OPEN ACCESS Freely available online

IJESP International Journal of Environmental Sustainability and Protection

ISSN 2737-5447
Volume 4 Issue 3
https://www.iikii.com.sg/journal/IJESP
International Journal of Environmental Sustainability and Protection

Article

Analysis of the Relationship between Extreme Precipitation Pattern and Maximum Runoff in Hongze County From the Perspective of Urban Underlying Surface Production and Confluence

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Received: Jan 24, 2024; **Revised:** Apr 8, 2024; **Accepted:** May 2, 2024; **Published:** Jul 5, 2024

Abstract: Based on the hourly precipitation data and evaporation data of the meteorological in Hongze County from 1959 to 2020, we studied the relationship between extreme precipitation and annual runoff control rate from the perspective of the underlying surface of the Hongze County watershed. We conducted a literature review and statistical analysis using SPSS in this study. From 1959 to 2020, precipitation in the Hongze region varied greatly annually, with the maximum and minimum annual precipitation of 1473.8 and 349.6 mm. The precipitation fluctuated but increased, and the extreme precipitation was concentrated in July to August. The annual average evapotranspiration from 1959 to 2020 was 1165.8 mm with an inter-annual fluctuation and decrease due to the urbanization process. The process affected the local evapotranspiration condition. More evaporation was observed from May to August than from December to January with a difference of 50 mm. The evaporation data coincided with seasonal variation in Hongze County. In determining the control rate of annual total runoff, we considered the inter-annual and annual differences in precipitation. The natural runoff condition and economic cost before urbanization were explored, too. The greater the rain intensity, the earlier the runoff generation time, the shorter the confluence time, and the greater the possibility of floods. In short-duration extreme precipitation, it is necessary to pay attention to its middle period, while for long-duration extreme precipitation, it is necessary to focus on its late period.

Keywords: Extreme precipitation, Runoff, Rainstorm event, Hongze County

1. Introduction

Extreme precipitation causes disasters such as the destruction of buildings and floods as observed in the extremely heavy rain event in Zhengzhou, Henan Province, China, in July 2021. With the developed economy and technology, disasters caused by extreme weather can be prevented and controlled limitedly. Concentrated precipitation causes floods in urban areas. In this study, we selected Hongze County of Huai'an City in China for a case study of the spatial and temporal extreme precipitations. The pattern of extreme precipitation and urban runoff control rate were explored to determine factors affecting runoff production and confluence to prevent damages from urban floods. China's monsoon climate is common, and the affected areas are huge. Monsoon in summer shows precipitation concentrations in a short time, resulting in floods in a wide area. Excluding the arid inland areas in Northwest China, the Qinghai-Tibet Plateau and the Gobi Desert, 67% of Chinese inland is experiencing flood disasters in varying degrees. Hongze County of Huai'an City is located in the eastern coastal area of China and is affected by the monsoon directly. The coastal area has sufficient water vapor and frequent precipitation accompanied by occasional storm surges and extreme rainstorms. As the population in the area is large, related loss is severe.

Due to the rapid development of the economy, society, and technology, many areas are urbanized rapidly. Thus, the urban underlying surface is transforming. The different degrees of reconstruction in different places change urban hydrological conditions and zoning of the water cycle. These changes affect urban evapotranspiration and urban water-logging. Though rapid urbanization can make people's lives convenient, natural underlying conditions and local hydrological characteristics are changed by it. More than 70% of urban precipitation is runoff and discharge, increasing the occurrence of floods in cities [1]. The concept of runoff generation was proposed by Horton, who summarized the formation mechanism of surface runoff generation and put forward relevant theories of runoff generation. However, in the runoff generation and confluence theory, large areas and slopes are considered. Thus, the theory does not apply to the runoff generation and confluence in small cities such as Hongze County [2]. After urban runoff generation, surface confluence and underground network confluence occur.

Surface confluence is divided into slope and river confluences. Without urbanization, the natural underlying surface can be modified to a small degree with natural homogeneity. With urbanization, the conditions of the urban underlying surface are changed, and the infiltration and runoff of precipitation of various underlying surfaces are different. Therefore, the process of urban confluence in urbanization becomes complicated. To research the mechanism of urban production confluence, the simulation experiment with multi-scale popularization and application is necessary. Considering the regional characteristics of rainwater management, sophisticated plans and construction of sponge cities are demanded.

In this study, scientific theories related to geography and meteorological hydrology were applied to the precipitation of the urban area in Hongze County based on urban hydrology theories. The urban production and confluence conditions under extreme precipitation were studied to understand the extreme rain type and runoff control rate in the urban production and confluence. To avoid "urban flood damage" and construct an efficient sponge city, we studied the runoff production and confluence process based on the spatial and temporal distribution and runoff control rate of extreme precipitation. We combined the characteristics of the urban underlying surface and the status of the underground pipe network to determine the control rate of urban annual runoff. The inter-annual trend in precipitation and natural runoff and economic costs before and after urbanization were compared. At the same time, the peak value of precipitation intensity in short- and long-duration extreme precipitation patterns was estimated in the middle and late periods. To study the spatiotemporal distribution of precipitation in small catchments and the underlying surface condition after urbanization, theories of physics, mathematics, and meteorological hydrology were adopted. Based on the data of urban meteorological stations and the meteorological and climate characteristics of the region, we summarized the analysis results to determine the annual runoff control rate and the type of extreme precipitation.

