RETRACTED ARTICLE: Estimation of landscape pattern change on stream flow using SWAT-VRR

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ABSTRACT
With the development of landscape ecology and hydrology, the research in relationship between landscape pattern changes and hydrological process is pushed into a further level, and also to proposed a higher request to the development of related models. The SWAT-VRR model (Soil and Water Assessment Tool with Vegetation Runoff Regulation) is a distributed hydrological model to better show the effect of land use landscape change on hydrological processes. The Qihe watershed in Danjiangkou reservoir area was selected in a case study, and the applicability of SWAT-VRR was verified firstly, then set up two typical water-soil conservation scenario simulations to analyze the response to landscape pattern changes under SWAT-VRR. The results indicate that, the SWAT-VRR model achieved a notable improvement in monthly and daily hydrological simulation comparing to the SWAT model (Soil and Water Assessment Tool) simulation during 2003 to 2006. Compared with the two land use scenarios, the 300 m forest riparian along the Qihe River can adjust the runoff more effectively than the area greater than 15° is forest, and show a strong stability in water-soil conservation effect during different rainfall. The SWAT-VRR provides a more accurate scientific basis to estimate landscape pattern change on stream flow.

Introduction
The spatial pattern and type composition of land use not only directly control hydrological process on the slope (Jiao et al., 2017), but also constitute an important factor affecting water cycle and water quality in watershed (Fierro et al., 2017). Through study on the effects of vegetation landscape pattern on rainfall, runoff, evaporation and other water cycle processes, it is possible to consider changes in hydrological process caused by landscape pattern changes more comprehensively, thus providing theoretical basis for rational allocation of water resources, ecological environment protection and construction (Chicharo et al., 2015; Watson et al., 2006).

With the continuous development and innovation of computer technology and spatial information technology, distributed hydrological model has gradually become an important tool for effective simulation and analysis of the effect of land use variation on hydrological processes (Long et al., 2016; S. T. Zhang et al., 2016). Where Soil and Water Assessment Tool (SWAT) model has a strong physical basis as continuous distributed hydrological model, which can analyze and predict changes in runoff, sediment and non-point source pollution caused by land use changes and slope changes (Osei et al., 2019; Wei et al., 2018; H. Zhang et al., 2020). However, SWAT model homogenizes slope and spatial differences of land use, ignoring the effect of spatial changes in landscape patterns on hydrological processes, thus the effect of different land use on runoff and conflux regulation has been left out of consideration, and the relevant development of SWAT is lacking. (Neitsch et al., 2009; Tan et al., 2020). SWAT-VRR is a distributed hydrological model modified based on SWAT model to better show the effect of land use landscape change on hydrological processes in watershed (Wei et al., 2016). It considers the change in CN value of land use type with different slopes and forest runoff regulation in different slope zones, thus depicting hydrological characteristics of the study area more accurately.

The Qihe watershed with longitude between 110° 47’~111°15’E and latitude between 33°20’~33°49’N reservoir area was selected in a case study, and the applicability of SWAT-VRR was verified in this watershed firstly, then sets up two typical water-soil
conservation scenario simulations to analyze the response to the landscape pattern changes under this model, and evaluate the effect of different water-soil conservation methods on Qihe watershed through comparison of simulation results.

Methodology and data

Description of SWAT-VRR model

SWAT-VRR considers the change in CN value of land use type with different slopes and the effect of forest runoff regulation in different slope zones, thus the results are more accurately depicting hydrological characteristics of the study area.

Input data

(1) The DEM with 30 m resolution was provided by “National Science & Technology Infrastructure: National Earth System Science Data Sharing Infrastructure (http://www.geodata.cn/)”.

(2) The soil data, with 30 m resolution provides a database of all these soil properties, about 7 types of soils were classified by the genetic soil classification of China.

(3) The land use map: The map in 2005 (LUM) was constructed from digitizing the land use map (Figure 1).

