

# An analysis of effect of land use change on river flow variability

**Tao Zhang<sup>1,5</sup>, Yuting Liu<sup>2</sup>, Xinyue Yang<sup>3</sup> and Xiang Wang<sup>4</sup>**

<sup>1</sup> Bureau of Hydrology, Changjiang Water Resources Commission, Wuhan 430010, China;

<sup>2</sup> Changjiang River Estuary Bureau of Hydrology and Water Resources Survey, Shanghai 200136, China;

<sup>3</sup> College of Hydrology and Water Resources, Hohai University, Nanjing 210098, China;

<sup>4</sup> China Yangtze Power Co., Ltd., Yichang 443133, China.

<sup>5</sup> zhangtao\_hohai@163.com

**Abstract.** Land use scenario analysis, SWAT model, flow characteristic indices and flow variability technology were used to analyze the effect of land use quantity and location change on river flow. Results showed that river flow variation caused by land use change from forest to crop was larger than that caused by land use change from forest to grass; Land use change neither from upstream to downstream nor from downstream to upstream had little effect on annual average discharge and maximum annual average discharge. But it had obvious effect on maximum daily discharge; Land use change which occurred in upstream could lead to producing larger magnitude flood more easily; Land use change from forest to crop or grass could increase the number of large magnitude floods and their total duration. And it also could increase the number of small magnitude floods but decrease their duration.

## 1. Introduction

Water issue under changing environment is a hot topic of water science research in the 21st century. It attracts lots of governments and research institutes' attention[1]. Land use as a platform for human-environment interactions plays an important role in connecting local land use decisions to global impacts and responses [2]. And study of effect of land use change on hydrological process is an important part of water cycle research under changing environment. More and more researchers pay attention to this field. Throughout the domestic and international research results, methods applied in effect of land use change on hydrological process include experimental watershed method, characteristic variables time series analysis method, hydrological modeling and, comprehensive analysis [3](table 1). The first two methods are more used in early stage research of this field[4-11]. With the development of physical-based and distributed/semi distributed hydrological models, more researchers[12-20] are increasingly utilizing hydrological model to interpret and predict hydrological response to land use changes[20].

In recent decades, land use in Fu jiangqiao cathment which is upstream of Fujiang river changed significantly. Hydrological response to land use change cannot be neglected in this area. Thus it has important value in theory and applications to study the effect of land use spatial-temporal change on hydrological elements and process in typical small catchments. In this paper, SWAT (Soil and water



assessment tool) model was used to modeling hydrological process, land use scenario analysis method was used to get various land use scenarios with different land use compositions and spatial distributions, follow characteristic indices and flow variability technique were introduced to analyze the effect of land use quantity and location change on river flow.

## 2. Materials and Methods

### 2.1. Study area

Fu river is right branch of Jialing River which is the largest branch of the Yangtze River. Study area of this paper is a typical small watershed located in the upstream of Fu river. Because watershed outlet is at Ganxi hydrological station, it is called Ganxi watershed (figure 1). Ganxi watershed covers an area of approximately 1064 km<sup>2</sup>. The land uses in Ganxi watershed primarily include crop, forest and grass which account for 14.2%, 79.6% and 6.2%.

This region is located in the subtropical zone and has a humid monsoon climate. It has an annual average temperature of 14.8 °C (Pingwu station) to 16.5 °C (Mianyang station), an average annual precipitation of 970mm and an average annual discharge of 15 m<sup>3</sup>/s.

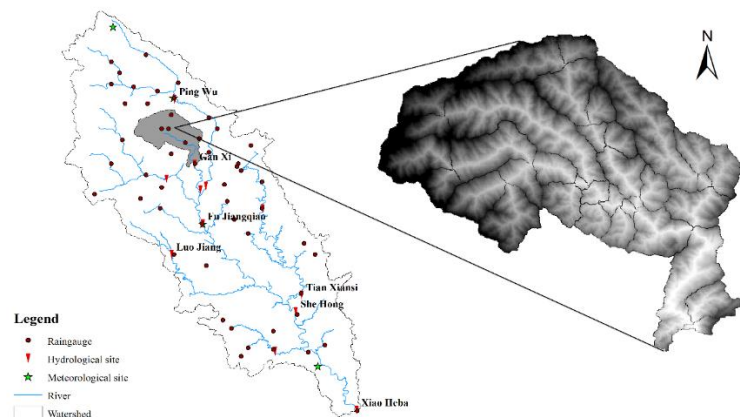


**Figure 1.** Location of Ganxi watershed.

### 2.2. Data

Data used in this paper include hydrological and meteorological data, land use data, spatial soil data and the digital elevation model (DEM). A series of daily precipitation and streamflow data from 6 precipitation stations and 1 hydrological station in Ganxi watershed between 1980 and 1987 was obtained from the Annual Hydrological Report of the Jialing River Basin. Meteorological data (1980-1987) from 2 meteorological stations (Pingwu and Mianyang) was obtained from the China Meteorological Data Sharing Service System. It includes average daily temperature, maximum daily temperature, minimum daily temperature, average daily relative humid and average daily wind speed. Land use of 1980s with a resolution of 1km was obtained from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) [21]. Spatial soil data which has a resolution of 2 km was obtained from the Institute of Soil Science, Chinese Academy of Sciences (RESDC). DEM with a spatial resolution of 3 arc-seconds was obtained from the Shuttle Radar Topography Mission (SRTM) website.

**Table 1.** Summary of study methods of effect of land use change on hydrological process.

| Methods                                          | Description                                                                                                                                                                                                                             | Advantage                                                                                                   | Disadvantage                                                                                                                                  | Study case           |
|--------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| Experimental watershed                           | intensively observing on selected experimental watersheds; analyzing relationships between land use change and hydrological elements; including individual watershed method, controlled watershed method and parallel watersheds method | eliminating disturbance of climate change; easy to discover vegetation-soil-hydrology interaction mechanism | difficult to find appropriate watersheds, long experimental periods, limited to small watersheds                                              | References [4]~[7]   |
| Time series analysis of Characteristic variables | selecting characteristic indices which can represent hydrological elements and land use change; eliminating impact factors; assessing effect of land use change on hydrological elements base on the induces changes                    | simple calculation method; mature theoretical basis; high maneuverability                                   | difficult to get data series with long periods; unable to reveal the physical mechanism of hydrological response; limited to small watersheds | References [8]~[11]  |
| Hydrological modeling                            | Applying hydrological models to modeling hydrological process under different underlying surface of different periods. the most used models: HBV, XAJ, SWAT and VIC.                                                                    | Considering influence factors on water cycle in watershed scale, easy to do scenarios analysis              | hard to describe underlying surface for lumped models; high data requirements for distributed models                                          | References [12]~[16] |
| Comprehensive analysis                           | analyzing effect of land use change on hydrological process by combination of mathematical statistic method, hydrological model or multiple hydrological models and land use change model                                               | available to modeling and predicting impact of land use change on hydrological process                      | low maneuverability, high data requirements, more uncertainties brought by model selections                                                   | References [17]~[20] |

### 2.3. Methods

**2.3.1. SWAT model** SWAT is a river basin or watershed scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). It has been widely applied in USA, European, China and other regions. Many researchers[22-24] use it in the study of hydrological response to climate change and land use change and get satisfied results. SWAT consists of 3 parts: sub-basin water cycle process, river flow routing process and reservoir water balance process. Model structure and theory can be found in reference [25].