2. Theoretical Backgrounds

2.1 Analysis Methods

Urban waterlogging is used to monitor urban floods. Urban production confluence pertains to the urban water cycle. Urban hydrology is applied to solve the hydrologic problems in the city. Urban hydrology focuses on the analysis of the urban water cycle process and explores the various influences of urbanization in the water cycle to solve the problems caused by urban waterlogging and propose relevant measures such as the sponge city [3]. We used urban hydrology to propose the healthy development and reasonable planning of cities.

2.2 Hydrological Effects Of Urbanization On Precipitation And Evaporation

The hydrological effects of urbanization are studied from the following three aspects: rainstorm waterlogging, water cycle process, and water environment [4]. Urbanization affects cities hydrologically in terms of the water cycle and security. Rainstorms sometimes cause disasters and affect sustainable development. Thus, it is necessary to study the hydrological effects of precipitation and evaporation.

The island effect of rain and heat in the urban area has been recognized by many scholars. In intense urban precipitation, extreme precipitation frequency increases compared with that before urbanization [5]. The impact of urbanization on precipitation is closely related to seasonal change, urban topography, and geographical location, and the specific degree of its impact needs to be further explored. Urbanization weakens evaporation, which is manifested by the impervious layer due to the loss of forest, grassland, and vegetation after urbanization, and the transpiration of vegetation decreases. The water body inside the city is replaced by constructions in urbanization which decreases the urban water coverage rate. The impervious layer blocks the channel of underground water evaporation [6]. On the contrary, urbanization can increase evaporation [7]. The evapotranspiration of urban areas is higher than that of the natural underlying surface and is related to heat, evapotranspiration, and leakage factors of buildings. In general, precipitation and evaporation are important in exploring urban water problems, in which positive and negative effects exist at the same time. Thus, there are many factors in the study of urbanization hydrological effects.

2.3 Urban Production-Confluence Theory

Urbanization causes hydrological problems in the city. Urban waterlogging is closely related to the urban production confluence mechanism. Therefore, it is imperative to study the effect of urbanization from the perspective of production confluence on the underlying surface based on the theory of urban production confluence. Urban runoff and generation are affected by precipitation intensity, the type of precipitation, and underlying soil properties. At present, it is difficult to directly carry out runoff generation observation in cities. Therefore, urban solid models are used to simulate runoff generation. Wu and Gao conducted experiments to explore the characteristics of runoff production under different urban underlying surface conditions. However, they did not take into account the influence of slope and precipitation kinetic energy. A reliable technology was used to research using a small watershed model of urban production confluence [8].

The underlying surface after urbanization becomes complicated and influences the production and confluence. According to the characteristics of the underlying surface, six small units of urban hydrological response are defined, and each unit has its corresponding flow generation mechanism. The units are used for zoning research on urban flow generation. The analysis method of runoff production and confluence is based on hydrology and hydraulics. The production confluence mechanism is an important basis for the construction of sponge cities. Considering the mechanism of urban production and confluence, the type of sponge cities is determined. Satellite remote sensing data and meteorological data are used to solve problems such as urban waterlogging.

3. Study Area

3.1 Hongze County and Huai'an City

Hong ze is located in Huai 'an City, Jiangsu Province in China. Hongze County is located in the central part of Jiangsu Province, and, its coordinate is 118°28 '-119°9' east, 33°2-34°24 'north. the Hongze District is located in the boundary between the North and South of Jiangsu and is neighboring Yangzhou in the east. It is connected with Xuyi and Jinhu and the north is shared with Huai'an city. Hongze County has 12 towns and a provincial economic development zone, with a length of 63 km from east to west and a width of 39.4 km from north to south, with a total area of 1394 km^2, including 637 km^2 of land. The Hongze area belongs to the temperate monsoon climate. It is cold and dry in winter and hot and rainy in summer with sufficient sunlight and short frost periods, The area is affected by monsoons. the Hongze District is near the Yellow Sea and is affected by the water body of Hongze Lake, with abundant and uneven annual precipitation, so is prone to flood (Fig. 1). As the research on urban production and confluence must be conducted in an area of the distinctive spatial and temporal distribution of precipitation and the sponge city construction, Hongze County of Huai'an City was selected as the study area.

