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A study on the flood risk influenced by climate changes in the Lixiahe region, China

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ABSTRACT

Flood happens frequently in Lixiahe region of Jiangsu Province, China, which is caused by rainstorms, the flat terrain and bad drainage conditions. And floods tend to be more severely influenced by climate changes during recent years. The paper investigated the abnormal climate conditions which causes storm floods, analyzed the correlation between the rainstorm process and water levels, and calculated the inundated water level and area. The research indicated that the following: (1) There is a linear relationship between the cumulative runoff depth of single rainstorm with the daily average water level; (2) The flood inundated area has been greatly increased when the precipitation is greater than 20 years return period in the Lixiahe region; (3) The anomalies of subtropical high intensity may cause precipitation to increase abnormally, resulting in high water level in the Lixiahe region; and the abnormal movement of subtropical ridge line position can be used as an important basis for the flood forecasting of Lixiahe region.

Keywords: Flood; Climate change; Water levels; Lixiahe region

1. Introduction

Flood is one of the natural calamities which happens frequently and causes severe losses. There are more and more studies about floods at home and abroad recently [1–3]. Losses caused by floods all over the world account for more than 50% of various types of natural calamities. Flood causes more and more losses with the development of the society and economics. Therefore, flood control is important and an urgent research issue of hydrology. Evolution trend of flood under climate change has become a hot topic of research [4,5]. Lixiahe region of Jiangsu Province is a flood-prone area (Fig. 1). In recent years, the increasing flood has seriously hampered the development of

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the region [6]. In addition, the runoff generation and concentration of this region is also a problem of flood control and disaster reduction research. Therefore, studying on the flood control and disaster reduction for Lixiahe region is significant.

Lixiahe region, which is in the north of Jiangsu and in the downstream of Huaihe River Basin, lies between north Jiangsu irrigation canal and Tongyang canal. The region is a transitional region from subtropical zone to warm temperate zone with a monsoonal climate. The 53-year (1953–2005) average precipitation is 1,006 mm [7]. The rainfall from June–September is about 65% of multi-year average precipitation, which may lead to concentrated heavy rainfall, continuous rainfall, typhoons, and sea tide. And the annual variation of precipitation is large. The multi-year average annual evaporation is about 960 mm [8,9].The drainage of the area is from the four harbors of Sheyanghe, Huangsha, Xinyang, and Doulong to the Yellow Sea, apart from pumping water into the Yangtze River by pumping stations [10]. Due to the special topography, the complex drainage, and the sea tide, flood happens easily in this region.

2. Materials and methods

In this paper, daily precipitation (eight stations) and daily water level (five stations) data of the Lixiahe region from 1957 to 2006 were collected to investigate the relationship between interval precipitation, single storm event, and flood water level, and the regional rainfall–water level relation was also obtained; then, the flood inundated situation was modeled under different precipitation conditions, and the flood risk was pre-evaluated, in the end, the causes of floods were further explored based on weather system and climate background analysis by using the western Pacific subtropical high indices.

The calculation of rainfall-runoff depth during single rainstorm of Lixiahe region was according to the results of correlation analysis of measured $P + P_a - R$ in Jianhu area, which was obtained from Hydrologic Handbook of Jiangsu Province performed by Jiangsu Province Hydrology and Water Resources Survey Bureau. The calculation formulas are as follows:

$$\text{when } P + P_a \leq 40 \text{ mm}, R = 0; \quad (1)$$

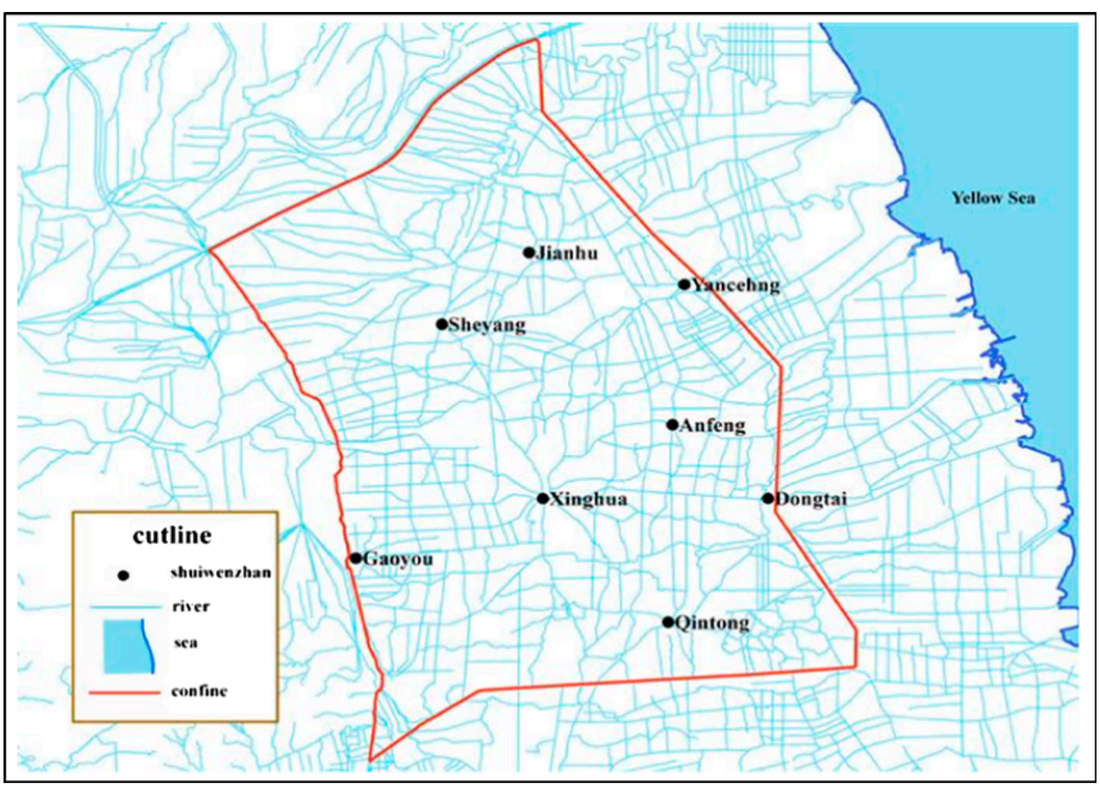

Fig. 1. The location of Lixiahe region and the hydrologic stations.

$$\text{when } 40\text{ mm} < P + P_a \leq 200\text{ mm}, R = m\,(P + P_a - 40)n \quad (2)$$

$$\text{when } P + P_a > 200\text{ mm}, R = P + P_a - 97 \quad (3)$$

where P is rainfall (mm); P_a stands for the antecedent precipitation (mm); R is runoff depth (mm). M and n are coefficients which are determined by basin characteristics. Here, $m = 0.0965$ and $n = 1.374$. P_a is calculated using the following formula:

$$P_{a,t} = K(P_{a,t-1} + P_{t-1}) \quad (4)$$

where $P_{a,\ t}$ is the antecedent precipitation for the day of t (mm); $P_{a,\ t\text{-}1}$ refers to the antecedent precipitation for t-1-d (mm); K is the reduction factor (dimensionless), $K = 0.89$. I_{max} is the maximum of the initial loss (mm). Here, $I_{max} = 70$ mm and $P_a = I_{max} = 70$ mm when the P_a value is greater than 70 mm.

This paper also selects subtropical high as the main weather systems which affect rainstorm precipitation, to investigate the relationship between the strength of subtropical high and the regional water level changes.

3. Results and analysis

3.1. Relation between interval rainfall and flood water-level

Through the hydrological frequency analysis of hourly precipitation in the Lixiahe region, the regional 5, 10, 20, 50, and 100 years return periods of maximum 3 days and maximum 7 days area rainfall were obtained, the former were 144, 166, 185, 209, and 226 mm, respectively, and the latter were 236, 280, 318, 366, and 400 mm, respectively. In combination with the analysis of corresponding flood water level in typical stations of each hydrologic area of "Lixiahe Water Resources Planning" (Table 1), it can be seen that the size of the precipitation and water levels are in good agreement, and heavy rain is the main factor for flood-prone characteristics of the region.