In this paper, calibration of SWAT model was conducted manually using trial and error. The water balance was controlled by the relative error (RE), and the goodness of fit was evaluated with the Nash–Sutcliffe model efficiency coefficient (NSE). The RE and NSE are defined as follows:

$$RE = (\bar{Q}_{sim} - \bar{Q}_{obs}) / \bar{Q}_{obs} \quad (1)$$

$$NSE = 1 - \frac{\sum_{i=1}^n (Q_{obs,i} - Q_{sim,i})^2}{\sum_{i=1}^n (Q_{obs,i} - \bar{Q}_{obs})^2} \quad (2)$$

Where  $Q_{obs,i}$  and  $Q_{sim,i}$  are the observed and simulated streamflows, respectively;  $Q_{obs}$  and  $Q_{sim}$  represent the mean values of the observed and simulated streamflows, respectively; and  $n$  is the length of the time series.

**2.3.2. Land use scenarios** To explore the effect of land use change on river flow, land use scenarios which represent land use quantity and spatial distribution are necessary. Thus, hypothetical scenario analysis method was applied in this paper to obtain various available land use scenarios. In order to clarify the effect of land use location change on river flow, land use was set to change from two directions. One was from upstream to downstream which was defined as scenario 1 (figure 2 (1)). And the other was from downstream to upstream. It was defined as scenario 2 (figure 2 (2)). In each scenario, two subscenarios, (a) and (b), were included. Subscenarios (a) and subscenarios (b) separately represented that land use change from forest to crop and grass. Because forestland in Ganxi watershed had the largest area, approximate 80%, land use type conversion scenarios were designed to change from forest to the other two land uses. Land use quantity changed in each sub-scenario from 10% to 100% of the area with an increment of 10%. All hypothetical scenarios are shown in table 2.

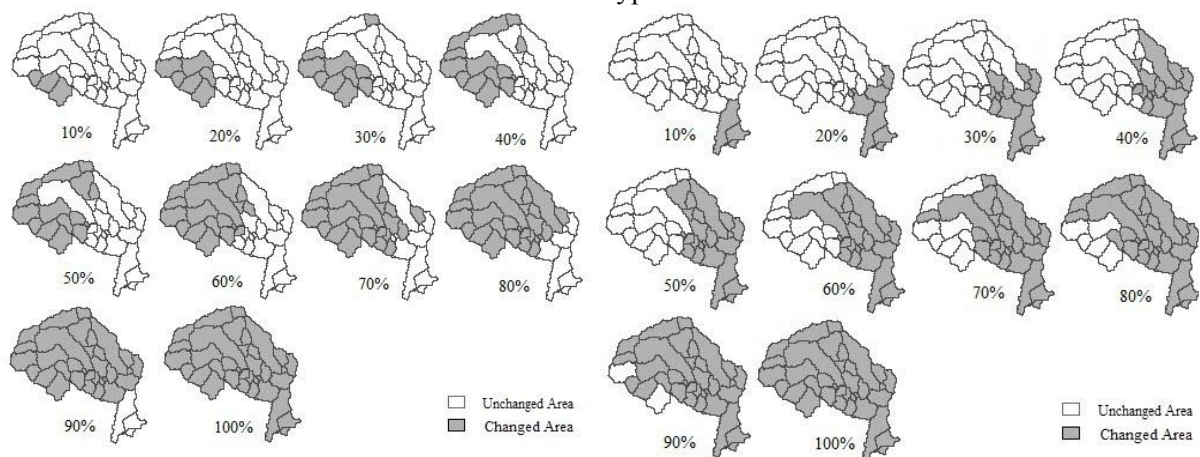


**Figure 2.** Land use change scenarios (1) land use change from upstream to downstream; (2) land use change from downstream to upstream.

**Table 2.** Land use change scenarios.

| Scenario   |               | Quantity change  | Location change | Land use change |
|------------|---------------|------------------|-----------------|-----------------|
| Scenario 1 | Scenario 1(a) | 10%、20%、...,100% | Upstream to     | Forest to Crop  |
|            | Scenario 1(b) |                  | Downstream      | Forest to Grass |
| Scenario 2 | Scenario 2(a) | 10%、20%、...,100% | Downstream to   | Forest to Crop  |
|            | Scenario 2(b) |                  | Upstream        | Forest to Grass |

**2.3.3. Flow variability analysis method** River flow variability analysis technology [9] was proposed by Archer, which is used to describe river flow change characteristic. It is more used in the research of hydrological response to land use change. This analysis of hydrological disturbance is based on the frequency and duration of pulses above threshold flows, selected as multiples of the median flow

(figure 3). A pulse is an occurrence of a rise above a given flow and pulse duration (between arrows on the figure) is the time from rising above the threshold to falling below the same threshold. Incomplete pulses at the beginning and end of the year were excluded. The full spectrum of disturbance was assessed by repeating for 19 selected multiples of median flow (M) as 1M, 2M, 3M, 4M, 5M, 6M, 7M, 8M, 9M, 10M, 15M, 20M, 30M, 40M, 50M, 60M, 80M, 90M and 100M.

Based on the hydrological modeling results, pulse frequency and duration of all hypothetical scenarios were counted. Considering the circumstances that land use change was not from one stage to another stage, it was possible to take total pulse frequency and duration as indices to assess the effect of land use change on river flow.