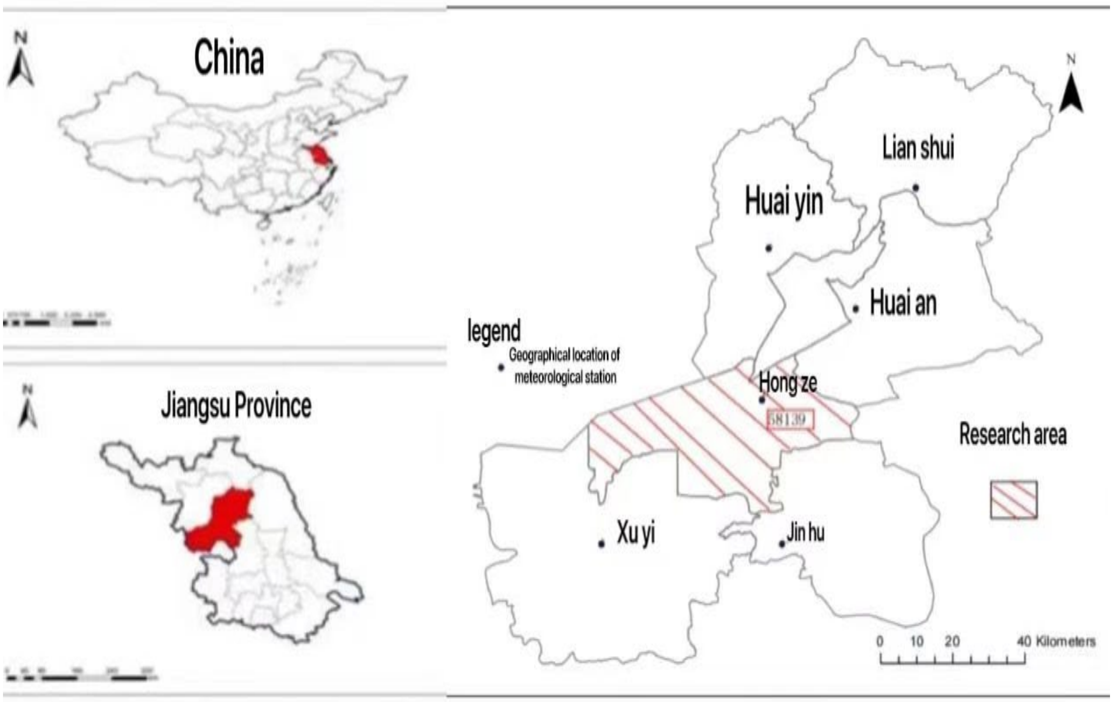


Fig. 1. Overview of the study area.

3.2 Hydrological Surveys

Hongze County is high in the west and low in the east with Baima Lake in the east and Huaihe River channels (three rivers) in the west of Hongze Lake. Hongze Lake is one of the five major freshwater lakes in China. In the north, there are the Subei irrigation canal and the sea waterway. The main rivers that run through the Hongze District include the Huai River, Subei Irrigation Canal, Huai River into the river channel, Laosan River, Caoze River, Zhangfu River, Hongjin Drainage River, as well as the Xunhe River, Yanlin River, Tiedui River, Xiangliang River, Huahe River and other rivers within the area.The watershed area of Hongze County is 757 km^2 with criss-cross waterways. With continuous urbanization and the increase of human activities, the water area of Hongze County has gradually decreased as shown in Fig. 2.

Fig. 2. Hongze area.

4. Methods

4.1. Data

The precipitation data from 1959 to 2020 was used to analyze the intra-annual and inter-annual variations in the Huai'an Meteorological Observation Station. The hourly precipitation data of Huai'an Meteorological Observatory from 2011 to 2021 were used to analyze the extreme precipitation process in Huai'an City. The number of permanent urban residents, the number of permanent residents at the end of the year, and the area of administrative districts were obtained from Huai'an Statistical Yearbook in 2020.

4.2 Research Methodology

We employed the precipitation design rain pattern analysis for data collection, processing, and analysis. The precipitation pattern refers to the interannual variation, intra-annual variation, and frequency of extreme precipitation over the years. The data on precipitation was processed using Microsoft Excel. In this study, the daily data of precipitation and evaporation were collected from Hongze station 58139. In the processing of station data, we considered weather indicators to select variables. For the analysis of the designed rain pattern, Excel and SPSS software were used. The design rain type was divided into short- and long-duration types. Various methods were proposed to derive the rain pattern of short-duration precipitation including the Chicago rain pattern method, the Huff rain pattern classification method, the SCS rain pattern method, the triangular rain pattern model method, and the Pilgrim & Cordery rain pattern model method [9]. In this study, the Chicago rain pattern method also known as the Keifer & Chu method was selected in this study to derive the rain pattern using the rainstorm intensity formula and the rain peak coefficient. In the Chicago rain pattern, the r-value is calculated by counting the number of local rainstorms, and the peak event of the precipitation was determined based on the number of rain peaks and their location (the first 1/3, the middle 1/3, and the last 1/3 of the precipitation duration) [10]. In addition to the seven common precipitation patterns in the selected study area, the three-peak rain patterns at the first, middle, and last periods were defined as T-patterns [11]. In the Chicago rain pattern, the extreme precipitation intensity formula is used to calculate the average precipitation intensity. Based on the rain peak coefficient, the variation law of precipitation in different periods is obtained by derivative integral and other steps [12]. In this study, the annual maximum value method was used to select 11 precipitation samples from 2010 to 2021, including 5, 10, 15, 20, 30, 45, 60, 90, and 180 min in the precipitation per minute. The selected data samples were arranged in descending order according to precipitation intensity regardless of year, and the empirical frequency of rainstorm intensity in each period in Hongze area was calculated according to the corresponding return period. In the fitting method, we used three theoretical frequency distribution curves: exponential distribution type, Pearson III, and Gengbell distribution curve [13]. According to the distribution curve, the parameters in the extreme precipitation intensity were determined, and the relevant design rain patterns were obtained. The most widely used method for the inference of long-duration rain patterns is the same frequency analysis method [14] but was not used in this study.

