RUNOFF AND SEDIMENT YIELD VARIATIONS UNDER DIFFERENT PRECIPITATION CONDITION AND LAND-USE TYPE: A CASE STUDY OF FANGXI WATERSHED IN THE POYANG LAKE BASIN, CHINA

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Abstract. A research was conducted on runoff and sediment yield variations under different precipitation and land-use conditions was performed based on the Soil and Water Assessment Too1 (SWAT) model using China Meteorological Assimilation Driving Datasets (CMADS). The observation data was collected in the Fangxi Lake Watershed, a typical irrigation district in the Poyang Lake basin of China. The results indicated a positive correlation between annual runoff and precipitation, as well as between annual sediment yield and precipitation. The correlation coefficient of annual runoff yield and precipitation was 0.94, whereas that of annual sediment yield and precipitation was 0.85. The monthly yield of runoff and sediment of a typical year (2004) was simulated. The runoff and sediment yields had the same tendency of changes with precipitation variations. Differences were found among the per unit area yield of total runoff from different land-use types in 2004. The order from highest to lowest was paddy land > rural residential land > dry land > water area. For the per unit area yield of total sediment from different land-use types, the order from highest to lowest was rural residential land > dry land > water area > paddy land. The results of this study might provide guidance for soil erosion control in irrigation districts.
Keywords: *land-use, precipitation, runoff and sediment yield, SWAT model, CMADS*

Introduction

The Soil and Water Assessment Too1 (SWAT) model is one of the distributed hydrological models. It is a physically based model developed by the Blackland Research and Extension Center and the United States Department of Agriculture – Agricultural Research Service to predict the effect of land management practices on water, sediment, and agricultural chemical yields in large, complex basins with varying soil types, land use, and management conditions over long periods of time (Gassman et al., 2007). The SWAT model can respond to the changes in land use, weather, topography, and soil data. The effectiveness and applicability of this model has been validated by numerous studies worldwide (Binh et al., 2011; Daggupati et al., 2018; Hao and Cheng, 2006; Himanshu et al., 2017; Koua et al., 2013; Lam et al., 2010; Loliyana and Patel, 2018; Santhi et al., 2006; Zettam et al., 2017).

Runoff and sediment simulation is one of the most basic and important functions of SWAT model. The SWAT model has been improved by numerous investigators by combining it with the local watershed. Some researchers demonstrated the applicability

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of SWAT model for runoff and sediment simulation under different temporal and spatial scales and different hydrogeological conditions in the Mississippi River basin and other river basins in the United States (Arnold et al., 1999; Green and Griensven, 2008). Several studies analyzed different aspects of SWAT model simulation, such as the correlation between runoff and precipitation and the impact of land use on sediment and non-point source pollution in other countries and districts (Bärlund and Kirkkala, 2008; Di Luzio et al., 2005; Lee and Kim, 2017; Min and Shibata, 2016; Panagopoulos et al., 2011; Weber et al., 2001).

Most of the studies were based on a natural watershed. However, huge differences were found between irrigation district and natural watershed on account of intensive human activities on land cover and hydrological cycle system in irrigation districts. The SWAT model has been improved with the practical situation of irrigation district to enhance the simulation accuracy. Some researchers (Dai and Cui, 2009a, b; Dechmi et al., 2012; Li et al., 2014) improved the SWAT model based on specific irrigated watershed considering the water cycle in paddy land, irrigation, and drainage management, and other irrigation channel management actions. The results indicated that the improved SWAT model could show more accurate and better simulation performance than the original SWAT model.