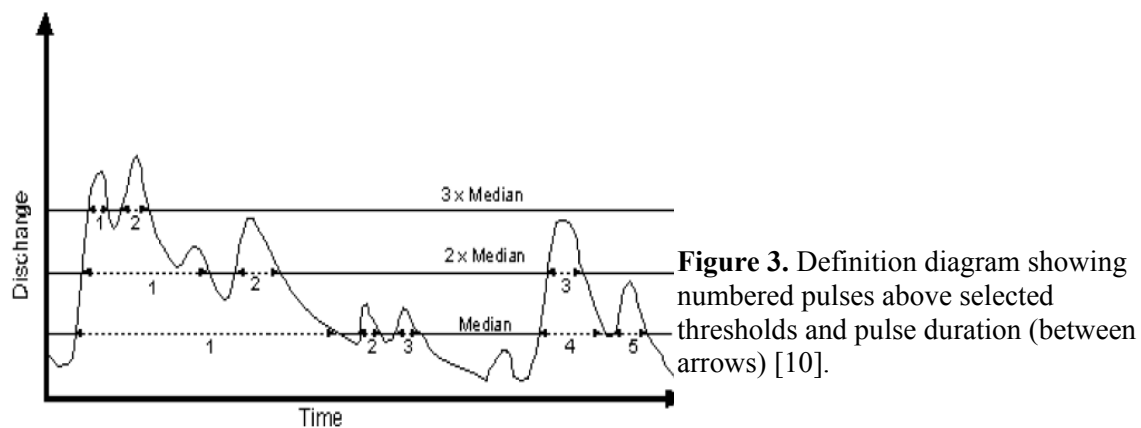


**Figure 3.** Definition diagram showing numbered pulses above selected thresholds and pulse duration (between arrows) [10].

**2.3.4. Simulation Scheme** Firstly, the SWAT model was calibrated and validated with collected data. Then the calibrated SWAT model was used to run under all hypothetical land use scenarios to get river flow simulation results of each scenarios. And then discharge characteristic indices and flow variability analysis method were used to analyze the effect of land use change (land use scenarios) on river flow. At last, analysis results were discussed and conclusions were given.

### 3. Results and discussion

#### 3.1. Hydrological modelling base on the SWAT model

**Table 3.** Calibration and validation results of SWAT model.

| Watershed | Calibration period (1981-1985) |           |             | Validation period (1986-1987) |           |             |
|-----------|--------------------------------|-----------|-------------|-------------------------------|-----------|-------------|
|           | RE (%)                         | NSE Daily | NSE Monthly | RE (%)                        | NSE Daily | NSE Monthly |
| Ganxi     | -5.3                           | 0.91      | 0.96        | -6.0                          | 0.86      | 0.91        |

Based on the collected data (hydrometeorological data for 1980–1987, land use map of 1980s, etc), the SWAT model was applied to the study area. The year of 1980 was taken as warm-up period. The period of 1981 to 1985 was taken as calibration period and the period of 1986 to 1987 was taken as validation period. The simulation results are shown in table 3, figure 4 and figure 5. Results indicate that the SWAT model performed well in both calibration and validation periods. The calibrated SWAT model was then used to simulate rainfall runoff process under all hypothetical land use scenarios.

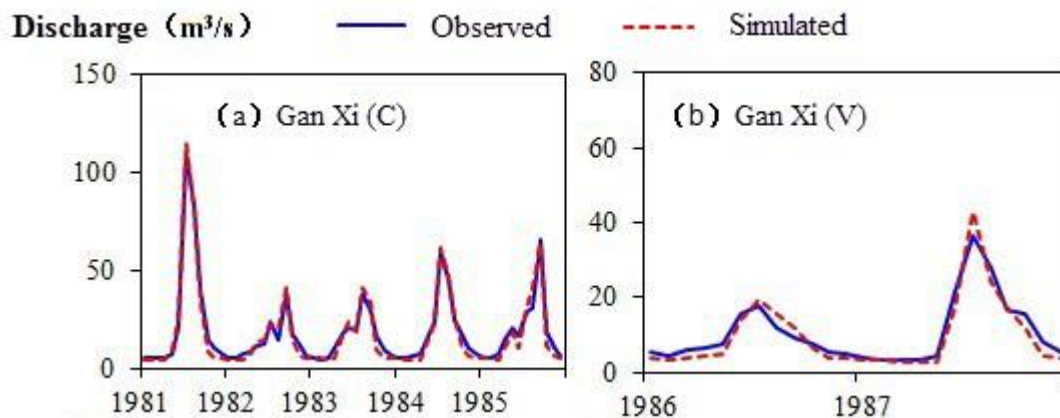


**Figure 4.** Monthly hydrographs for the calibration and validation periods.

(C: Calibration periods V: Validation periods)

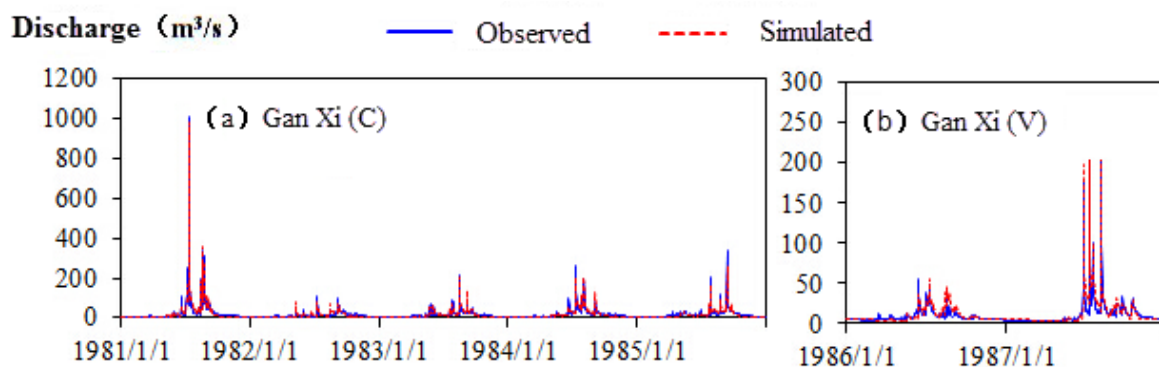


**Figure 5.** Daily hydrographs for the calibration and validation periods.

(C: Calibration periods V: Validation periods)

### 3.2. Discharge characteristic indices analysis under different land use scenarios

Discharge characteristic indices used in this paper included Annual Average Discharge (AAD), Maximum Annual Average Discharge (MAAD) and Maximum Daily Discharge (MDD). Results are listed in table 4 to table 7.

From table 4 to table 7, in general, we can see that all discharge characteristic indices increase with the decrease of forest (convert to crop or grass). It means that decrease of forestland would result in larger runoff peak and total runoff volume. It is in accordance with the finding of references [17-18, 26-27].

