Hydrologic Response to Land Use Changes in Lower-middle Yangtze River, China

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Abstract: The effects of land use change induced by human activities on hydrology have been a topic of much discussion in recent years. The purpose of this paper is to assess hydrologic response to land use variance between 1992 and 2003 in lower-middle Yangtze River using the Soil Conservation Service Curve Number (SCS-CN) method. In terms of the variance of direct runoff yield under 1992 and 2003 land use, it is concluded: (1) deforestation, agricultural area and water body reduction are the main reasons for the decreasing of direct runoff yield; (2) the human activities have much greater impact on direct runoff compared to the climate change in lower-middle Yangtze River during the period of 1992 to 2003.

1. Introduction

Rainfall-runoff relationships within a watershed are driven primarily by the interaction of the interplay factors such as climate, land cover, and soils (Mariano et al., 2000). As the rapid development of economic, industry and agriculture have taken place in China, the existing pattern of land use actually has changed dramatically especially after 1990(Shi et al., 2007). Land use change induced by intensive human activities like urbanization, irrigation and deforestation have obviously affected hydrology, water quality and hydrologic amenities. In terms of hydrologic response, there are mainly two interrelated but separable effects on a watershed: changes in direct runoff volume and changes in peak flow characteristics (Leopold, 1968). For example, direct runoff volume would increase as a result of increase of imperviousness because of less soil moisture replenishment and less ground water storage. And another result of imperviousness increasing is the alteration of water retention times in wetlands and lakes, and thus increasing flood peaks during storms (Robert and Raymond, 2004). Besides, deforestation and reduction of water bodies would oppositely cause the yield decreasing of direct runoff. Basically, the volume of direct runoff is governed by infiltration characteristics related to vegetation cover, topography and soil type.

The purpose of this paper is to explore the effect of land use variance on hydrology in terms of direct runoff based on an 8-class land use system in the basin of lower-middle Yangtze River. To date, numerous studies have linked hydrology with remote sensing data to explain some change phenomenon on hydrology (Sharma et al., 2001).In this paper, the land use maps are derived from 1-km resolution MODIS data in the year of 1992 and 2003 and laid out in GIS system. In order to assess the effect of land use change on direct runoff volume, the Soil Conservation Service Curve Number (SCS-CN) method which has been applied on a wide range of catchments in the United States and across the world is employed (Boughton, 1989). The direct runoff volume can be calculated from a simple formula with parameters only related to Curve Number (CN).

2. Study Area and Data Sources

2.1. Study Area

Hankou Basin, at the lower-middle area of the Yangtze River, situates between latitudes 29°01'N and 31°58'N and longitudes 111°14'E and 114°17'E. It covers a large land area of 66324 km^2, and has 11 climate stations distributed near and across the whole basin. As this basin locates along Yangtze River, it is a typical humid area with mean annual precipitation is approximately 1000mm.