According to the case with Qihe watershed as a source of Danjiang Reservoir and the requirements of Henan Provincial Land Use Master Plan (2006–2020), the study area is simulated as the following two land use scenarios for soil and water conservation:

- **Land Use Scenario 1 (LUS-1):** All land use types greater than 15° in Qihe watershed are set as forest land. (Figure 2)
- **Land Use Scenario 2 (LUS-2):** The 300 m forest riparian along the Qihe River is set as a buffer zone between forest and stream. (Figure 3)

(4) The climate data was derived from Henan meteorological Bureau for the period of 2000–2010, and the daily time series of stream flow observation data from 2000 to 2010 was derived from Xixia hydrologic station in Henan province.

CN weighted mean value ($\overline{CN}$)

The sub-basin CN weighted mean value ($\overline{CN}$) can reflect runoff generation and confluence of underlying surface of the sub-basin. The sub-basin $\overline{CN}$ formula is as follows:

$$\overline{CN} = \frac{\sum_{i=1}^{n} A_i \times CN_i}{A_{sub}}$$  

where $\overline{CN}$ is the sub-basin CN weighted average; $A_i$ is the sub-basin HRU area, km$^2$; $CN_i$ is the CN value of the HRU; $A_{sub}$ is the sub-basin area, km$^2$.

Results and discussion

Model setting and input data comparison

The SWAT-VRR model discretized Qihe watershed into 13 sub-basins, each sub-basin was divided into three slope grades consists of 0°~15°, 15°~25° and above 25°. The HRUs were derived with threshold levels of 0%, 15% and 0% for land use, soil types and slope, to ensure all attributes of land use and slope grades involved in computation and reduced the number of HRUs defined by the change of small areas of soil type. Respectively, SWAT-VRR resulted in a total of 390 HRUs comparing to 161 HRUs divided by SWAT model, and each CN value of HRUs has been recalculated in SWAT-VRR model.

Table 1 shows the HRU definition results in each sub-basin by using SWAT and SWAT-VRR. Large differences can be seen from the result of the two models. The number of HRUs in sub-basin divided by SWAT-VRR is greater than that of SWAT model. Table 1 also shows that sub-basins with smaller number difference of HRU are mainly located in the upper reaches of the watershed, and the minimum difference value is 10; sub-basins with greater number difference of HRU are mainly located in the middle and lower reaches of the watershed, and the maximum difference value is 27.

Further analysis reveals obvious difference between SWAT-VRR and SWAT in terms of $\overline{CN}$ value. The comparison of land use map (Figure 1) shows that, in SWAT model, $\overline{CN}$ value is obviously related to the proportion of forest area, the lower $\overline{CN}$ value in sub-basin with higher forest area and higher $\overline{CN}$ value in sub-basin with lower forest area. SWAT-VRR considers variation of CN value with different slopes. Although $\overline{CN}$ value will be lower for mountain forest with high coverage, CN value of forest land is increased owing to greater overall slope value of the area. Taking NO. 1 to NO. 8 sub-basis as an example, $\overline{CN}$ value of SWAT-VRR is higher than that of SWAT by more than 5. As slope and elevation gradually decrease, $\overline{CN}$ difference is obviously lower for the southern part of the watershed. The areas with difference value less than 4 are located in the downstream of Qihe watershed (e.g. NO. 9, 11, 12 sub-basins), and the minimum difference value is 2.01, which indicates that SWAT-VRR is very sensitive to slope variations and can provide better response to runoff generation and confluence characteristics on different slopes.
Stream flow simulation analysis

Stream flow for 2003–2004 at the outlet of the Qihe watershed was used to calibrate SWAT and SWAT-VRR model, and the observed data for 2005–2006 were used for model validation. In order to compare the sensitivities of the two models in runoff simulation, same parameter set (except CN) was used to calibrate both models. The Nash-sutcliffe efficiency ($E_{ns}$) was applied to assess the performance of the models in simulating stream flow.