5. Results and Discussion

The two important parameters of precipitation are rain intensity and pattern as changes in them reflect the process of precipitation and the production and confluence conditions. Even in the same underlying surface conditions, the continuous change of rain conditions makes runoff, confluence, steady flow and water retreat varied. On the underlying surface, the greater the intensity of precipitation, the earlier the time of runoff, and the shorter the process of confluence in the same topography. That is, the earlier the peak of the flow appears, the larger the value of the peak, and the longer it will take for the water to recede [9]. Therefore, the temporal and spatial distribution of rain intensity and pattern in the Hongze area was significant in this study. We analyzed the specific construction status of the Hongze District from the hydrological aspect of precipitation law to understand the problems and causes of urban rainwater in the Hongze District and estimate the degree of its influence by precipitation for the construction of sponge city in the Hongze District.

5.1 Interannual And Annual Variations Of Precipitation And Evaporation

5.1.1 Interannual Variation

Huai'an City is located in the transition area between the warm temperate zone in the south and the subtropical zone in the north, with northern and southern climate characteristics and strong monsoon. According to the analysis of precipitation data from 1959 to 2020, the average annual precipitation in the Hongze District of Huai'an City was 893.29 mm(Fig. 3). The inter-annual variation of precipitation in the Hongze District varied greatly, with the maximum annual precipitation reaching 1473.8 mm in 1991 and the minimum annual precipitation only 349.6 mm in 2019. The difference was 4.22 times. The causes of abnormal precipitation in years (abnormally low) were complex. The interannual precipitation in the Hongze area showed a fluctuating but increasing trend, and the frequency of extreme precipitation events also increased. This coincided with the theory of the urban hydrological effect. According to the analysis of evaporation data from 1959 to 2020, the average evaporation in Huai'an City was 1165.8 mm, and an overall decreasing trend was observed due to the urbanization process(Fig. 3). Urbanization affected local evapotranspiration and reduced evaporation and destructed vegetation by replacing water bodies and decreasing transpiration.

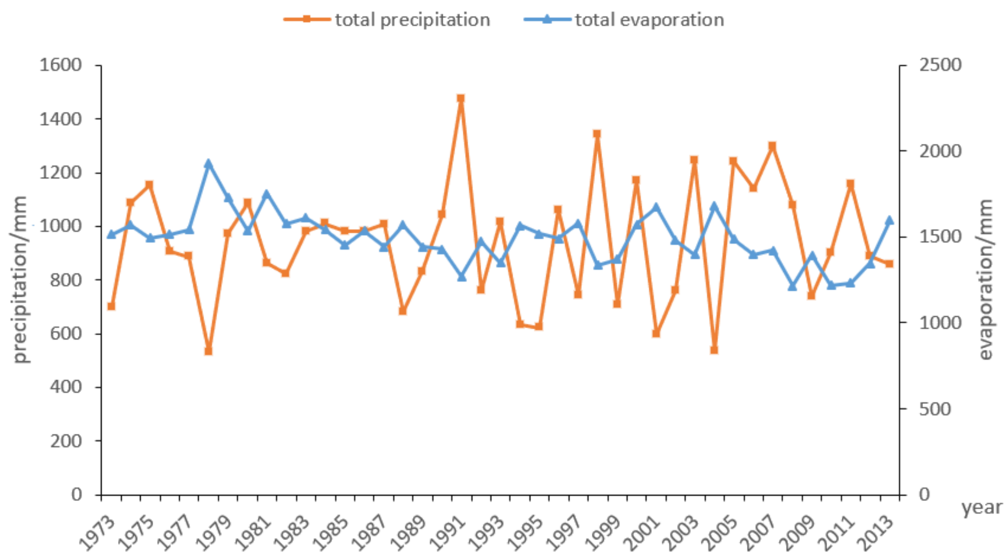


Fig. 3. Annual precipitation and evaporation in the Hongze District, Huai'an City from 1959 to 2020.

5.1.2 Intra-Year Variation

The precipitation in the Hongze District from June to September accounted for about 64% of that in the whole year, which was in line with the strong monsoon characteristics of the Hongze District. The months of heavy rain in Hongze County lasted from May to October, mainly concentrated in July and August (Fig. 4). The most precipitation was observed in July, followed by August. This reflected the characteristics of the summer monsoon. The precipitation in July accounted for 25% of total precipitation, followed by August (17%). 42% of the total precipitation was observed in July and August, which was about half of the annual precipitation. Extreme precipitation events were also concentrated in July and August every year. The evaporation from May to August was relatively stronger but stable while that from December to January was smaller than 50 mm. This trend also reflected the characteristics of seasonal changes in Hongze County.