Table 1
Water levels of different return periods in the Lixiahe region

Stations	Water levels of different return periods (m)				
	5 years	10 years	20 years	50 years	100 years
Xinghua	2.44	2.89	3.31	3.85	4.2
Qintong	2.41	2.8	3.28	3.80	4.18
Sheyangzhen	2.42	2.75	3.07	3.45	3.72
Jianhu	1.82	2.12	2.48	2.92	3.2
Yancheng	1.74	2.13	2.49	2.92	3.25

3.2. Relation between single rainstorm and flood water level

This paper selected 15 typical rainstorms from 1984 to 2006, and calculated the cumulative runoff depth of single storm event, and then, correlation analysis was performed with the one day lagged daily average water level of the same rainstorms. Xinghua Station, Qintong Station, and Yancheng Station were taken for example, the fitting equation between accumulated runoff depth of single storm event and water level is as follows: $y = 0.0068\ x + 1.6653$, $R^2 = 0.6137$; $y = 0.006\ x + 1.688$, $R^2 = 0.5384$; $y = 0.0066\ x + 1.1506$, $R^2 = 0.6646$, respectively. Generally, there exists a linear relationship between them, but the simulation result is not very satisfactory.

The corresponding next day average highest water levels of No. 198401 torrential rain in Xinghua, Qintong, and Yancheng stations were 1.84, 1.92, and 1.7 m, none of them were above the warning level, and the previous continuous 30 day area rainfall was only 52 mm, thus belongs to a sharp reversal process between floods and droughts, causing the water level not to change significantly. The area rainfall of No. 199104 rainstorm was only 43.34 mm, while the next day average maximum water levels were 2.33, 2.55 and 1.42 m in Xinghua, Qintong, and Yancheng stations. Apart from Yancheng Station, the water levels were all over the warning level. Thus, there appeared the phenomenon of relatively drought with high water level. This is due to the fact that this rainstorm happened during the withdrawal period of the maximum flood stage, and the water level in the study area is still at a high level, thus the water level caused by this torrential rain did not change significantly. The previous rainstorm interval was very short for No. 200302 rainstorm, and the rising water level was high; thus, it was difficult to reflect the actual situation. Therefore, these three rainstorms were removed. From the adjusted simulation analysis (Fig. 2), the relation model of daily average water level and the cumulative runoff depth has better applicability under the situation of higher intensity of rainstorms and higher water levels (Table 2). In summary, the relation between climate change and flood risk is very complicated, and the outliers are very important for the understanding of their relationship. However, this kind of research is still an open question and need more detailed data to do further analysis.

3.3. Flood inundated area and depth analysis

Due to the low-lying terrain of Lixiahe region, the water level directly affects the possible inundated area. In the same region of the study area, water level

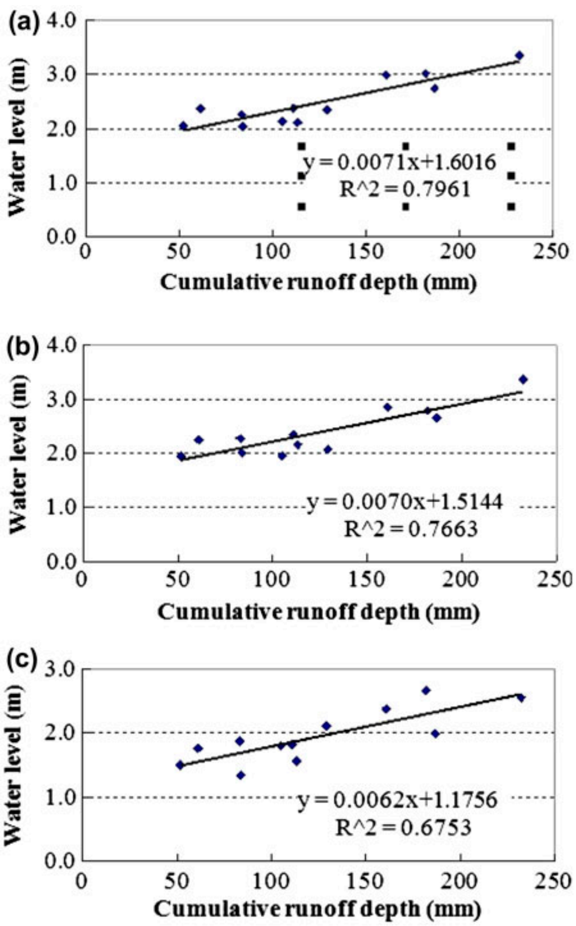

Fig. 2. The relationship between the accumulated runoff depth of single storm event and daily average water level in (a) Xinghua Station, (b) Qintong Station and (c) Yancheng Station.

differences are small between different regions, so the flood water level of each station was used to represent that of the hydrologic area. Through the grid calculation of the DEM and each flood water level in the research area, the results were merged and classified according to the submergence depth. The figure of submergence area and depth of the research area can be drawn under the precipitation in different return periods (Fig. 3).