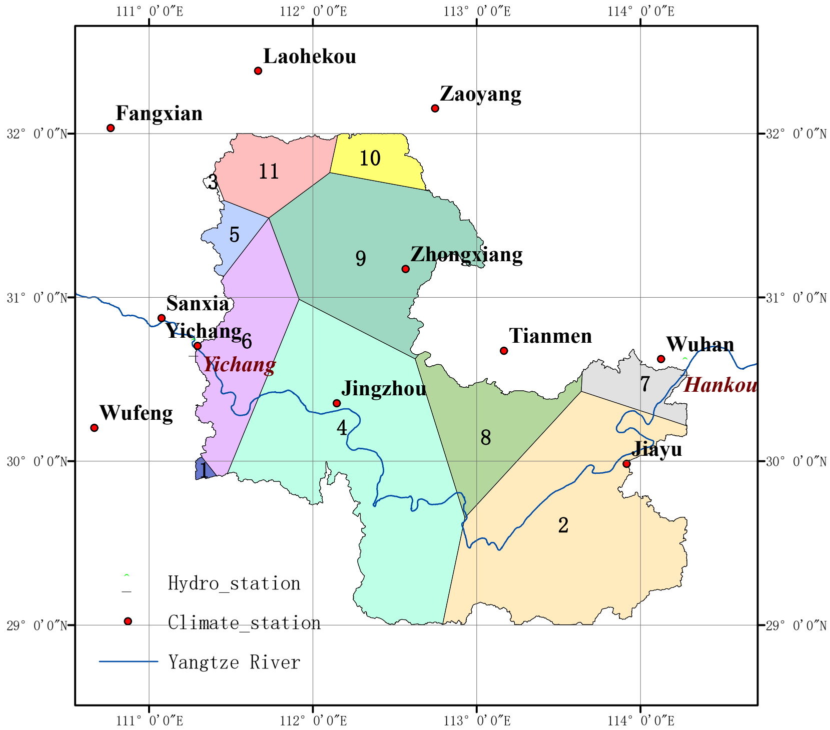
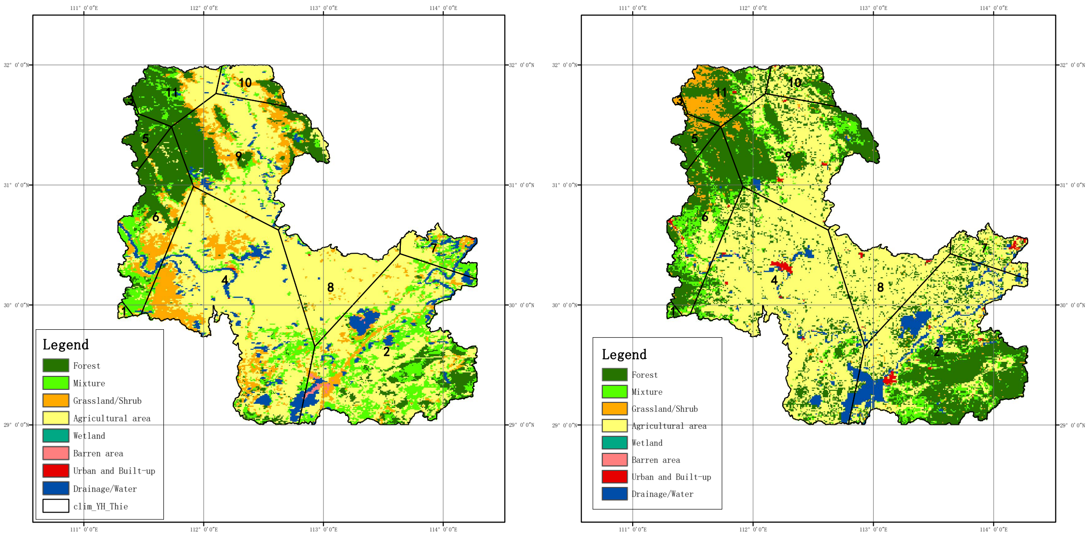


Figure 1: Location of Hankou Basin.

2.2. Land Use Data

The land use data of the study area in 1992 and 2003 are acquired from 1-km observed MODIS data. The land use classification in Figure 1 includes 8 categories ranging from forest to urban and built-up area.



(a)Land Use in 1992 (b) Land Use in 2003

Figure 2: Land Use Map of Hankou Basin.

2.3. Soil Data

The soil data used in the determination of curve numbers is obtained from Harmonized World Soil Database (HWSD) by Food and Agriculture Organization of the United Nations (FAO). The data in the area of China has a scale of 1:1,000,000 which represents 100m resolution.

3. The Curve Number Method

3.1. Basic Concept

The basic assumption of the SCS curve number method is that, the ratio of actual soil retention to potential maximum retention is equal to the ratio of direct runoff to potential maximum runoff which is rainfall minus initial abstraction. After algebraic manipulation and inclusion of simplifying assumptions, direct runoff is calculated by the expression

$$\begin{cases} Q = \frac{(P-I_a)^2}{(P-I_a+S)}, & P \geq I_a \\ Q = 0 \quad , & P < I_a \end{cases} \tag{1}$$

Where Q is direct runoff depth (mm); P is rainfall depth (mm); S is the potential maximum soil moisture retention (mm); I_a is the initial abstraction (mm), or the depth of water before runoff such as infiltration or vegetation interception.

The parameter S is expressed as

$$S = 25400/CN - 254 \tag{2}$$

Where CN is the curve number and ranges from 0 to 100; it is determined by land use, hydrologic soil group and AMC (USDA-SCS, 1972).

3.2. Factors Derternining the Curve Number Value

The curve numbers represent an empirical relationship between land use, hydrologic soil group and AMC. Therefore in order to identify the specific value of curve number, all these factors are necessarily taken into consideration.

Based on CN values estimated for land use types of LANDSAT imagery, the curve numbers of 8 land use categories with different hydrologic soil types under average antecedent moisture condition are listed in Table 1. In the table, the order of the curve number value according to each land use type can be concluded: Water> Urban> Barren area> Agriculture> Wetland> Forest> Grass> Mixture.

Table 1: Curve Number Summary with Associated Land Use Categories.

