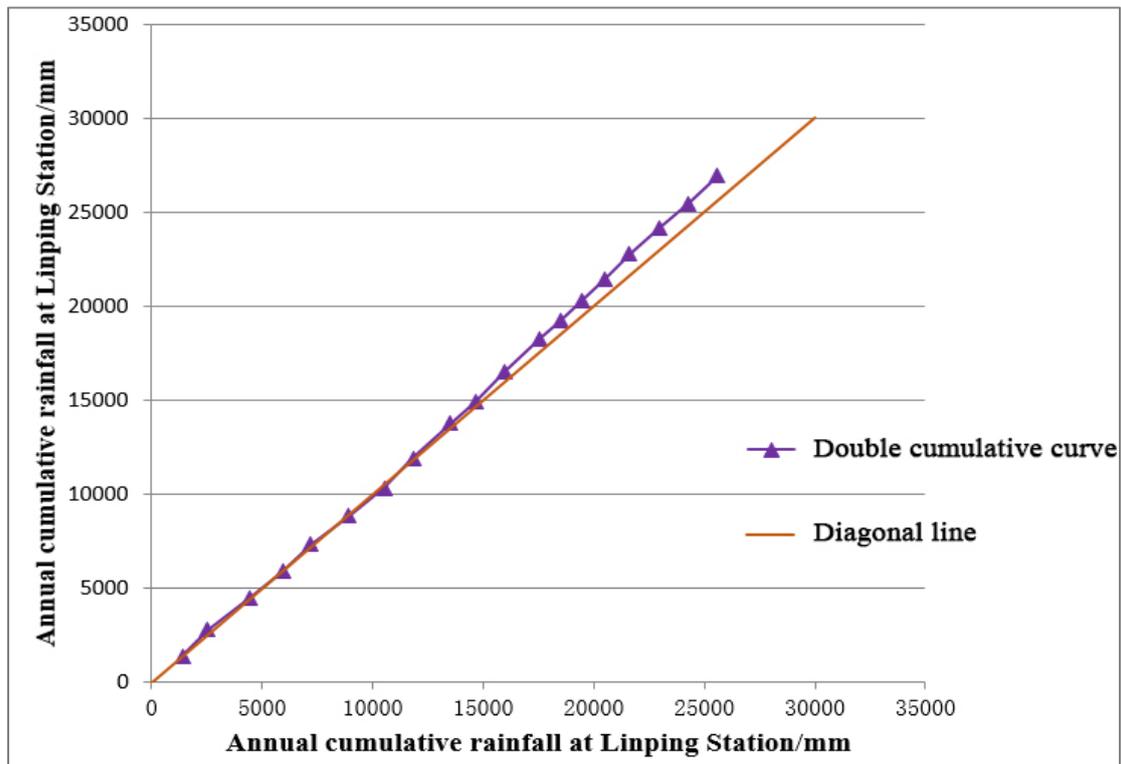


Figure 3. Double cumulative curve of annual rainfall at Zhakou and Linping station

