Hydrological Effects of Urbanization in the Qinhuai River Basin, China

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Abstract

The effects of urbanization on river network and hydrological process were investigated at Qinhuai River basin. RS and GIS technology were applied to extract land use information and analyze the land cover changes according to RS images and topographic maps. Regression analysis was carried out based on long-term observation data. Results showed that build-up land proportion increased rapidly from 8.34% to 16.83% from 1991 to 2006. River network structure was simplified. From 1961 to 2001, the rainfall increased with a widening gap between urban and suburban area. Imperviousness presented logarithm relevant to runoff, with correlation coefficient as high as 99%.

1. Introduction

Hydrological process is determined by both climate and underlying surface conditions. As one of land cover changing factors, urbanization effects greatly on the whole process of the hydrological cycle [1]. Rapid urbanization strongly changes the nature of the land surface and river network structure, resulting in evident variations of hydrological process or hydrological extreme events. Recent results from GE Yi et al. [2] and SHI Peijun et al. [3] indicate that land use changes caused by urbanization are the major factor of runoff variation in the basin. QIN Lili et al. [4] analyzed the long-term influence of the urbanization on the runoff and discovered that under the same circumstance of rainfall, the main factor leading to runoff changes was the change of the underlying surface. WANG Yanjun et al. [5] found that under the conditions of the same land use changes, the strongest hydrological response to land use

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changes happened in dry years, the next happened in normal years, and the weakest happened in flood years. Qinhuai River basin is located in Nanjing City standing in the lower reaches of the Yangtze River. In recent years, with the rapid development of urbanization, a large number of natural river systems have been destroyed, resulting in a sharp drop of the number of river branches, which led to a series of water resource and environment problems, such as water quality deterioration, habitat destruction, biodiversity reduction, flood and drought disasters. The problems all above strongly restrict the urban constructions and sustainable development in Nanjing. Under this circumstance, Qinhuai River basin was chosen as a typical study area to center on the impacts of the development of urbanization on the land surface, river systems and hydrological features, which could provide more support to flood prevention, water environmental protection and sustainable development of economy in this area.

2. The study area

Qinhuai River watershed is located in the south bank of Nanjing, part of the lower reaches of Yangtze River. Qinhuai River has the sources of Lishui River and Jurong River which flow together as mainstream in Xibei village of Jiangning district. Its topography is a structural basin, like a cattail leaf fan, surrounded by hills and mountains. The hinterland is low-lying dyke areas. From surrounding areas to the center, the landscape types are mountains and hills, loess hillock and dyke plains, and dyke plains area accounting for 25%. The length and width of the basin are about 50km, and the area is approximately 2631km². Water finally flows into the Yangtze River via the Qinhuai New River in northwest corner of the basin and Wuding floodgate. Study area belongs to subtropical wet monsoon climate. Average temperature is 15.4°C, annual average rainfall is 1047.8mm, and average runoff in the basin is 6.95 × 10⁸m³. Rain and heat have the same cycle period. Flood and drought disasters occur sometimes. In recent decades, river network structure and hydrological processes were affected by rapid urbanization in Nanjing, which has aggravated the threats of rain storm and floods.

3. Materials and methods

3.1. Data and pretreatment

The 1:50000 topographic maps were digitalized to obtain topographic data. Landsat-TM remote sensing images of the year 1991, 2001 and 2006 were used to extract land cover information including urban land, paddy filed, dry land, forest and waters. Daily rainfall data from 1961 to 2006 was collected from 7 hydrological stations such as Jurong station, Dongshan station etc. Meteorological data for nearly 40 years was provided by Nanjing weather station, and daily water discharge data by Qinhuai New River floodgate (118 ° 40'E, 31 ° 58'N) and Wuding floodgate (118 ° 51'E, 32 ° 02'N).

3.2. Methods

Radiometric and geometric correction was conducted on remote sensing images with ERDAS IMAGINE 9.1, controlling the error in less than a pixel. Then deal with the images of different time by image enhancement treatment. Through interactive interpretation, the land use maps of the year 1991, 2001 and 2006 were obtained. 5 types land cover were classified including paddy field, dry land, forest, water and urban land. The changes of the area of the 5 land covers were analysed in order to reflect the land use/ cover changes. The changes of river network in the study area are discussed by analysing the changes of river structure due to urbanization adopted measurement, the statistics of river gradation and map overlaying [6].
Based on daily rainfall data from 1961 to 2006, precipitation changes in Qinhuai River basin were discussed and analysed by means of linear regression analysis from a different perspective of time. Through regression analysis, annual total runoff depth, monthly runoff depth of flood season and runoff coefficient was calculated to analyse the impact of the urbanization on hydrology.

4. Results

4.1. Impacts of urbanization on underlying land surface and river network

4.1.1. Impacts on land surface

With urban expansion and the construction of Jiangning Development Zone, the Qinhuai River basin, especially middle and lower reaches where the land use types have changed greatly. The main changes were reflected in huge reduction of paddy fields and sharp increase of build-up land. Waters in the basin such as rivers, lakes, etc. has decreased a lot, while urban area has significantly increased under the condition of urban development.