Land Use Category	Title	Imperviousness (%)	Hydrological Soil Group			
			A	B	C	D
1	Forest	0	40	63	75	81
2	Mixture	0	35	56	70	77
3	Grassland/ Shrub	0	30	58	71	78
4	Agricultural area	0	62	75	83	84
5	Wetland	0	78	78	78	78
6	Barren area	72	77	86	91	94
7	Urban and Built-up	90	89	92	94	95
8	Water	0	100	100	100	100

Soils are classified into 4 hydrologic soil groups (HSG) as one element for determining curve numbers. Group A soils have lowest runoff potential and Group D soils have highest runoff potential.

The soil moisture condition before runoff generation is another important factor influencing CN value. Based on the 30-day antecedent rainfall for humid area, the soil moisture condition in this paper is classified into 3 Antecedent Moisture Condition (AMC) categories: AMC Ⅰ (<40mm); AMC Ⅱ (40-100mm); AMCⅢ(>100mm). I_a is assigned to be 0.3S for AMC Ⅰ or 0.1S in case of both AMC Ⅱ and AMCⅢ.

Table 2: Soil Textures of 4 Hydrological Soil Groups.

Hydrological Soil Group	Soil Textures
A	Sand, Sandy Loam
B	Loam or Silty Loam
C	Sandy Clay Loam
D	Silty Clay Loam, Silty Loam, Sandy Loam, Clay

4. Results

4.1. Base-flow Separation Results

Using digital filter technique to separate the base flow from observed runoff, the direct runoffs of both Hankou and Yichang station can be obtained. The difference between the direct runoff of Hankou and Yichang station is the direct runoff of the study basin. The total direct runoff result from SCS-CN method for the study area is turned out to be approximate to the result from this separation technique, with relative error of 3% in 1992 and 3.7% in 2003. Therefore, the result computed by SCS-CN method is thought to be reasonable on the study area.

4.2. Land Use Change

For the whole basin, the area of forest increases by 16.41% while mixture and grassland decrease by an approximately equal percent in total. There is a slight decrease in terms of both agricultural area and barren area. It seems that the degree of urban development is not as great as we supposed because the change percent is 0.62%. However, the change of water which is hardly to ignore is obvious to some degree. The drought caused by the increasing of annual mean temperature maybe one of the reasons to explain the decrease of water body, but some human activities like excessive use of water also has great impact on water shortage.

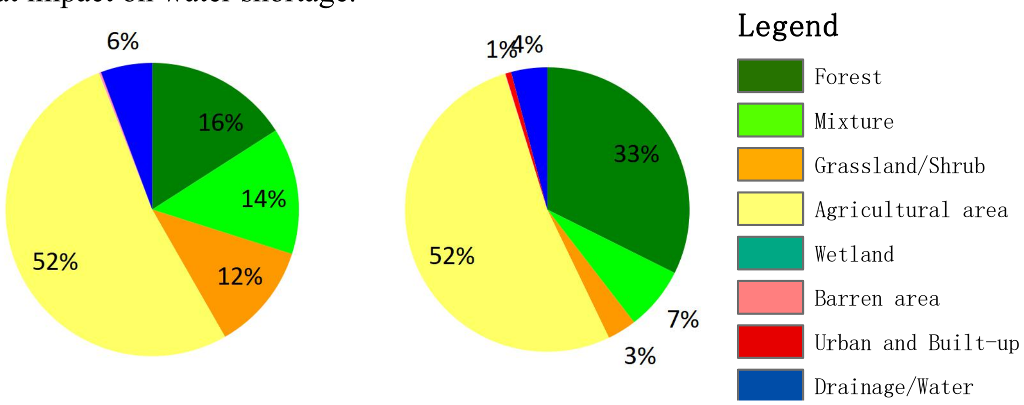


Figure 3: Land Uses for the Whole Basin in 1992 and 2003.

4.3.Regression Analysis

In this section, two regression relationships are established to explore the difference of the relationship between precipitation and direct runoff in 1992 and 2003. In Eq. 3, the coefficient a reflects the ratio that the rain is turned to be direct runoff. For the whole basin, a in 2003 is higher than in 1992, which indicates that the yield of precipitation to direct runoff in 2003 is greater than that in 1992. Combining the land use change for the whole basin, the increase of urban and forest area between 1992 and 2003 probably explain the increase of direct runoff yield. Actually, whether the increase of forest increase or decrease direct runoff is a debate that depends on the actual situation and canopy type, but the types of forest are ignored in this paper.