Table 2 demonstrates the results of model calibration and validation by using stream flow data, the $E_{ns}$ values in monthly and yearly simulation are all above 0.75, which satisfies the accuracy requirements of the model simulation (Abdelwahab et al., 2018). The $E_{ns}$ values of daily simulation results are all greater than 0.6, and the effect is relatively good. The results suggest that the SWAT-VRR model is capable for simulating runoff responses to changes of land use variability during calibration and validation periods in Qihe watershed.
In terms of annual runoff simulation, both SWAT and SWAT-VRR can accurately simulate annual runoff changes in calibration and validation periods, the difference between the two models is small. It is because average annual runoff smoothes hydrological process, then runoff generation and confluence characteristics in different periods cannot be accurately reflected. Compared with annual runoff simulation, monthly runoff simulation of SWAT-VRR has more significantly increased than that of SWAT, with Ens values in calibration and validation periods increased from 0.75 and 0.77 to 0.78 and 0.80, respectively. In terms of daily runoff simulation, SWAT-VRR has a better simulation effect in calibration and validation periods as compared to SWAT model. Although all Ens are not optimal (Ens > 0.75), Ens values are, respectively, increased from 0.63 and 0.67 to 0.69 and 0.72 with obvious range, exhibiting good daily simulation effect.

**Scenario simulation analysis**

Table 3 shows annual runoff results of Qihe watershed in 2005 and 2006 obtained by simulating LUS-1 and
LUS-2 using SWAT-VRR under the premise that other conditions remain the same. It can be seen that the simulation results based on LUS-2 are smaller than those based on LUS-1, regardless of annual runoff or rainy season runoff. Combining Figures 2 and 3, it can be concluded that although LUS-2 has lower proportion of forest area than LUS-1, the water-soil conservation effect achieved by constructing a 300 m riparian is significantly higher than that achieved by constructing forest land for all areas above 15°.

Figure 4 illustrates the difference in monthly water yield between LUM and LUS-1 in 2005 and 2006 from June to August. The difference in sub-basin water yield gradually increases from north to south. However, water yield difference between No. 2 and No. 11 sub-basins is significantly smaller than that of the surrounding sub-basins, and the difference is more pronounced as rainfall increases. Analysis of the proportion of forest in sub-basins reveals that, for No. 2 sub-basin, as the areas above 15° are almost forest originally, the increase is particularly small, so the water yield variation is very limited. For No. 11 sub-basin, as the area above 15° is very small, the difference is also not high. With the changes in...
monthly rainfall, sub-basins show different variation trends in water yield difference, indicating the instability of water-soil conservation effect. Figure 5 illustrates the difference in monthly water yield between LUM and LUS-2 in 2005 and 2006 from June to August. The sub-basin water yield difference gradually increases from north to south, and that between NO. 9, 11, 12, and 13 sub-basins is the highest. Such a trend shows strong stability with the increase of rainfall. Therefore, compared with the two land use scenarios, the 300 m forest riparian along the Qihe River can adjust the runoff more effectively than the area greater than 15° is forest, and the LUS-2 show a strong stability in water-soil conservation effect during different rainfall.

Conclusion

This paper selected Qihe watershed in the Danjiangkou reservoir area as an example, first verified the applicability of SWAT-VRR, then set up two typical water-soil conservation scenario simulations to analyze the response to the landscape pattern changes under this model, and evaluated the effect of different water-soil conservation methods on Qihe watershed through comparison of simulation results. The conclusions are as follows:

With the application of SWAT-VRR model, the Qihe watershed was divided into three slope grades in each sub-basin and the CN value of each land use type was renewed; the water yield in monthly temporal

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**Table 1.** HRU definition and CN of SWAT and SWAT-VRR model.