Table 1. Characteristics of land use in Qinhuai River basin

<table>
<thead>
<tr>
<th>Year</th>
<th>Build-up land</th>
<th>Paddy fields</th>
<th>Dry land</th>
<th>Forest</th>
<th>Waters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area(km²)</td>
<td>Percent</td>
<td>Area(km²)</td>
<td>Percent</td>
<td>Area(km²)</td>
</tr>
<tr>
<td>1991</td>
<td>321.06</td>
<td>8.34%</td>
<td>2587.52</td>
<td>67.25%</td>
<td>245.31</td>
</tr>
<tr>
<td>2001</td>
<td>320.39</td>
<td>8.33%</td>
<td>2469.57</td>
<td>64.17%</td>
<td>267.57</td>
</tr>
<tr>
<td>2006</td>
<td>647.2</td>
<td>16.83%</td>
<td>2112.99</td>
<td>54.96%</td>
<td>202.99</td>
</tr>
</tbody>
</table>

Fig.1. Land use changes among the year 1991, 2001 and 2006

The figure showed that there was a significant increase of construction land from 1991 to 2006, urban land use proportion extending rapidly from 8.34% to 16.83%. But the area of paddy fields and water decreased. Dry land occupied only a smaller proportion and almost remained unchanged. Previously, land use changed from paddy fields and waters to forest, while lately changed from paddy fields and other types directly to build-up land and forest. These changes caused a reduction of waters and farmland and an evident increase of urban land area. In general, with the rapid development of urbanization, impervious areas spread quickly and imperviousness increased greatly in Qinhuai River basin.

4.1.2. Impacts on river network
With the land use changes in the process of urbanization in the Qinhuai River basin, the river network structure has been changing gradually with the intrinsic link. To take Jiangning District as example, the research showed that: As the urbanization level rising up, the drainage density decreased and the river network structure was simplified. The drainage density decrease was positively related to the increase of the urban land. Urban land expansion and shrinkage of river network, especially the disappearance of branches were well correlated. As the urbanization level became higher, drainage density decreased more greatly, the river network suffered greater damage, and the stream structure was simpler. Flood control capacity of the river network was linked to water quantity and the spatial variations of the river. In addition, it had a positive relation with the river level, and a reverse relation with urbanization.

4.2. Analysis of the hydrological response to urbanization

4.2.1. Impact of urbanization on rainfall
Urban heat island effect has led to an obvious increase of the annual rainfall and flood season rainfall. And the distribution of rainfall during the year had a trend to focus on the main flood season. Qinhuai River basin is located in the Yangtze River Delta, where the weather conditions in downtown and urban fringe are basically the same. According to the rainfall data of this area from 1961 to 2006, the linear regression analysis was conducted and the result was shown in Fig.2.

Fig.2.Statistical characteristics of annual rainfall and flood season rainfall in urban and sunburn area

Both of the annual rainfall and the flood season rainfall have increased under urbanization. The growth rate of annual rainfall in downtown was 25.16mm/10a, while in suburb it was 20.28 mm/10a. And the growth rate of flood season rainfall in downtown was 12.0 mm/10a, while in suburb it was 7.3 mm/10a. The increasing trend in urban area was greater than suburban area. The increasing rainfall coefficient in rapid urbanization period is higher than that in slow period. The precipitation gap between suburban and urban areas expanded and urban rain island effects were more obvious.

4.2.2. Impacts on the runoff
The urbanization has turned the ground surface into an impermeable layer in a large area, increased runoff coefficient, shortened the concentration time, increased the total volume of flood water and peak discharge and increased the frequency of floods of city rivers[7]. Under the same rainfall conditions, the land use change was a major factor leading to the changes of runoff. In this section, statistical methods were applied for the analysis of runoff in Qinhuai River basin and the results were followed. (a) Under the same rainfall conditions, the increase of the imperviousness led to the increase of annual runoff, runoff
depth and runoff coefficient. Urbanization ratio had logarithmic relevant to the runoff coefficient, with the best correlation coefficient of 99%. (b) The runoff depth always increased in the dry year, normal year and the flood year, and the difference just lied in the degree, which was the slightest in the flood year but the greatest in the dry year. According to curve-fitting process, whatever types the year belonged to, imperviousness had logarithmic relevant to runoff and evaporation, with correlation coefficient as high as 99%. (c) Land use changes due to urbanization had a great impact on the flood process as well, which has increased the total volume of flood water and peak discharge of floods. The degree of the impact of urbanization differed in the scale of floods. The smaller-scale flood suffered the greater impact.

5. Conclusion

The rapid development of urbanization of Nanjing has caused a range of hydrological problems. After analysing the land use changes, river structure changes as well as rainfall-runoff variations adopted measurement, statistics and map overlaying by means of RS and GIS technologies, we obtained four conclusions as followed. (a) From 1991 to 2006, land use changed from waters and paddy fields to urban construction land, thus the impervious surface expanded widely. (b) The density of river network was declining and the river network structure was simplified. (c) Both of the annual rainfall and the flood season rainfall have increased during the urbanization process. But the increase in downtown was greater than rural areas. The gap of the precipitation between them was getting wider. Urban rain island effect was more obvious. (d) The runoff depth and runoff coefficient have increased. Urbanization rate had logarithm relevant to runoff, with the best correlation coefficient of 99%.

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