In both scenario 1 and scenario 2, discharge variation caused by land use conversion from forest to crop is larger than that caused by land use conversion from forest to grass. AAD, MAAD and MDD increase 4.20%, 5.94% and 48.46% separately when 100% forest land converts to crop. Similar changes could be found in the scenario that 100% forest converts to grass. AAD, MAAD, MDD have an increase of 0.43%, 1.63% and 24.12% separately. It is indicated that crop and grass would yield more runoff than forest. And crop has the largest yield ability. It is also found that MDD increased most obviously in all discharge characteristic indices. Taking land use conversion from forest to crop for example, as crop area increases from 10% to 100% of the study area, change magnitude of MDD increases from 3.06% to 48.46% in scenario 1 and from 6.68% to 48.46% in scenario 2. Compared to the large increase of MDD, AAD and MAAD changes relatively smaller. AAD in 100% crop scenario

is only 4.2% larger than that of 100% forest. And in the same scenario, MAAD is only 5.94% larger than that of 100% forest. In rainfall-runoff process, forest canopy interception is larger than that of crop and grass, so throughfall of forest land is smaller than that of the other two land uses. It makes soil under forest land get saturated later than that under the other two land use. That makes surface runoff of forest land yield later. And in a flood event, surface runoff contributes more to flood peak which makes MDD of forest to be the smallest one of the three land uses.

In addition, position of land use change (scenario 1: from upstream to downstream; scenario 2: from downstream to upstream) could also impacts river flow discharge. AAD and MAAD in scenario 1 are slightly larger than that in scenario 2. But MDD in scenario 1 is obviously smaller than that of scenario 2. It indicates that MDD is more easily affected by the position of land use change. Land use change (Forest to crop and grass) occurred in downstream would result in larger maximum daily discharge. This is because that, taking land use conversion from forest to crop for example, (1) land use conversion (forest to crop) could lead to larger runoff which is mentioned above; (2) runoff yield in downstream area could flow into river channel more quickly; (3) attenuation effect of river routing would reduce the increased discharge caused by land use change in upstream.

**Table 4.** Hydrological modeling results (Land use change from forest to crop) of scenario 1.

| Scenario | AAD(m <sup>3</sup> /s) | Change(%) | MAAD(m <sup>3</sup> /s) | Change(%) | MDD(m <sup>3</sup> /s) | Change(%) |
|----------|------------------------|-----------|-------------------------|-----------|------------------------|-----------|
| Base     | 14.98                  | --        | 24.55                   | --        | 912                    | --        |
| F-C10    | 15.11                  | 0.89      | 24.80                   | 1.01      | 939                    | 3.06      |
| F-C20    | 15.23                  | 1.70      | 25.05                   | 2.05      | 976                    | 7.03      |
| F-C30    | 15.29                  | 2.10      | 25.18                   | 2.58      | 1006                   | 10.31     |
| F-C40    | 15.41                  | 2.84      | 25.39                   | 3.42      | 1039                   | 13.93     |
| F-C50    | 15.42                  | 2.90      | 25.43                   | 3.60      | 1054                   | 15.57     |
| F-C60    | 15.50                  | 3.45      | 25.62                   | 4.37      | 1114                   | 22.15     |
| F-C70    | 15.50                  | 3.46      | 25.68                   | 4.62      | 1181                   | 29.50     |
| F-C80    | 15.57                  | 3.96      | 25.83                   | 5.23      | 1226                   | 34.43     |
| F-C90    | 15.59                  | 4.07      | 25.89                   | 5.46      | 1293                   | 41.78     |
| F-C100   | 15.61                  | 4.20      | 26.01                   | 5.94      | 1354                   | 48.46     |

Notes: F-C: Forest convert to crop. The same abbreviations are used in the following tables

**Table 5.** Hydrological modeling results (Land use change from forest to grass) of scenario 1.

| Scenario | AAD(m <sup>3</sup> /s) | Change(%) | MAAD(m <sup>3</sup> /s) | Change(%) | MDD(m <sup>3</sup> /s) | Change(%) |
|----------|------------------------|-----------|-------------------------|-----------|------------------------|-----------|
| Base     | 14.98                  | --        | 24.55                   | --        | 912                    | --        |
| F-G10    | 15.00                  | 0.16      | 24.61                   | 0.24      | 929                    | 1.91      |
| F-G20    | 15.02                  | 0.29      | 24.68                   | 0.51      | 949                    | 4.12      |
| F-G30    | 15.03                  | 0.34      | 24.71                   | 0.65      | 964                    | 5.79      |
| F-G40    | 15.05                  | 0.47      | 24.77                   | 0.89      | 984                    | 7.89      |
| F-G50    | 15.05                  | 0.44      | 24.78                   | 0.95      | 990                    | 8.61      |
| F-G60    | 15.05                  | 0.49      | 24.84                   | 1.19      | 1021                   | 11.95     |
| F-G70    | 15.04                  | 0.43      | 24.86                   | 1.24      | 1052                   | 15.35     |
| F-G80    | 15.06                  | 0.51      | 24.91                   | 1.46      | 1077                   | 18.09     |
| F-G90    | 15.04                  | 0.42      | 24.92                   | 1.50      | 1105                   | 21.16     |
| F-G100   | 15.04                  | 0.43      | 24.95                   | 1.63      | 1132                   | 24.12     |

Notes: F-G, Forest convert to grass. The same abbreviations are used in the following tables

**Table 6.** Hydrological modeling results (Land use change from forest to crop) of scenario 2.

| Scenario | AAD(m <sup>3</sup> /s) | Change(%) | MAAD(m <sup>3</sup> /s) | Change(%) | MDD(m <sup>3</sup> /s) | Change(%) |
|----------|------------------------|-----------|-------------------------|-----------|------------------------|-----------|
| Base     | 14.98                  | --        | 24.55                   | --        | 912                    | --        |
| F-C10    | 15.02                  | 0.29      | 24.67                   | 0.50      | 973                    | 6.68      |
| F-C20    | 15.01                  | 0.21      | 24.73                   | 0.74      | 1043                   | 14.36     |
| F-C30    | 15.01                  | 0.22      | 24.79                   | 0.98      | 1100                   | 20.61     |
| F-C40    | 15.09                  | 0.70      | 24.94                   | 1.57      | 1151                   | 26.21     |
| F-C50    | 15.09                  | 0.70      | 25.00                   | 1.83      | 1188                   | 30.26     |
| F-C60    | 15.17                  | 1.25      | 25.18                   | 3.10      | 1233                   | 35.20     |
| F-C70    | 15.23                  | 1.69      | 25.31                   | 3.10      | 1263                   | 38.49     |
| F-C80    | 15.35                  | 2.48      | 25.53                   | 3.98      | 1298                   | 42.32     |
| F-C90    | 15.48                  | 3.34      | 25.77                   | 4.98      | 1329                   | 45.72     |
| F-C100   | 15.61                  | 4.20      | 26.01                   | 5.94      | 1354                   | 48.46     |

