Impact of Human Activities on Flood Control Capacity of Southern Jiangsu Province in Taihu Basin

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Abstract. Southern Jiangsu Province in Taihu Basin is one of the regions with high urbanization degree in China. In recent years, with the continuous progress of urbanization, the human activities, have further increase the pressure of flood disasters. This paper analyzed the trends of most significant human activities, namely the land use pattern, surface water storage capacity, and construction of polder areas and urban flood control projects; simulated the water yield and water level of regional river network by using a digital watershed model. The results indicated that in the past decades, the construction land expanded significantly, the capacity of flood storage decreased gradually, and the drainage module increased by large-scale construction of polder areas and urban flood control projects. The change of these factors would lead to the increase of the regional water yield and rise of flood level of river network, which would further increase the flood risk of the region.

1. Introduction
Southern Jiangsu Province in Taihu Basin is located in the Yangtze River Delta, with a relatively developed economy, a dense population and a high level of urbanization. In recent years, human activities have a great influence on the river network areas in the southern Jiangnan Province plain. Urbanization construction has led to a large increase in the area of construction land and a decrease in the area of arable land and water area[1]; under over-exploitation and utilization, the sewage area has shrunk, and a large number of small polders have combined together, resulting in a sustained reduction of water storage surface; under rapid economic and social development, both urban protection standards and polder construction standards have been greatly improved, leading to increase of the coverage area of drainage system. Change of land use pattern, storage capacity of surface water, and polder area and urban flood control project construction will have a great impact on the process of runoff yield and concentration, thus affecting the flood control capacity of the region. Recently, various researchers have investigated the urbanization effects on the flood risk, and most of them used statistical model[2-4]. However, there are relatively limited studies on the impact of different human activities on the flood control.

This paper will focus on land use pattern, water surface ratio, and construction of polder areas and urban flood control project, to simulate the water yield and water level of regional river network by using a digital watershed model, and analyze the impact of changes of the above three important factors on flood control capacity in southern Jiangnan Province area.
2. Trends of the impact factors

2.1. Land use pattern.
The process of urbanization in southern Jiangnan Province has accelerated remarkably. After Year 2000, the construction land has increased significantly by occupying the arable land, leading to the great reduce of the permeable area land[5]. Compared to Year 1999, the area of arable land has decreased by 25%, while the area of construction land has increased by 70%.

2.2. Storage capacity of surface water
Due to the pursuing of economic benefits in some areas of southern Jiangnan Province, the phenomenon of occupying and filling of rivers and lakes without permission occurs from time to time. Large-scale polder construction and small polder combination also reduced the area of water surface outside the polder dramatically. Compared to Year 1999, the water surface ratio outside the polder in Year 2015 has decreased by 20%, which would significantly reduce the storage capacity of surface water.

2.3. Construction of polder areas and urban flood control projects
In recent years, with the rapid development of social economy, urban population, property and productivity have become more and more concentrated. In order to improve its flood control capacity, southern Jiangnan Province has carried out large-scale construction of polder areas and urban flood control projects[6]. The drainage modulus of the main city are above 1.5 m³/(s·km²), which is much higher than that in Year 1999 (about 1.0 m³/(s·km²)).

3. Model simulation

3.1. Model description
A digital watershed model developed by Hohai University was used in this study[7]. The model integrated hydrological model and hydrodynamic model. In the hydrological model, the underlying surface is divided into four categories according to the runoff characteristics: dry land, water surface, paddy field and construction land, and different runoff generation mechanisms are used to simulate rainfall-runoff in studied area. Among them (1) Water surface runoff can be obtained by deducting evaporation from rainfall according to water balance equation. (2) The runoff yield process of paddy field is obtained according to the water requirement of crop growth period, the suitable water depth of paddy field, the depth of water resistance to flooding and the mode of rice irrigation and drainage. In dry season, it is necessary to draw water from rivers to irrigate paddy fields and maintain the average suitable water depth of paddy fields. In rainy days, when the paddy fields exceed the waterlogging depth, the drainage capacity is the upper limit. (3) The runoff yield of non-paddy field is calculated by using the stored-full runoff model. (4) The urban underlying surface is divided into two types: permeable and impervious areas for runoff calculation. Permeable area includes roads, squares, roofs, etc., and runoff generation is equal to effective rainfall.

The Saint-Venant equations are used to simulate the unsteady flow of one-dimensional river network in Taihu basin. The factors affecting the flow movement in the region are simulated by three kinds of factors: zero-dimensional model (storage nodes such as lakes, swamps, polders), one-dimensional model (e.g. River channel) and connection elements (e.g. weirs, sluices, and pumps, etc.).

3.2. Generalization of river network
The river network mathematical model covering the whole Taihu Lake basin is adopted, and the calculation range is the whole Taihu Lake basin. In the model, there are 743 rivers with a total length of 3825 km and 2078 River cross-sections, 62 lakes, 104 sluice and pump stations along Yangtze
River, Lake Taihu, and control line inside the studied area were generalized. Figure 1 shows the generalized graph of river network.

Figure 1. Generalized graph of river network.

4. Result analysis
The digital watershed model was used to calculate and analyze the impact of land use pattern, water surface ratio and the change of drainage modulus in polder area on regional flood control situation. When one factor changes, the other factors remain at the Year 1999 level.

4.1. Impact of land use pattern
According to the calculation results of the model, after the change of land use pattern, the permeable areas and water areas are obviously reduced compared with 1999, and the impervious areas such as urban construction land are obviously increased, resulting in an increase in regional water production. Compared with land use in 1999, the total amount of rainfall design flood increased by 1.24, 2.47 and 464 million m$^3$ in the maximum 30 days, 60 days and 90 days, respectively. Among them, the increase around Wuxi area was the most obvious, and the increase in water yield under the maximum 30 days, 60 days and 90 days of design rainstorm was 11.3%-15.7%.