| Sub-basin | SWAT-HRU | HRU differences | SWAT-CN | SWAT-VRR-CN | CN differences |
|-----------|----------|----------------|---------|-------------|----------------|
| 1         | 28       | 11             | 17      | 49.02       | 55.9           | 6.88           |
| 2         | 30       | 13             | 17      | 48.2        | 54.92          | 6.72           |
| 3         | 19       | 7              | 12      | 49.3        | 55.33          | 6.03           |
| 4         | 16       | 6              | 10      | 49.8        | 56.26          | 6.46           |
| 5         | 27       | 10             | 17      | 49.3        | 55.36          | 6.06           |
| 6         | 26       | 11             | 15      | 51.1        | 57.61          | 6.51           |
| 7         | 30       | 13             | 17      | 54.1        | 59.63          | 5.53           |
| 8         | 41       | 15             | 26      | 48.6        | 53.67          | 5.07           |
| 9         | 23       | 13             | 10      | 62.5        | 64.51          | 2.01           |
| 10        | 44       | 17             | 27      | 48.2        | 52.83          | 4.63           |
| 11        | 32       | 14             | 18      | 60.8        | 63.25          | 2.45           |
| 12        | 36       | 16             | 20      | 56.6        | 59.29          | 2.69           |
| 13        | 38       | 15             | 23      | 50.7        | 54.68          | 3.98           |

**Table 2.** Evaluation (Ens) of model simulation results.

| Model | Calibration (2003–2004) | Validation (2005–2006) |
|-------|-------------------------|------------------------|
|       | Year | Month | Day | Year | Month | Day |
| SWAT  | 0.85 | 0.75  | 0.63 | 0.87 | 0.77  | 0.67 |
| SWAT-VRR | 0.89 | 0.78  | 0.69 | 0.88 | 0.80  | 0.72 |

**Table 3.** The flow results of SWAT-VRR based on different land use map.

| Year   | Period  | Precipitation (mm) | LUM (m³/s) | LUS-1 (m³/s) | LUS-2 (m³/s) |
|--------|---------|--------------------|------------|--------------|--------------|
| 2005   | Whole year | 886               | 8.65       | 8.51         | 8.35         |
|        | June    | 101               | 7.27       | 7.01         | 6.89         |
|        | July    | 229               | 25.87      | 25.16        | 24.83        |
|        | August  | 151               | 18.29      | 18.08        | 17.95        |
| 2006   | Whole year | 559               | 3.67       | 3.61         | 3.53         |
|        | June    | 187               | 8.16       | 8.01         | 7.92         |
|        | July    | 178               | 17.79      | 17.34        | 17.15        |
|        | August  | 924               | 15.5       | 15.21        | 15.07        |

**Figure 4.** The difference of monthly water yield between LUM and LUS-1 in 2005 and 2006.

**Figure 5.** The difference of monthly water yield between LUM and LUS-2 in 2005 and 2006.
scales were simulated to compare the results created by SWAT model and SWAT-VRR model. The results indicate that, the SWAT-VRR model achieved a notable improvement in monthly and daily hydrological simulation comparing to the SWAT model simulation during 2003 to 2006, the more fragment the landscape is, the higher precision the SWAT-VRR simulates. Two typical water-soil conservation scenarios were set up and simulated by SWAT-VRR. The results show that the 300 m forest riparian along the Qihe river can more effectively regulate runoff in different rainfall periods and give full play to forest land role in water-soil conservation.

In conclusion, the SWAT-VRR can simulate the effect of land use landscape changes on hydrological processes under different rainfall conditions more accurately, which provides a more accurate scientific basis for further exploration into rational allocation of land use, prediction of water-soil loss and non-point source pollution trends, as well as sustainable use of water resources and integrated river basin management in the Danjiangkou reservoir area, thus guaranteeing water safety of Middle Route of South-to-North Water Transfer Project.

Disclosure statement
No potential conflict of interest was reported by the authors.

Funding
This work is partially supported by the National Key Research Priorities Program of China [2016YFC0402402], Henan Colleges and Universities Key Scientific Research Project [18A170009], Scientific Research Foundation for High-level Personnel of North China University of Water Resources and Electric Power [40480], Water Conservancy Science and Technology Project of Henan province [GG201805].

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