**Table 7.** Hydrological modeling results (Land use change from forest to grass) of scenario 2.

| Scenario | AAD(m <sup>3</sup> /s) | Change(%) | MAAD(m <sup>3</sup> /s) | Change(%) | MDD(m <sup>3</sup> /s) | Change(%) |
|----------|------------------------|-----------|-------------------------|-----------|------------------------|-----------|
| Base     | 14.98                  | --        | 24.55                   | --        | 912                    | --        |
| F-G10    | 14.98                  | -0.01     | 24.58                   | 0.13      | 938                    | 2.88      |
| F-G20    | 14.96                  | -0.11     | 24.59                   | 0.18      | 969                    | 6.21      |
| F-G30    | 14.96                  | -0.16     | 24.61                   | 0.26      | 994                    | 9.04      |
| F-G40    | 14.97                  | -0.10     | 24.66                   | 0.46      | 1022                   | 12.06     |
| F-G50    | 14.95                  | -0.17     | 24.68                   | 0.52      | 1037                   | 13.71     |
| F-G60    | 14.97                  | -0.09     | 24.73                   | 0.74      | 1060                   | 16.23     |
| F-G70    | 14.98                  | -0.03     | 24.78                   | 0.92      | 1075                   | 17.87     |
| F-G80    | 15.00                  | 0.10      | 24.83                   | 1.16      | 1096                   | 20.18     |
| F-G90    | 15.00                  | 0.10      | 24.90                   | 1.43      | 1112                   | 21.93     |
| F-G100   | 15.04                  | 0.43      | 24.95                   | 1.63      | 1132                   | 24.12     |

### 3.3. Flow variability analysis

**3.3.1. Pulse number** Figure 6 and figure 7 show total numbers of pulse above each threshold in both scenario 1 and scenario 2. It can be seen that as the decrease of forest land (convert to crop or grass), total number of pulse above each threshold increases. It indicates that forest has the effect of reducing flood peak.

In the scenario that 10% forest converting to crop (grass), discharge above 3 M (3 multiples of the median flow) has the largest total number of pulse. And in the scenario that 100% forest convert to crop (grass), discharge above 4 (5) M has the largest total number of pulse. It indicates that dominated discharge in river which has the largest total number of pulse becomes larger when forest convert to the other two land use types.

**3.3.2. Pulse duration** Table 8 ~ table 15 illustrate pulse duration above each threshold in all scenarios. From table 8 ~ table 11 (scenario 1) we can see that (1) Forest converts to crop (F-C): when discharge is between 1M and 10M, pulse duration increases with the decrease of forest land. And when discharge exceeds 10M, pulse duration would decrease with the decrease of forest land. The turning point is at 15M; (2) Forest converts to grass (F-G): when discharge is between 1M to 15M, pulse duration increases with the decrease of forest land. And when discharge exceeds 30M, pulse duration would decrease obviously with the decrease of forest land. The turning point is at 30M. In scenario 2

(table 12 and table 15), pulse duration, the same as in scenario 1, decreases first and then increases with the decrease of forest land. The turning points are also the same as that of scenario 1.

It is worthy of note that the turning points of scenario (F-C) and scenario (F-G) are different. Turning point of land use change from forest to crop (F-C) is smaller than that of land use change from forest to grass (F-G). For the small magnitude flood processes (1-10M/15M), the decrease of forest area leads to increase of pulse number (figure 6~7) and decrease of pulse duration (table 8~15). It indicates that more small floods with short duration and sharp flood peak occur after land use conversion from forest to the other two. And as the threshold becomes larger, pulse duration turns to increase obviously. It not means that decrease of forest would result in large magnitude floods with long duration. Normally, non-forest area responds quickly to rainfall mainly because of larger thorough fall which make the river flow change quickly. However, this kind of flood would subside quickly as the stop of rainfall. This is why there produce more small floods with short duration and sharp flood peak after the decrease of forest. The reason why duration time increases is that definition of duration time here is total time. As we know, water conservation effect of non-forest area is little than forest area, so large magnitude floods occur more often in non-forest area. Occurrences of large magnitude floods increase, so total duration increases.

To sum up, land use change (quantity and location) has different degrees of impact on flood magnitude and duration especially on that of maximum daily discharge. It should be considered by flood decision-making and water resource management departments.