It can be seen from Fig. 3 that the inundated depth appears over 1 m in the northern Sheyang Town, and even up to about 2 m within part of the region when the precipitation reaches 5 years return period in the Lixiahe region, which is affected by the low-lying terrain; the flood map shows the characteristics of submergence for the whole region when the precipitation reaches 20 years return period; and the submergence is relatively high under different return periods in the Xinghua, Qintong, and Jianhu area.

Table 2
Accumulated runoff depth of single storm event and the one day lagged daily average water level

Rain storm event	Period of single storm event	Cumulative runoff depth (mm)	Water level of stations (m)		
			Xing-hua	Qin-tong	Yan-cheng
198,401	8.30–9.2	106.16	1.84	1.92	1.7
198,402	9.6–9.10	110.98	2.38	2.35	1.82
198,701	7.3–7.7	83.65	2.04	2.01	1.34
198,702	8.23–8.29	105.02	2.13	1.95	1.8
199,001	8.31–9.3	83.14	2.26	2.27	1.87
199,101	6.9–6.15	113.27	2.12	2.16	1.56
199,102	6.28–7.3	186.64	2.74	2.66	1.99
199,103	7.6–7.12	232.21	3.35	3.37	2.55
199,104	8.2–8.8	43.34	2.33	2.55	1.42
199,601	7.2–7.5	60.98	2.37	2.25	1.76
200,301	6.30–7.6	160.67	2.99	2.86	2.37
200,302	7.8–7.12	145.35	3.2	2.97	2.59
200,303	8.13–8.20	51.79	2.05	1.94	1.5
200,501	8.2–8.8	129.15	2.35	2.07	2.11
200,601	6.28–7.4	181.93	3.02	2.79	2.66

Therefore, the flood inundated area map has important reference value for flood early warning and forecasting in the region.

3.4. Relation between anomalies of Subtropical high and precipitation

Considering the fact that the standard of implementation of flood detention dikes in Lixiahe lake area is according to the water level in Xinghua. When the water level reaches 2.5 m, the first flood detention dikes will be used. Take water levels of Xinghua Station for example, the highest daily average level in Xinghua above 2.5 m was selected. The annual maximum daily average water levels of 8 years (1957, 1958, 1962, 1965, 1969, 1974, 1991, 2003, and 2006) were compared with the corresponding strength indices of the Western Pacific subtropical high from June–September. The results are shown in Fig. 4.

It can be seen from the chart, there is a good correlation between the highest daily average water levels in Xinghua Station and the subtropical high intensity indices. The determination coefficient of linear regression $R^2 = 0.5829$, which is quite satisfactory. The result shows that the greater the intensity index of the subtropical high is, the higher the annual maximum average water level is, leading to the increased accumulated runoff depth, so that the high level increased. And this relation has a good indication