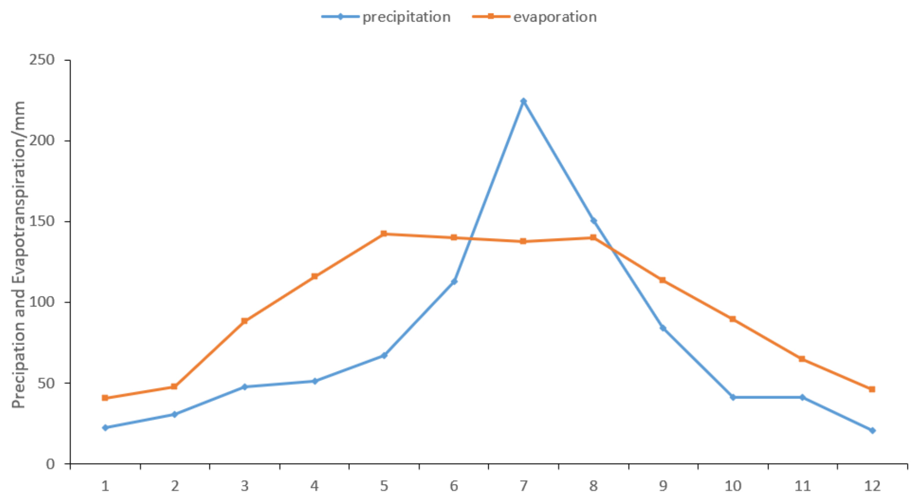


Fig. 4. Precipitation and evaporation from 1959 to 2020.

5.2 Interannual Variation Of 24-Hour Extreme Rain Patterns

The average extreme 24-hour precipitation in Hongze County was 94.6 mm (Fig. 5). The maximum 24-hour precipitation was observed on August 31 1984 with 193.8 mm, and the minimum one was 50 mm. The 24-hour extreme precipitation was about 100 mm. Therefore, we focused on precipitation of over 100 mm for damage prevention and control in rainstorms.

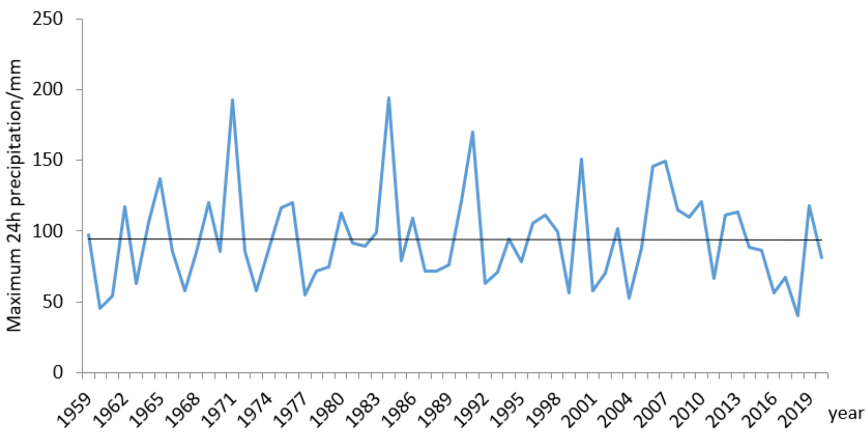


Fig. 5. Maximum precipitation in 24-hour from 1959 to 2020.

5.3 Hourly And Minutely Precipitation

Rain patterns present the characteristics of precipitation intensity in different precipitation durations and are determined by the precipitation process. For extreme precipitation, the intensity is the most important factor as it may cause storm runoff. The rainstorm intensity formula is used to calculate the average precipitation intensity but cannot accurately represent the complete rainstorm process. Thus, it is necessary to understand runoff curves to calculate storage capacity. Therefore, we derived the formula of rainstorm intensity and established a rain-type model of rainstorms. We also explored the short- and long-duration precipitation patterns.

5.3.1 Minutely Extreme Precipitation Pattern

The duration of extreme precipitation in minutes was defined as the short-duration precipitation pattern. We used the Chicago rain method to calculate the rain peak coefficient. According to the statistics of the precipitation data samples of Hongze County for 10 years from 2011-2021, the precipitation field times of the annual maximum precipitation of different precipitation durations will be divided into tables with the maximum precipitation samples of 30min, 60min, 90min, 120min, 150min and 180min divided into 5min intervals, to find out the peak precipitation of this sample and define the peak type of each sample.

Table 1. Peak precipitation data in 30 min.

Serial Number	Year	Amount Of Precipitation (0.1 mm)	5 Min Precipitation Maximum Period	Peak Type	Rain Peak Coefficient
1					0.67
2	2011	145	4	Unimodal (Medium)	0.5
3	2012	278	3	Unimodal (Medium)	0.5
4	2013	392	3	Unimodal (Medium)	0.83
5	2014	259	5	Bimodal (anterior, posterior)	0.33
6	2015	397	2	Unimodal (front)	0.33
7	2016	197	2	Unimodal (front)	0.33
8	2017	161	2	Unimodal (front)	1
9	2018	296	6	Unimodal (rear)	0.67
10	2019	713	4	Unimodal (medium)	0.83
11	2020	214	5	Homogeneous(4)	0.33
Average value	2021	331	2	Doublets (front, middle)	0.57

8 peak precipitation events in 30 min were observed from 2011 to 2021. The single-peak precipitations in 60, 90, 120, 150, and 180 min were very high. The arithmetic average and weighted average of the rain peak coefficient of each duration were determined as shown in Table 2.