Table 1 shows the comparison of water level of regional representative stations under different land use pattern. After the change of land use pattern during the past two decades, the water level of regional representative stations has increased significantly. According to the simulation results, under the design rainstorm of 100-year return period, the average daily maximum water level of regional representative stations rose by 0.02-0.08m in Year 2015 compared that in Year 1999, which means the change of land use pattern had a negative impact on control of regional flood and water-logging. Generally speaking, the change of land use pattern makes the permeable area of the area replaced by impervious buildings such as residential buildings, streets, factories, etc. The water retention and permeability of underlying surface have changed obviously, leading to the increase of runoff and peak flow, the increase of total flood volume and the increase of regional flood control pressure.

Table 1. The average daily maximum water level of regional representative stations under different land use pattern.

| Stations   | Year 1999 (m) | Year 2015 (m) | Variation (m) |
|------------|---------------|---------------|---------------|
| Wang muguan| 6             | 6.04          | 0.03          |
| Fangqian   | 5.41          | 5.43          | 0.02          |
4.2. Impact of storage capacity of surface water

The higher the water surface ratio is, the more developed the water system is and the stronger the flood storage capacity is. Due to over-exploitation and utilization, the water area shrinks, and a large number of small polders combined together, the water surface outside the polder deceased, leading to the decrease of the adjustable water storage rate. Moreover, The area of fishpond in Jiangsu is large, reaching about 1200km². Especially in Suzhou, a large area of arable land has been gradually changed to fish ponds.

Table 2 shows the comparison of water level of regional representative stations under different storage capacity of surface water. From the results of calculation and simulation, the higher the water surface ratio, the more developed the water system, and the stronger the flood storage capacity. In the case of design rainstorm of 100-year return period, the daily maximum water level of representative stations in 2015 is higher than that in 1999 by 0.03-0.07m. It can be seen that due to the reduction of water surface ratio, the overall flood storage capacity of the region decreases, and the flood control pressure of the backbone rivers increases significantly.

| Stations | Year 1999 (m) | Year 2015 (m) | Variation (m) |
|----------|--------------|--------------|---------------|
| Wangmuguan | 6            | 6.04         | 0.04          |
| Fangqian | 5.41         | 5.45         | 0.04          |
| Qingyang | 4.44         | 4.47         | 0.03          |
| Chenshu  | 4.47         | 4.50         | 0.03          |
| Fengqiao | 4.59         | 4.66         | 0.07          |
| Xiangchen| 4.25         | 4.31         | 0.06          |
| Chenmu   | 3.97         | 4.04         | 0.07          |

4.3. Impact of construction of polders and urban flood control projects

The water level comparison of the main representative stations before and after t is shown in Table 3. Under the design rainstorm of 100-year return period, the water level of area surrounding Suzhou, Wuxi and Changzhou basically shows a increase trend. The water level along the Jiangnan canal is affected by the operation of the sluice pump project surrounded by the city. A large number of urban logged water enters the Jiangnan canal. The water level along the upper reaches of the canal generally rises by 0.01-0.3m, among which the daily maximum water level of Fengqiao and Luoshe stations rises by 0.3m and 0.17m. It can be seen that although the construction of the urban flood control projects can effectively guarantee the safety of the inner city, it has a negative impact on the surrounding areas outside the city. The rise of the regional flood level has increased the flood control pressure of the surrounding areas outside the city and also the areas along the Jiangnan canal and the upstream and downstream cities.
Table 3. The comparison of average daily maximum water level of regional representative stations before and after the construction of polders and urban flood control projects

| Stations     | Before construction (1) | After construction (2) | Variation (2) - (1) |
|--------------|-------------------------|------------------------|---------------------|
| Suzhou       | Inside 4.41             | 3.46                   | -0.95               |
|              | Outside 4.59            | 4.89                   | 0.3                 |
| Wuxi         | Inside 4.54             | 3.97                   | -0.57               |
|              | Outside 4.54            | 4.7                    | 0.16                |
| Changzhou    | Inside 4.8              | 4.54                   | -0.26               |
|              | Outside 4.83            | 4.98                   | 0.15                |
|              | Danyang 6.5             | 6.5                    | 0                   |
| Along Jiangnan canal | Luoshe 4.59       | 4.76                   | 0.17                |
|              | Yaoguan 4.72            | 4.82                   | 0.1                 |
|              | Fengqiao 4.59           | 4.89                   | 0.3                 |
|              | Guajingkou 4.4          | 4.41                   | 0.01                |

5. Conclusion
Based on a large number of measured and surveyed data, a hydrodynamic model was used to calculate and analyze the impact of land use pattern, water surface ratio, and polder drainage modulus on regional flood control situation. The main conclusions are as follows:

(1) The change of land use pattern in southern Jiangnan Province has increased the impervious area. In the case of design rainstorm in 100-year return period, the regional water yield has increased, and the flood level of representative water level stations would rise by 0.02-0.08m.

(2) In 2015, the storage capacity of water surface in southern Jiangnan Province decreased compared with that in 1999, and the flood level of representative water level stations would rise by 0.03-0.07m in the case of design rainstorm in 100-year return period.

(3) The current drainage modulus of polder areas and urban flood control projects increased by 50% compared with that in Year 1999, and the pressure of flood control and drainage of major cities along the main rivers outside polder areas and the Jiangnan Canal increased significantly. According to the simulation results, in the case of design rainstorm in 100-year return period, the flood level of representative water level stations would rise obviously, especially for the stations along the Jiangnan canal.

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