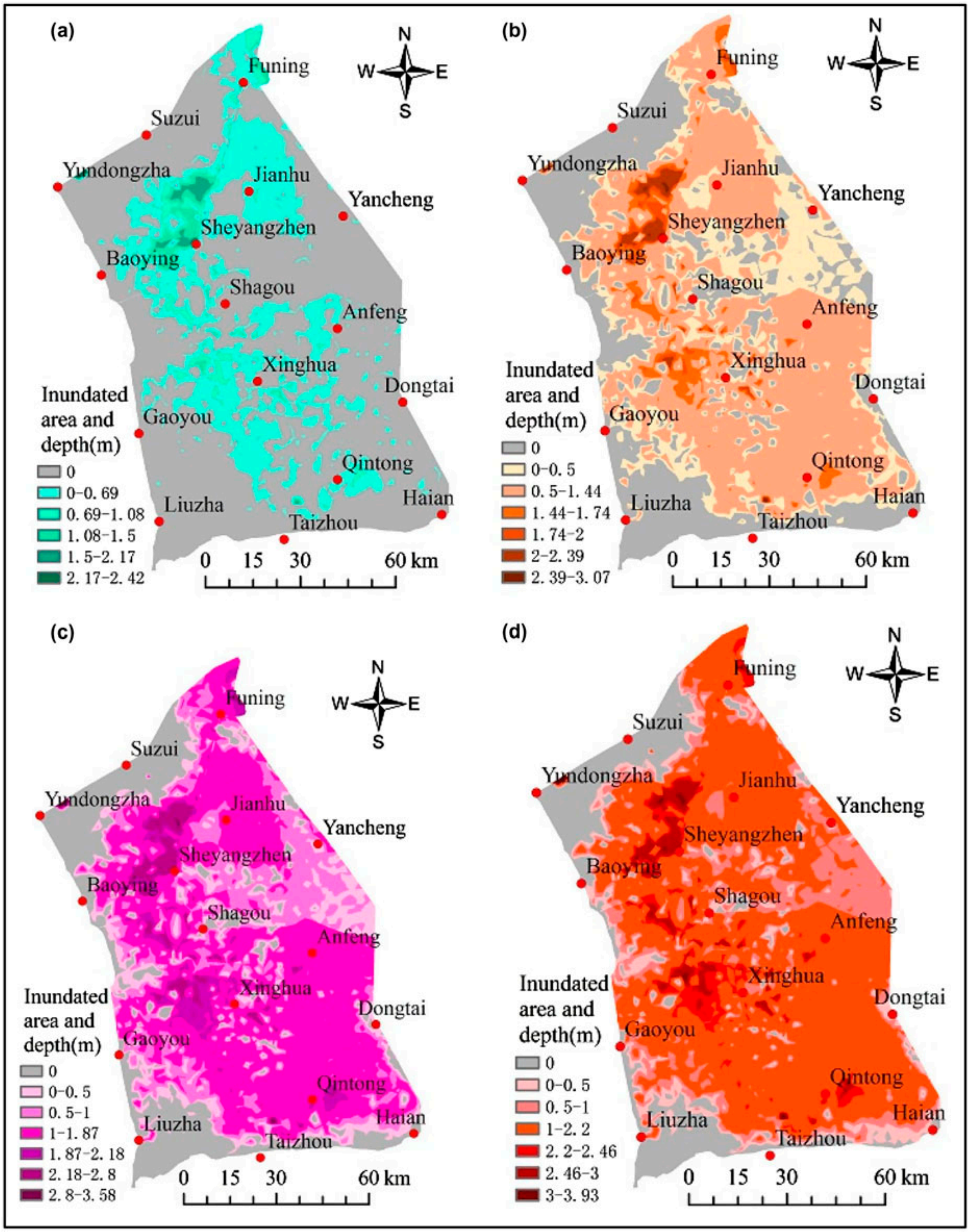

Fig. 3. The submergence area and depth of the Lixiahe region under different return periods of rainfall (a, b, c, d represent storms of 5, 20, 50, and 100 years return periods).

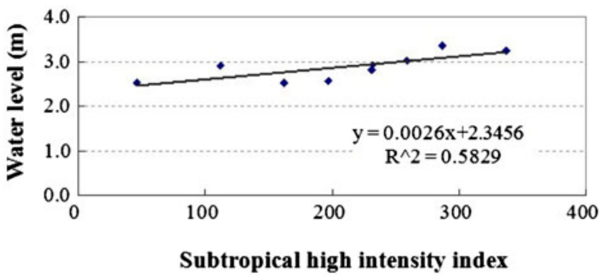

Fig. 4. The relationship between the highest daily average water level and the strength of subtropical high.

when the water level is above 2.5 m in Xinghua Station.

The position of subtropical ridge fluctuates between 20 and 27˚N in normal years. However, the corresponding position of subtropical ridge of rainstorm in 1954, 1991, and 2003 indicates that the average ridge position during May–July moved north to 29˚N ahead of time. Besides, the relative north position of ridge and the center of rainfall located in 31–33˚N, right in the Lixiahe region, leading to the abnormal precipitation, the higher water level and the appearance of catastrophic floods.

4. Conclusions

A comprehensive analysis of the multi-disciplinary approach was applied to investigate the mechanism and evolution of flood disasters under the background of climate changes in the Lixiahe region, by using precipitation, water level, and rainstorm flood data. The main conclusions are as follows:

(1) Generally, there is a linear relationship between the cumulative runoff depth of single rainstorm with the daily average water level: the greater the cumulative runoff depth is, the higher the average daily water level is, and this relation is more significant especially under higher water level scenarios.

(2) The flood inundated area has greatly increased when the precipitation is greater than 20 years return period in the Lixiahe region; and the inundated area is relatively high in Xinghua, Qintong, and Jianhu area under the precipitation of different return periods.

(3) The anomalies of subtropical high intensity may cause precipitation to increase abnormally, resulting in high water level in the Lixiahe region; and the abnormal movement of subtropical ridge line position can be used as an important basis for the flood forecasting of Lixiahe region.

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