Table 2. Rain peak coefficients

Precipitation Duration (min)	Arithmetic Rain Peak Coefficient	Weighted Rain Peak Coefficient
30	0.57	
60	0.67	
90	0.49	0.52
120	0.45	
150	0.43	
180	0.48	

The original formula for the intensity of a rainstorm is

$$i = \frac{167\,A(1 + C\lg P)}{(t + b)^n} \tag{1}$$

where *i* is precipitation intensity (mm/min), *t* is the duration of the rainstorm (min), *P* is the return period (a), *A, b, C*, and *n* are parameters related to the characteristics of the local rainstorm. *A* is the rain force parameter, i.e. the return period is 1 min, *C* is the rain force variation parameter (dimensionless), *b* is the precipitation duration correction parameter, a time constant added to the curve (min), and *n* is the rainstorm attenuation index, which is related to the return period [10].

According to the *r*-value, the rainstorm intensity in the Hongze District is calculated by

$$i = \frac{13.928\,(1 + 0.72\lg P)}{(t + 11.28)^{0.711}} \tag{2}$$

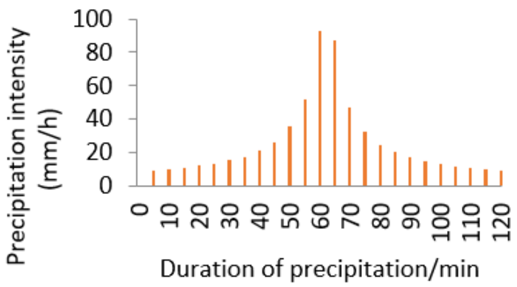
Therefore, the hourly precipitation of different periods in Hongze area for 120 min is shown in Table 3.

Table 3. Precipitation in 120 min in the Hongze District (mm/h).

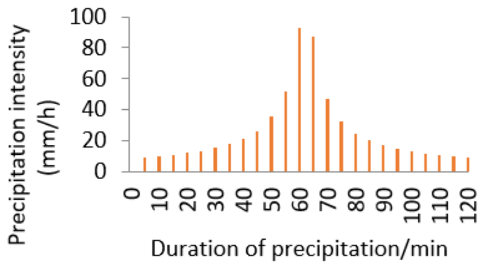
Precipitation Duration/min	1a	2a	3a	5a	10a
5	9.51	11.58	12.79	14.31	16.37
10	10.26	12.48	13.78	15.41	17.64
15	11.14	13.56	14.97	16.75	19.17

20	12.23	14.88	16.43	18.38	21.03
25	13.58	16.62	18.25	20.42	23.36
30	15.33	18.65	20.60	23.04	26.37
35	17.68	21.68	23.75	26.57	30.40
40	20.99	25.54	28.48	31.55	36.10
45	26.02	31.66	34.96	39.11	44.76
50	35.61	42.05	46.42	51.94	59.42
55	51.96	63.22	69.81	78.11	89.37
60	92.84	126.69	139.89	156.52	179.09
65	86.93	105.77	116.79	130.68	149.52
70	47.19	57.41	63.39	70.93	81.16
75	32.41	39.16	43.54	48.72	55.74
80	24.82	30.20	33.34	37.30	42.68
85	20.22	24.60	27.19	30.40	34.78
90	17.15	20.86	23.04	25.77	29.49
95	14.85	18.18	20.07	22.46	25.70
100	13.28	16.16	17.85	19.97	22.85
105	11.99	14.59	16.11	18.02	20.62
110	10.95	13.32	14.71	16.46	18.84
115	10.10	12.29	13.57	15.18	17.37
120	9.38	11.42	12.60	14.10	16.14

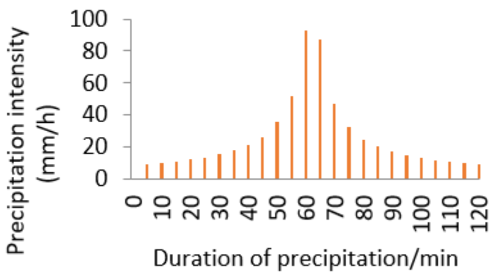
The precipitation in 120-minute in one, two, three, five, and ten years were 52.38, 63.73, 70.37, and 78.74 mm (Fig. 6). With the increase in the period, the precipitation increases, and the peak of precipitation intensity was observed in the middle of the precipitation period. The intensity gradually increased with the increase of the period. Therefore, for the prevention of damage, it is necessary to pay attention to the mid-period precipitation[15].