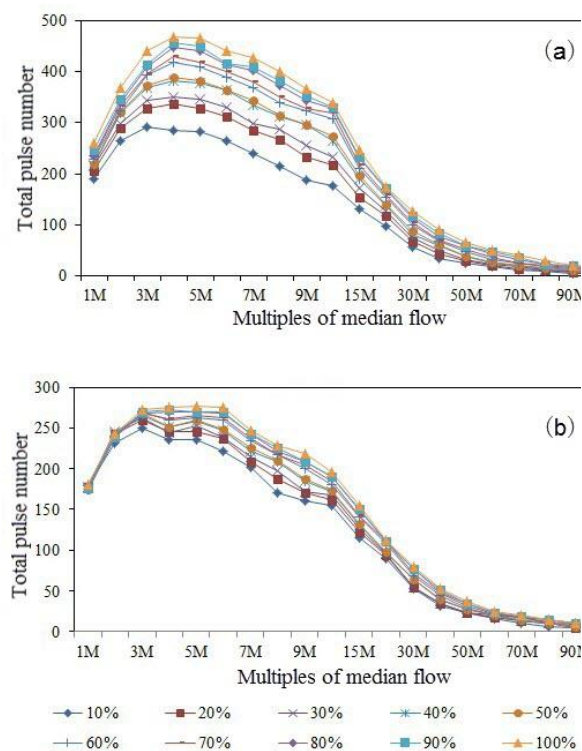


**Figure 6.** Total pulse numbers in Scenario 1 (a)Forest to crop (b)Forest to grass.

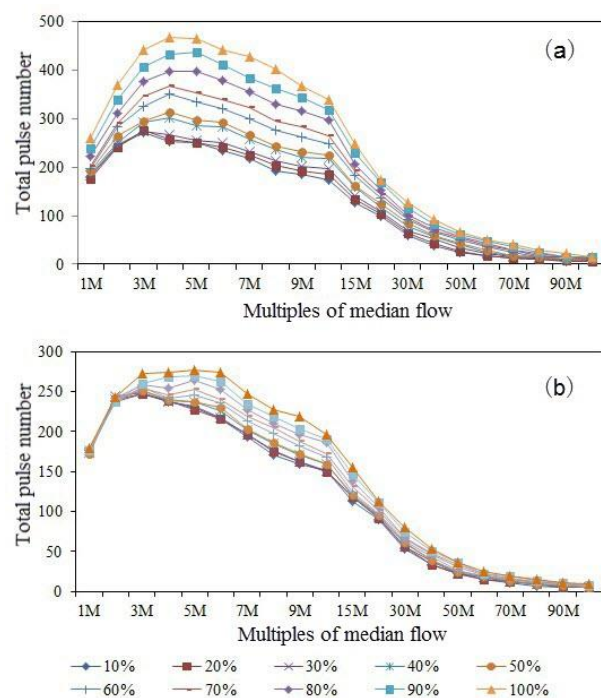


**Figure 7.** Total pulse numbers in Scenario 2 (a)Forest to crop (b)Forest to grass.

**Table 8.** Pulse duration of land use convert from forest to crop in scenario 1 (1M-10M/Day).

| F-C  | 1M   | 2M   | 3M   | 4M   | 5M   | 6M   | 7M   | 8M   | 9M  | 10M |
|------|------|------|------|------|------|------|------|------|-----|-----|
| 10%  | 7290 | 4928 | 3695 | 2803 | 2166 | 1699 | 1360 | 1113 | 925 | 779 |
| 20%  | 7192 | 4833 | 3614 | 2750 | 2126 | 1673 | 1361 | 1126 | 945 | 794 |
| 30%  | 7126 | 4785 | 3566 | 2719 | 2101 | 1657 | 1353 | 1121 | 931 | 790 |
| 40%  | 7045 | 4710 | 3521 | 2667 | 2072 | 1630 | 1344 | 1105 | 931 | 789 |
| 50%  | 6999 | 4679 | 3497 | 2644 | 2051 | 1625 | 1336 | 1101 | 925 | 787 |
| 60%  | 6882 | 4594 | 3380 | 2561 | 1971 | 1570 | 1281 | 1055 | 899 | 775 |
| 70%  | 6810 | 4540 | 3323 | 2513 | 1931 | 1538 | 1236 | 1018 | 874 | 742 |
| 80%  | 6742 | 4478 | 3265 | 2447 | 1866 | 1488 | 1226 | 1002 | 850 | 737 |
| 90%  | 6661 | 4418 | 3198 | 2387 | 1814 | 1436 | 1160 | 964  | 810 | 705 |
| 100% | 6565 | 4319 | 3088 | 2284 | 1728 | 1371 | 1112 | 931  | 784 | 685 |

**Table 9.** Pulse duration of land use convert from forest to crop in scenario 1 (15M-100M/Day).

| F-C  | 15M | 20M | 30M | 40M | 50M | 60M | 70M | 80M | 90M | 100M |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| 10%  | 375 | 211 | 91  | 49  | 30  | 22  | 15  | 11  | 7   | 6    |
| 20%  | 385 | 228 | 104 | 59  | 38  | 26  | 18  | 15  | 10  | 6    |
| 30%  | 394 | 235 | 113 | 70  | 40  | 28  | 23  | 15  | 12  | 9    |
| 40%  | 402 | 254 | 122 | 79  | 51  | 31  | 25  | 16  | 13  | 10   |
| 50%  | 406 | 256 | 128 | 81  | 52  | 35  | 26  | 19  | 13  | 10   |
| 60%  | 409 | 273 | 147 | 96  | 63  | 39  | 30  | 24  | 18  | 13   |
| 70%  | 410 | 276 | 154 | 102 | 70  | 48  | 33  | 25  | 20  | 14   |
| 80%  | 418 | 290 | 176 | 110 | 78  | 55  | 40  | 29  | 22  | 17   |
| 90%  | 414 | 296 | 179 | 118 | 81  | 60  | 46  | 30  | 24  | 20   |
| 100% | 437 | 299 | 196 | 131 | 87  | 68  | 53  | 36  | 25  | 20   |

**Table 10.** Pulse duration of land use convert from forest to grass in scenario 1 (1M-10M/Day).

| F-R  | 1M   | 2M   | 3M   | 4M   | 5M   | 6M   | 7M   | 8M   | 9M  | 10M |
|------|------|------|------|------|------|------|------|------|-----|-----|
| 10%  | 7363 | 4966 | 3717 | 2795 | 2163 | 1686 | 1339 | 1090 | 913 | 781 |
| 20%  | 7346 | 4942 | 3703 | 2775 | 2143 | 1673 | 1326 | 1080 | 902 | 770 |
| 30%  | 7322 | 4927 | 3684 | 2762 | 2131 | 1663 | 1318 | 1078 | 898 | 760 |
| 40%  | 7308 | 4906 | 3659 | 2747 | 2116 | 1651 | 1312 | 1069 | 899 | 758 |
| 50%  | 7292 | 4903 | 3652 | 2744 | 2109 | 1645 | 1310 | 1065 | 898 | 757 |
| 60%  | 7259 | 4875 | 3600 | 2719 | 2085 | 1632 | 1297 | 1057 | 886 | 738 |
| 70%  | 7220 | 4833 | 3573 | 2678 | 2054 | 1600 | 1282 | 1041 | 871 | 731 |
| 80%  | 7219 | 4830 | 3573 | 2676 | 2054 | 1599 | 1281 | 1041 | 870 | 731 |
| 90%  | 7196 | 4818 | 3556 | 2666 | 2039 | 1586 | 1268 | 1034 | 858 | 724 |
| 100% | 7171 | 4788 | 3531 | 2645 | 2005 | 1563 | 1246 | 1010 | 847 | 716 |

**Table 11.** Pulse duration of land use convert from forest to grass in scenario 1 (15M-100M/Day).

| F-R  | 15M | 20M | 30M | 40M | 50M | 60M | 70M | 80M | 90M | 100M |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| 10%  | 360 | 200 | 85  | 46  | 30  | 20  | 14  | 9   | 7   | 6    |
| 20%  | 359 | 205 | 87  | 50  | 30  | 22  | 16  | 12  | 7   | 6    |
| 30%  | 354 | 206 | 89  | 50  | 30  | 24  | 17  | 13  | 9   | 7    |
| 40%  | 356 | 204 | 97  | 54  | 34  | 26  | 17  | 13  | 9   | 7    |
| 50%  | 356 | 204 | 98  | 55  | 35  | 26  | 18  | 13  | 9   | 7    |
| 60%  | 357 | 208 | 104 | 60  | 40  | 27  | 21  | 14  | 11  | 9    |
| 70%  | 349 | 213 | 114 | 67  | 46  | 29  | 23  | 18  | 13  | 9    |
| 80%  | 349 | 212 | 114 | 67  | 46  | 30  | 23  | 18  | 13  | 9    |
| 90%  | 347 | 208 | 116 | 70  | 47  | 30  | 24  | 18  | 13  | 10   |
| 100% | 348 | 211 | 120 | 73  | 49  | 32  | 25  | 18  | 13  | 11   |