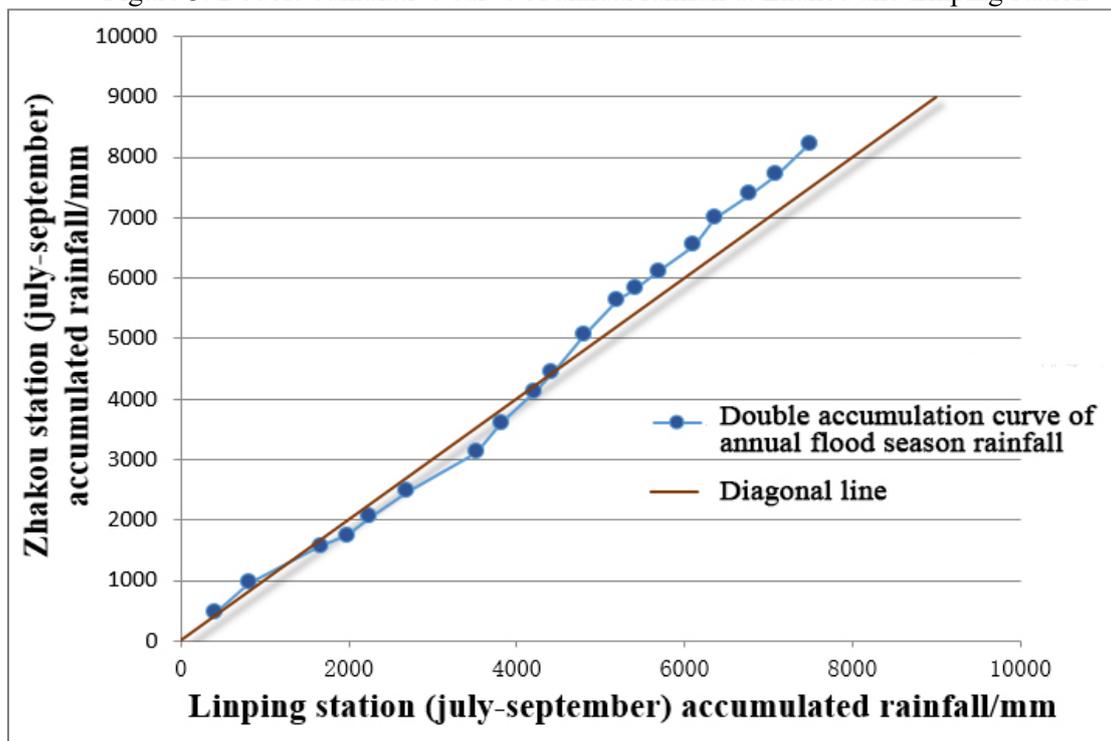


Figure 4. Double cumulative curve of main flood season rainfall at Zhakou and Linping station

(3) Significance analysis of rainfall difference between urban and suburban areas

The fluctuation of precipitation series data mainly comes from periodicity, trend and noise [6]. The precipitation in urban and suburban areas of Hangzhou is affected by the same atmospheric circulation, and its periodicity and trend are basically synchronized. The noise of the two areas includes the impact

of urbanization process, especially after 2000, the urbanization of Hangzhou has developed rapidly, and the impact is more obvious. In this paper, the difference significance test is carried out by means of pairwise two-sample analysis in the precipitation series from 2000 to 2009 at the Zhakou and Linping station.

$$d_i = x_i - y_i \tag{1}$$

Let d_i come from normal population $N(\mu_d, \sigma^2)$, $\mu_x = \bar{x}_i, \mu_y = \bar{y}_i, \mu_d = \bar{d}_i$, the significant level is α , hypothesis testing: $H_0: \mu_d = 0 (\mu_x = \mu_y)$; $H_0: \mu_d \neq 0 (\mu_x \neq \mu_y)$. The test statistics obey t distribution:

$$t = \frac{\bar{d} - 0}{s_d / \sqrt{n}} \tag{2}$$

Test reject region: For a given α , reject the hypothesis H_0 when $|t| > t_{\frac{\alpha}{2}}(n - 1)$. Assuming $\alpha = 0.05$, the hypothesis test of annual precipitation Zhakou and Linping station is carried out:

$$|t| = 3.5095 > t_{\frac{\alpha}{2}}(n - 1) = 2.2622 \tag{3}$$

Rejecting the original hypothesis H_0 , it is considered that there is a significant difference in annual rainfall between the Zhakou rainfall station Located the urban area and Linping rainfall station Located the suburban area.

(4) Analysis of Rainfall Increase Coefficient

Define rainfall increase coefficient as $K_{\text{increase}} = P_{\text{urban}} / P_{\text{suburb}}$. Calculate the rainfall increase coefficients of annual average rainfall, main flood season average rainfall and monthly average rainfall at Zhakou and Linping station in different periods respectively. See table 2, 3 and 4 for details.