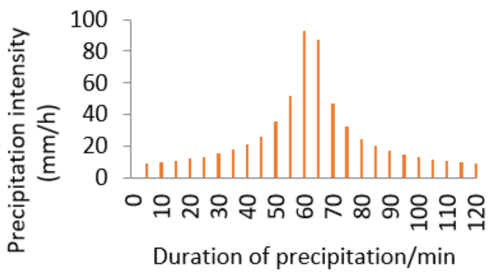
(**a**) Precipitation in 120 min once a year



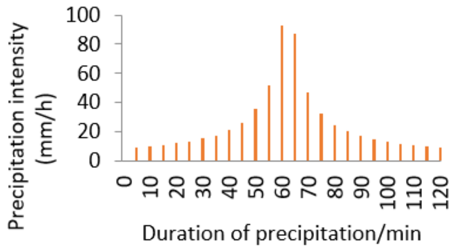
(**b**) Precipitation in 120 min every two years



(**c**) Precipitation in 120 min every three years



(**d**) Precipitation in 120 min every five years



(e) Precipitation in 120 min every ten years

Fig. 6. Precipitation in 120 min in different periods.

5.3.2 Hourly Extreme Precipitation Pattern

Hourly extreme precipitation was defined as a long-duration precipitation pattern in this study. Three, six, and 24-hour precipitation data are shown in Table 4. The maximum 24-hour precipitation in 2011 was 66.5 mm, but the maximum in 2021 reached 263.7 mm.

Table 4. Maximum precipitation in 1, 3, 6, and 24 hours from 2011 to 2021.

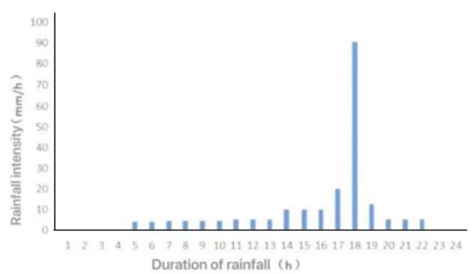
Year	1 h	3 h	6 h	24 h
2011	21.4	40.1	54.8	66.5
2012	38.3	51.4	90.9	111.4
2013	52.6	111.6	111.7	111.7
2014	47.4	63.1	74.3	88.8
2015	47.3	102.2	105.6	130.5
2016	33.9	56.0	67.2	130.2
2017	20.0	40.9	57.6	107.0
2018	47.7	104.3	117.7	170.7
2019	76.4	88.6	95.5	137.5
2020	30.8	58.8	77.9	81.4
2021	57.4	67.6	116.4	263.7

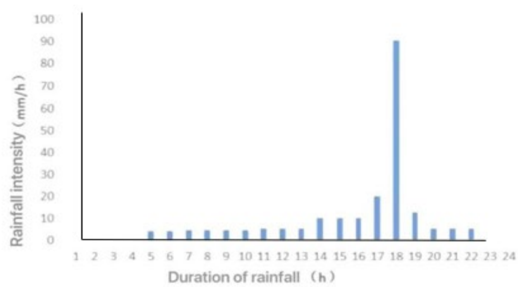
A P-III type frequency curve was drawn to determine the long-duration precipitation pattern of the Hongze District. The results are shown in Table 5.

Table 5. Long-duration precipitation pattern obtaeind from P-III type frequency curve.

Period	1 h	3 h	6 h	24 h
10 years	69.84	103.27	128.72	195.10
20 years	78.64	116.28	144.94	219.69
30 years	83.79	123.90	154.43	234.07
50 years	90.27	133.49	166.38	252.19

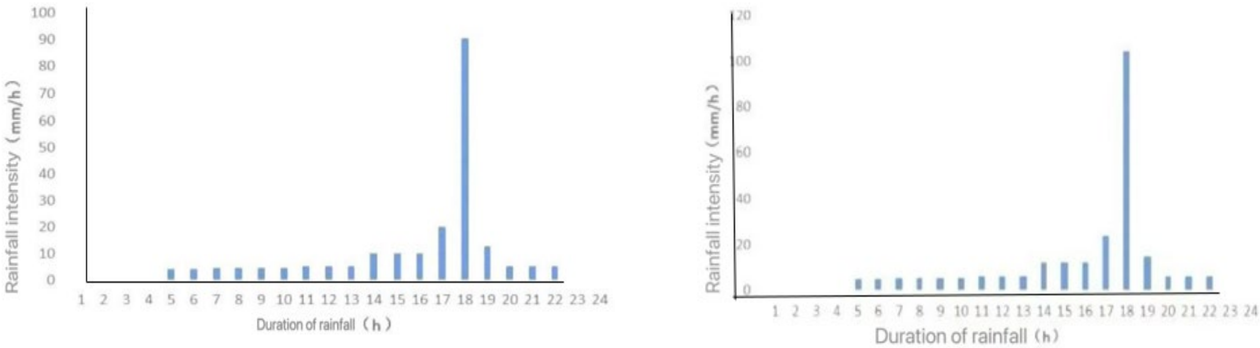
The long-duration extreme precipitation pattern is shown in Fig. 7.





(**a**) 24-hour attern in 10 years

(**b**) 24-hour attern in 20 years



(**c**) 24-hour rainstorm n 30 years

(**d**) 24-hour rainstorm in 50 years

Fig. 7. Long-duration extreme precipitation pattern.