**Table 12.** Pulse duration of land use convert from forest to crop in scenario 2 (1M-10M/Day).

| F-A  | 1M   | 2M   | 3M   | 4M   | 5M   | 6M   | 7M   | 8M   | 9M  | 10M |
|------|------|------|------|------|------|------|------|------|-----|-----|
| 10%  | 7305 | 4922 | 3666 | 2752 | 2122 | 1656 | 1314 | 1069 | 909 | 773 |
| 20%  | 7241 | 4866 | 3618 | 2712 | 2084 | 1607 | 1297 | 1049 | 885 | 752 |
| 30%  | 7187 | 4817 | 3580 | 2677 | 2048 | 1579 | 1257 | 1018 | 864 | 736 |
| 40%  | 7121 | 4757 | 3520 | 2634 | 1995 | 1559 | 1235 | 1004 | 849 | 716 |
| 50%  | 7045 | 4713 | 3470 | 2600 | 1960 | 1525 | 1215 | 989  | 833 | 701 |
| 60%  | 6962 | 4632 | 3398 | 2545 | 1910 | 1493 | 1193 | 970  | 815 | 694 |
| 70%  | 6729 | 4466 | 3238 | 2421 | 1843 | 1448 | 1159 | 947  | 803 | 685 |
| 80%  | 6806 | 4518 | 3279 | 2426 | 1847 | 1454 | 1161 | 940  | 802 | 694 |
| 90%  | 6696 | 4422 | 3185 | 2356 | 1780 | 1408 | 1136 | 938  | 787 | 678 |
| 100% | 6565 | 4319 | 3088 | 2284 | 1728 | 1371 | 1112 | 931  | 784 | 685 |

**Table 13.** Pulse duration of land use convert from forest to crop in scenario 2 (15M-100M/Day).

| F-A  | 15M | 20M | 30M | 40M | 50M | 60M | 70M | 80M | 90M | 100M |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| 10%  | 361 | 212 | 96  | 57  | 32  | 20  | 15  | 12  | 7   | 7    |
| 20%  | 354 | 207 | 100 | 63  | 36  | 21  | 16  | 12  | 11  | 7    |
| 30%  | 345 | 208 | 109 | 72  | 47  | 27  | 18  | 15  | 12  | 9    |
| 40%  | 351 | 219 | 123 | 80  | 55  | 32  | 21  | 17  | 13  | 12   |
| 50%  | 347 | 225 | 131 | 81  | 58  | 36  | 23  | 18  | 13  | 12   |
| 60%  | 362 | 241 | 143 | 91  | 67  | 47  | 30  | 20  | 16  | 13   |
| 70%  | 378 | 262 | 156 | 103 | 74  | 56  | 37  | 23  | 20  | 15   |
| 80%  | 390 | 268 | 160 | 109 | 76  | 59  | 38  | 27  | 20  | 17   |
| 90%  | 414 | 287 | 179 | 118 | 82  | 64  | 45  | 31  | 20  | 20   |
| 100% | 437 | 299 | 196 | 131 | 87  | 68  | 53  | 36  | 25  | 20   |

**Table 14.** Pulse duration of land use convert from forest to grass in scenario 2 (1M-10M/Day).

| F-R  | 1M   | 2M   | 3M   | 4M   | 5M   | 6M   | 7M   | 8M   | 9M  | 10M |
|------|------|------|------|------|------|------|------|------|-----|-----|
| 10%  | 7351 | 4963 | 3712 | 2799 | 2158 | 1679 | 1331 | 1089 | 916 | 779 |
| 20%  | 7339 | 4951 | 3700 | 2782 | 2140 | 1667 | 1323 | 1080 | 904 | 771 |
| 30%  | 7321 | 4934 | 3688 | 2770 | 2124 | 1659 | 1315 | 1071 | 891 | 760 |
| 40%  | 7294 | 4916 | 3664 | 2746 | 2106 | 1645 | 1299 | 1066 | 886 | 745 |
| 50%  | 7277 | 4901 | 3646 | 2736 | 2099 | 1641 | 1295 | 1056 | 881 | 740 |
| 60%  | 7257 | 4884 | 3614 | 2716 | 2087 | 1618 | 1279 | 1040 | 875 | 735 |
| 70%  | 7239 | 4865 | 3593 | 2718 | 2079 | 1622 | 1279 | 1042 | 880 | 738 |
| 80%  | 7218 | 4842 | 3568 | 2697 | 2050 | 1594 | 1272 | 1030 | 862 | 730 |
| 90%  | 7135 | 4767 | 3528 | 2658 | 2036 | 1592 | 1268 | 1032 | 861 | 727 |
| 100% | 7171 | 4788 | 3531 | 2645 | 2005 | 1563 | 1246 | 1010 | 847 | 716 |

**Table 15.** Pulse duration of land use convert from forest to grass in scenario 2 (15M-100M/Day).

| F-R  | 15M | 20M | 30M | 40M | 50M | 60M | 70M | 80M | 90M | 100M |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| 10%  | 359 | 201 | 84  | 47  | 27  | 18  | 14  | 9   | 7   | 7    |
| 20%  | 357 | 200 | 88  | 48  | 29  | 19  | 15  | 12  | 7   | 7    |
| 30%  | 351 | 200 | 88  | 52  | 31  | 21  | 16  | 12  | 8   | 7    |
| 40%  | 347 | 203 | 95  | 56  | 33  | 21  | 16  | 12  | 9   | 7    |
| 50%  | 348 | 199 | 96  | 58  | 34  | 22  | 17  | 12  | 10  | 7    |
| 60%  | 343 | 196 | 101 | 62  | 38  | 24  | 18  | 13  | 11  | 8    |
| 70%  | 344 | 203 | 104 | 65  | 44  | 26  | 20  | 15  | 12  | 9    |
| 80%  | 347 | 205 | 108 | 67  | 44  | 28  | 20  | 16  | 12  | 10   |
| 90%  | 346 | 206 | 115 | 70  | 47  | 29  | 23  | 17  | 13  | 10   |
| 100% | 348 | 211 | 120 | 73  | 49  | 32  | 25  | 18  | 13  | 11   |

#### 4. Conclusions

Base on the analysis above we reached the following 4 conclusions:

(1)The SWAT model was applied in study area. The SWAT modeled the hydrological processes for both the calibration and validation periods with an RE of less than 10%, a monthly NSE of more than 0.9 and a daily NSE of more than 0.86. It could be used in the research of effect of land use change on hydrological process.