Table 2. Annual average rainfall and rainfall increase coefficient at Zhakou and Linping Station in different periods

Period	Annual average rainfall		rainfall increase coefficient K_{increase}
	Zhakou station	Linpings station	
1991-1995	1470.6	1441.0	1.021
1996-2000	1514.4	1490.0	1.016
2001-2005	1303.9	1171.2	1.113
2006-2009	1379.7	1265.0	1.091

Table 3. Main flood season(July to September) average rainfall and rainfall increase coefficient at Zhakou and Linping Station in different periods

Period	Flood season average rainfall		rainfall increase coefficient K_{increase}
	Zhakou station	Linpings station	
1991-1995	410.9	451.1	0.911
1996-2000	476.7	433.6	1.099
2001-2005	422.0	337.5	1.250
2006-2009	416.6	346.7	1.202

In each period, the annual average rainfall of Zhakou station is greater than that of linping station, and the rainfall increasing coefficient tends to increase, reaching 1.113 at the maximum, especially in the mian flood season. From 1991 to 2009, the rainfall increase coefficients of year-round and main flood season reached 1.060 and 1.116 respectively.

Table 4. Monthly average rainfall and rainfall increase coefficient at Zhakou and Linping Station in different periods

rainfall increase coefficient K_{increase}	1991-1995	1996-2000	2001-2005	2006-2009	1991-2009
January	1.242	0.907	0.963	1.025	1.034
February	1.145	0.996	1.128	1.017	1.072
March	1.038	1.025	1.322	1.112	1.124
April	1.250	1.012	1.089	1.092	1.111
May	1.083	1.123	1.069	1.145	1.105

rainfall increase coefficient $K_{increase}$	1991-1995	1996-2000	2001-2005	2006-2009	1991-2009
June	1.009	0.910	0.852	1.032	0.951
July	0.997	1.090	1.039	1.254	1.095
August	0.725	1.016	1.401	1.417	1.140
September	1.134	1.433	0.889	0.960	1.104
October	0.853	1.087	0.948	1.023	0.977
November	1.231	1.025	1.094	0.982	1.083
December	1.025	0.944	0.884	1.017	0.968

Table 4 lists the monthly average rainfall increasing coefficients of Zhakou and linping station in different periods. The most obvious period of monthly average rainfall increase was from 2006 to 2009. The monthly average rainfall of Zhakou station was greater than that of linping station for 10 months. In the distribution of the year, the monthly average rainfall coefficient in August is the largest. Monthly average rainfall increase coefficient is 1.064 in 1991 to 2009 , flood season(May to September) monthly average rainfall increase coefficient is 1.079,and main flood season(July to September) monthly average rainfall increase coefficient is 1.113. Thus it can be seen that the effects of urbanization on rainfall during flood season(May to September) is greater than the whole year, especially during the main flood season (July to September). The main reason is that in the main flood season,typhoon activity is frequent and the temperature is the highest., and the heat island and blocking effect of the city are relatively significant.

(5) Impact of urbanization on annual rainfall distribution

Rainfall in Hangzhou is mainly in the main flood season (July to September), about 30% of the annual rainfall. The proportion of rainfall stations in annual main flood season is analyzed, and the results are shown in Figure 5.

It can be seen from Figure 5 that the variation range of Linping station main flood season rainfall accounted for the proportion of the year is greater than that of Zhakou station. From the perspective of trend, the proportion of rainfall in the main flood season of Zhakou station in different periods is basically stable, while that in the main flood season of linping station is decreasing.