5.4 Relationship Between Annual Runoff Control Rate And Precipitation

Based on the above analysis of the daily precipitation data in Huai'an City from 1959 to 2020, the relationship between the total annual runoff control rate and the precipitation in the Hongze District was drawn by using the analysis method provided in the "Technical Guide for Sponge City Construction - Construction of Rainwater System for Low-impact Development (Trial)". The total annual runoff control rate is the proportion of the total annual precipitation in the site through natural and artificial enhanced infiltration, storage, evaporation, and transpiration [16]. In other words, the larger the total annual runoff control rate, the more successful the volume control of precipitation will be. Figure 8 shows that when the precipitation also increased, the annual runoff control rate increased. For the higher total annual runoff control rate, multiple perspectives must be considered to determine the underlying surface conditions. If the total annual runoff control rate is too high, economic pressure can occur including the cost of building facilities under manual control. If the total annual runoff control rate is too small, it may lead to serious urban stormwater. The annual runoff control rate needs to be close to the original level before urbanization.

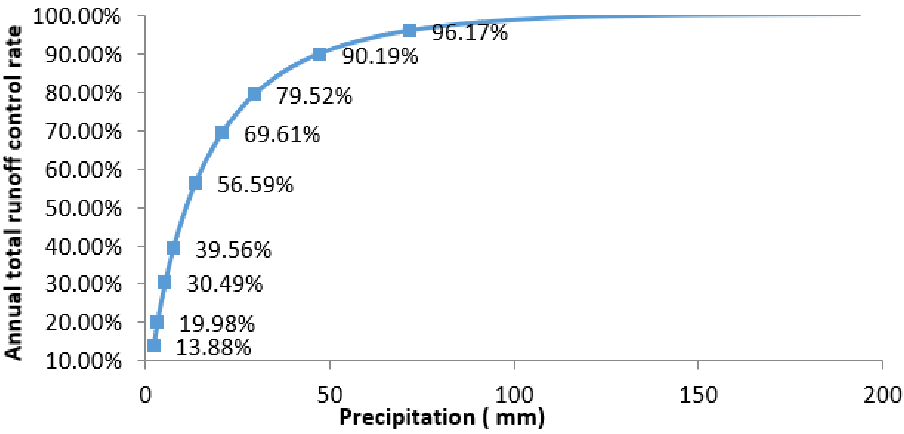


Fig. 8. Annual total runoff control rate and precipitation.

6. Conclusions

We studied the influence of different urban precipitation and underlying surface distribution on urban runoff to understand the relationship between extreme precipitation patterns and maximum runoff in the Hongze District of Huai 'an City, Jiangsu Province in China. The result can be a reference for the construction of the sponge city and the planning and construction of an urban water supply and drainage network.

From 1959 to 2020, the precipitation in Hongze area varied greatly annually with the maximum and minimum precipitation reaching 1473.8 and 349.6 mm. The annual variation was large, and the extreme precipitation was concentrated in July and August.

The multi-year average evaporation from 1959 to 2020 was 1165.8 mm, with an overall decrease with fluctuations due to the urbanization that affected the local evapotranspiration. The evaporation from May to August was larger, and the evaporation from December to January was smaller than 50 mm. The evaporation was in line with the seasonal variation of Hongze County. When determining the total annual runoff control rate, the interannual difference in precipitation, the natural runoff conditions, and costs were considered. The peak precipitation intensity in the short- and long-duration extreme precipitation patterns appeared in the middle and last periods. The greater the precipitation intensity, the earlier the runoff time, the shorter the confluence time, and the greater the possibility of rainstorms. Therefore, it is necessary to focus on the middle and last periods for the prevention of damage.

In the context of climate change, rapid urban development increasingly impacts microclimate, leading to a highly uneven spatial distribution of precipitation intensity. Due to data limitations, only 11 years of minute-by-minute precipitation data were used, resulting in limited interpretationSubsequent research is necessary to interpolate precipitation data in adjacent areas and for simulation and prediction [17]. The rainstorm intensity formula in neighboring regions needs to be modified [18]. It is essential to collect more data and enhance the accuracy of the estimation. Given the changing intensity and frequency of urban rainstorms under the backdrop of climate change, it is recommended to calculate the rainstorm intensity in Hongze County every 10 years. The results of this study provides a basis for the construction of sponge cities and solve the problems caused by urbanization.

Author Contributions: Conceptualization, Y. Niu; methodology, J. Cheng, Y. Lu; validation, Y. Xia; data curation, J. Tang; writing—original draft preparation, J. Cheng; writing—review and editing, Y. Niu. All authors have read and agreed to the published version of the manuscript.

Funding: The work in this study was supported by Huai'an Natural Science Research Program Project, China (HAB202159); Huai'an Social Science Foundation, China (2024SK49), University-level innovation project "Development of Rainstorm Intensity Formula and Rain Pattern Design in Huai'an City under the Background of Climate Change", Higher Education Collaborative Innovation Program of Jiangsu, China (HSXT30511).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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