(2)Hydrological modeling results showed that discharge variation caused by land use change from forest to crop was larger than that caused by land use change form forest to grass.

(3)Land use change ( from forest to crop or forest to grass, from upstream to downstream or downstream to upstream) had little effect on annual average discharge and maximum annual average flow. But it had larger effect on daily discharge process.

(4)Land use change that occurred in upstream could lead to producing larger magnitude floods than that occur in downstream; Decrease of Forest would lead to increasing number and total duration of large floods and increasing number of small flood and decreasing small flood duration at the same time.

#### Acknowledgment

The study is financially supported by the National Key Research and Development Program of China (2016YFC0402708).

## Reference

- [1] Lu G H and He H 2006 View of global hydrological cycle *Advance in water science*, **17**(3) 419-424.
- [2] IGBP, IHDP, GLP-OSM 2014.
- [3] Zhang T 2015 Spatial-temporal hydrological effect of land use change (Nanjing: Hohai University)
- [4] Ye B Y, Zhang Y Z, Zhang S W and Cheng L P 2003 Effect of land cover change in Neijiang watershed on runoff volume *Bulletin of Soil and Water Conservation* **23**(2) 15-18.
- [5] Sahin V. and Hall M. J. 1996 The effects of afforestation and deforestation on water yields *Journal of Hydrology* **178**(1-4) 293-309.
- [6] Sun N and Li X B 2005 A summary of the effects of afforestation and deforestation on annual water yields *International Geoscience and Remote Sensing Symposium (IGARSS)*, **4** 2266-2269.
- [7] Liu C M and Chung C H 1978 The influence of forest cover upon annual runoff in the loess plateau of China. *J. Geogr. Sci.* **33**(2) 112-127.
- [8] Zhang Y K and Schilling K. E. 2006 Increasing streamflow and baseflow in Mississippi river since the 1940 s: effect of land use change. *Journal of Hydrology* **324**(1-4) 412-422.
- [9] Archer D. and Newson M. 2002 The use of indices of flow variability in assessing the hydrological and instream habitat impacts of upland afforestation and drainage *Journal of Hydrology* **268**(1-4) 244-258.
- [10] Archer D. R. 2007 The use of flow variability analysis to assess the impact of land use change on the paired Plynlimon catchments, Mid-Wales *Journal of Hydrology* **347**(3-4) 487-496.
- [11] Beven K., Young P. and Romanowicz R. 2008 Analysis of historical data sets to look for impacts of land use and management change on flood generation *Defra R&D Final Report FD2120* (London: Defra).
- [12] Lin Y P, Hong N M, Wu P J, Wu C F and Verburg P H. 2007 Impacts of land use change scenarios on hydrology and land use patterns in the Wu-Tu watershed in northern Taiwan *Landscape and Urban Planning* **80**(1-2) 111-126.
- [13] Tong S T. Y., Sun Y, Ranatunga T, He J and Yang Jeffrey 2012 Predicting plausible impacts of sets of climate and land use change scenarios on water resources *Applied Geography* **32**(2) 477-489.
- [14] Serneels S 2001 Priority of questions for land use/cover change research in the next couple years *LUCC Newsletter*.
- [15] Dunn S. M. and Mackay R. 1995 Spatial variation in evapotranspiration and the influence of land use on catchment hydrology *Journal of Hydrology* **195**(171) 49-73.
- [16] Jin C, Zhang B, Song K S, Wang Z M and Yang G 2009 RS-based analysis on the effects of land use/cover change on regional evapotranspiration——A case study in Qian'an county, Jilin province *Arid Zone Research* **26**(5) 734-743.
- [17] Liu Y Y, Zhang X N, Xia D Z, You J S, Rong Y S and Bakir M 2013 Impacts of land-use and climate changes on hydrologic processes in the Qingyi river watershed, China *Journal of Hydrologic Engineering* **18**(11) 1495-1512.
- [18] Fohrer N., Haverkamp S., Eckhardt K. and Frede H G 2001 Hydrologic response to land use changes on the catchment scale *Physics and Chemistry of the Earth Part B-Hydrology Oceans and Atmosphere* **26**(7-8) 577-582.
- [19] Zhang X N, Liu Y Y, Fang Y H, Liu B J and Xia D Z 2012 Modeling and assessing hydrologic processes for historical and potential land-cover change in the Duoyingping watershed, Southwest China *Physics and Chemistry of the Earth* **53-54**(12) 19-29.
- [20] Zhang T, Zhang X N, Xia D Z and Liu Y Y 2014 An analysis of land use change dynamics and its impacts on hydrological processes in the Jialing river basin *Water* **6**(12) 3758-3782.
- [21] Shi X Z, Yu D S, Warner E D and Weindorf D C 2004 Soil Database of 1:1,000,000 Digital

- Soil Survey and Reference System of the Chinese Genetic Soil Classification System *Soil Survey Horizons* **45**(4)129-136.
- [22] Sananda K, Deepak K and Arun M 2017 Individual and combined impacts of future climate and land use changes on the water balance *Ecological Engineering* **105** 42-57.
- [23] Wang H, Sun F B, Xia J and Liu W B 2017 Impact of LUCC on streamflow based on the SWAT model over the Wei River basin on the Loess Plateau in China *Hydrol. Earth Syst. Sci.* **21**(4) 1929-1945.
- [24] Neupane R P, Sandeep K 2015 Estimating the effects of potential climate and land use changes on hydrologic processes of a large agriculture dominated watershed *Journal of Hydrology* **529** 418–429.
- [25] Neitsch S. L., Arnold J. G., Kiniry J. R. and Williams J R 2009 *Soil and water assessment tool theoretical documentation version 2009* (Texas: Texas A & M University System).
- [26] Hundecha Y and Bardossy A 2004 Modeling of the effect of land use changes on the runoff generation of a river basin through parameter regionalization of a watershed model *Journal of Hydrology* **292**(1-4) 281–295.
- [27] Archer D R, Climent-Soler D and Holman I P 2010 Changes in discharge rise and fall rates applied to impact assessment of catchment land use *Hydrology Research* **41**(1) 13–26.