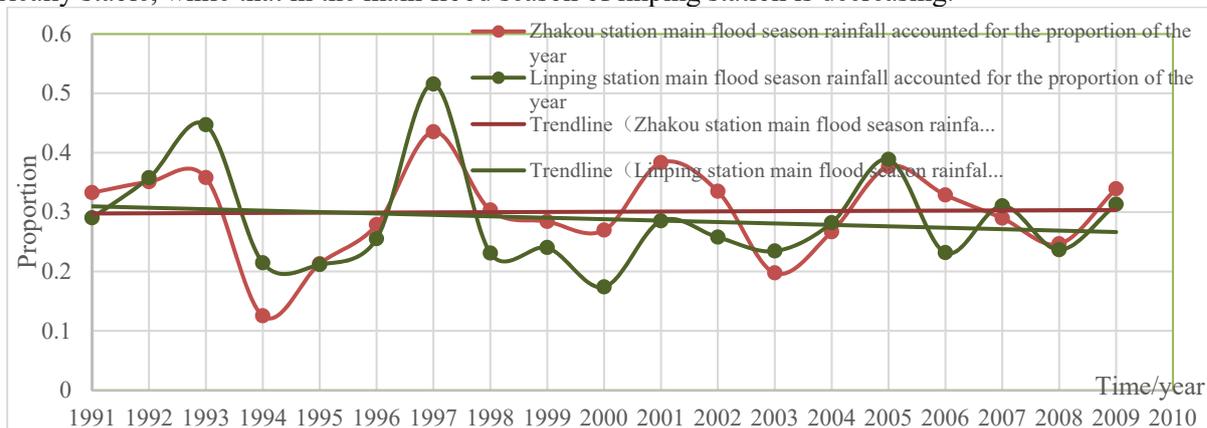


Figure 5. The annual percentage change of rainfall in the main flood season in Zhakou and Linping station in the whole year

(6) Effects of urbanization on different types of rainfall

China Meterological Administration stipulates: The rainfall within 24 hours is called the daily rainfall, where the daily rainfall is less than 10mm is called light rain, 10.0 to 24.9mm for moderate rain, 25.0 to 49.9mm for heavy rain, the rainstorm is 50.0~99.9mm, the heavy rain is 100 to 250mm, more than 250.0mm is called torrential rain. According to this regulation, the daily rainfall of Zhakou and Linping station from 1991 to 2009 was calculated, and the statistical results are shown in table 5.

From Table 5, the urbanization process of Hangzhou has a significant impact on the number of rainstorm days: From 1991 to 2000; Urbanization has no significant influence on daily rainfall frequency

From 2001 to 2005, the ratio of the daily rainstorm frequency reached 2.200. From 2006 to 2009, urbanization increased the daily rainfall frequency above moderate rain.

Table 5. Daily rainfall frequency ratios of each type in different periods at Zhakou and Linping station

Period	Rainfall station	Rainy days (d)			
		Light rain	Moderate rain	Heavy rain	Rainstorm
1991-1995	Zhakou	20	3.4	3.4	1.6
	Linping	19.4	3.6	3.6	2.6
	Rainfall frequency	1.031	0.944	0.944	0.615
1996-2000	Zhakou	28.2	3.2	3.2	2
	Linping	21.2	4.2	4.2	1.4
	Rainfall frequency	1.330	0.762	0.762	1.429
2001-2005	Zhakou	21.8	2.2	2.2	2.2
	Linping	21.6	3.8	3.8	1
	Rainfall frequency	1.009	0.579	0.579	2.200
2006-2009	Zhakou	21	3.75	3.75	1.75
	Linping	25.25	3	3	1.25
	Rainfall frequency	0.832	1.250	1.250	1.400

4. Conclusions

Urbanization leads to changes in underlying surface conditions, urban heat island effect leads to certain changes in climate characteristics, especially in rainfall. With the continuous development of urban construction in Hangzhou, the urbanization process directly or indirectly changes the urban water cycle. Based on the observed data of Zhakou and Linping rainfall station, this paper analyzes the impact of urbanization on rainfall characteristics in Hangzhou. The research shows that although the annual precipitation cycle doesn't change much and the annual rainfall distribution of urban areas is relatively stable, the rainfall increase coefficient and the rain day frequency all show that there is an obvious precipitation increasing effect in urban areas compared with the suburbs, and the heavy rain tends to occur in a centralized way. The urbanization process makes the strong convection and rainstorm weather increase in Hangzhou, which is easy to cause flood disaster. In addition, due to the limitation of data and the complexity of urbanization's influence on rainfall characteristics, a large amount of data is still needed for relevant research and analysis.

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