$$Q_{t,s} = a \cdot P_{t,s} + e_s \tag{3}$$

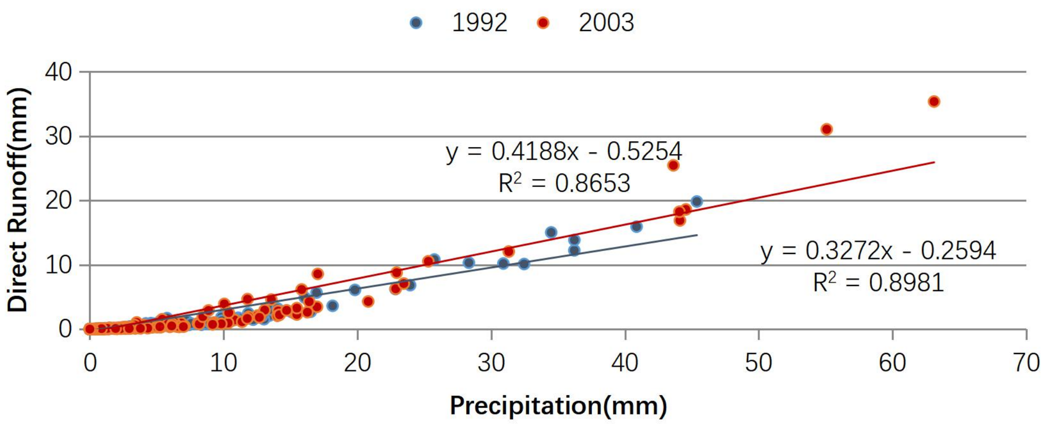


Figure 4:The Linear Regression Relationship between Precipitation and Direct Runoff.

Eq. 4 is the relationship between precipitation change and direct runoff change between 1992 and 2003. The coefficient *b* can represent the contribution of precipitation change (climate factor) to the direct runoff change and thus distinguish the direct runoff change due to the human factor. Fig. 5 is the relationship for the whole basin, with *b* value is 0.3899 which indicates that nearly 40% of direct runoff change is the result of precipitation change and the most important factor is human activities instead of climate change.

$$Q_{t,s}^{2003} - Q_{t,s}^{1992} = b \cdot \left(P_{t,s}^{2003} - P_{t,s}^{1992}\right) + e_s^{'} \quad (4)$$

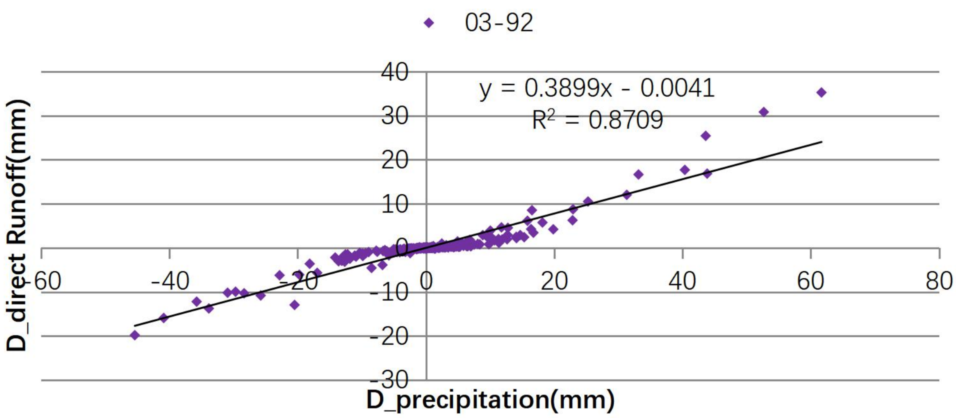


Figure 5: The Linear Regression Relationship between Precipitation Difference and Direct Runoff Difference between 1992 and 2003.

5. Conclusion

By using SCS-CN method, this study investigates the hydrologic response to land use change coupling with RS and GIS data in lower-middle Yangtze River during the period of 1992 to 2003. Digital filter technique is employed in this paper in order to validate the precision of the total direct runoff derived by SCS-CN method with observed total direct runoff. The result seems good as the relative error is around 3% in both 1992 and 2003.

At last, the regression analysis between precipitation and direct runoff are established to explore the ratio of direct runoff to rain and also the contribution of precipitation change to the direct runoff change. For the whole basin, deforestation, agricultural area and water body reduction are the main reasons for the decreasing of direct runoff yield. Furthermore, the contributions of both climate factor and human activities factor that cause direct runoff change between 1992 and 2003 are distinguished. In general, the human activities have much greater impact on direct runoff compared to the climate change in lower-middle Yangtze River during the period of 1992 to 2003.

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