Although the SWAT model has been widely used across the world, it is difficult to apply in areas where meteorological data are scarce (Meng et al., 2018). Therefore, the meteorological data is needed for runoff and sediment simulation in a watershed with scarce data (Meng et al., 2016). The China Meteorological Assimilation Driving Datasets for the SWAT model was developed by Meng from the China Institute of Water Resources and Hydropower Research (IWHR). It covers the entire East Asian region between 2008 and 2014 (Meng and Wang, 2017). Some studies demonstrated that the SWAT model yielded better results for runoff simulation with CMADS (Liu et al., 2017, 2018). Meng et al. also used three different datasets to simulate runoff in the Heihe basin, and the results indicated that the simulation accuracy of the CMADS was higher than that of other datasets (Meng et al., 2016).

The SWAT model and CMADS data were used in the present study to simulate the runoff and sediment yield under different precipitation and land-use conditions in the study area, a small irrigated plain district of Poyang Lake region. The correlation between runoff and precipitation, as well as between sediment and precipitation, was investigated. In addition, the diversities of runoff yield and sediment yield from different land-use types were simulated and analyzed. The results obtained in this study might provide guidance for soil and water conservation and land-use management of the study area as well as other irrigation districts of Poyang Lake region.

Materials and methods

Study area

The Fangxi Lake Watershed is located in the southwestern region of Poyang Lake basin, which is in the southeastern of China, between 116°0’E and 116°5’E and between 28°29’N and 28°33’N, covering an area of 3080.20 ha (*Fig. 1*). The Fangxi Lake Watershed features a subtropical monsoon climate and has four distinct seasons, where summers are warm with abundant precipitation whereas winters are cold and dry with little precipitation. The multi-year average precipitation is 1624.4 mm per year, and the annual rainy days are about 147.3 days. The annual average temperature is 17.6 °C.

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The main soil type in this watershed is paddy clayey soil, which occupies 90.69% of the total area. It includes three subclasses: yellow clayey soil (76.52%), lake clayey soil (12.38%), and sand clayey soil (1.79%). The main land-use types in the study area are paddy land (79.27%), water area (12.63%), rural residential land (6.11%), dry land (1.71%), forest and grass land (0.24%), and bare land (0.04%). The main crop is rice and the double-cropping paddy area occupies approximately 95% of the total cultivated area. Other crops include watermelon, muskmelon, garlic, and fragrant-flowered garlic.

The area has 17,404 permanent residents, and the main types of livestock and poultry industry are ducks, chickens, pigs, cattle, and sheep. Aquaculture is highly developed because of its abundant water resources in this area. The aquaculture area occupies 30% of the water area.

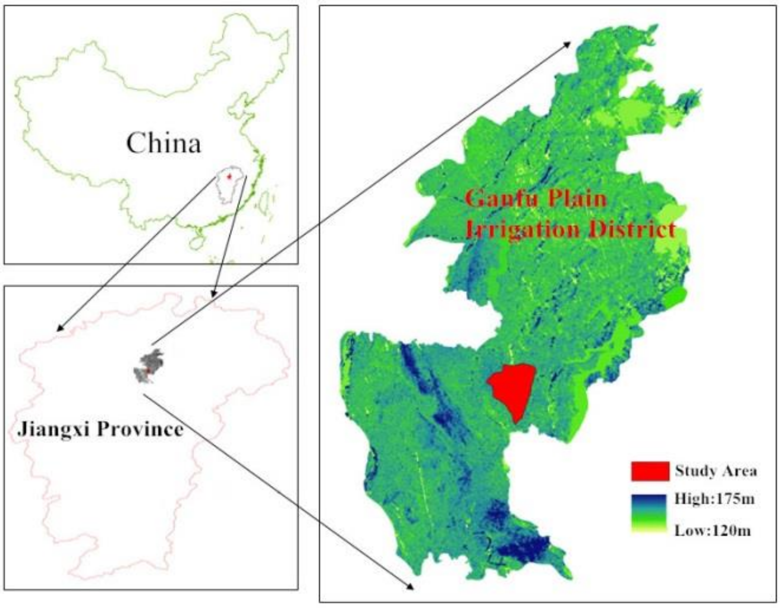

Figure 1. *Location of the study area*

Data collection

The distributed model based on the SWAT model requires spatial and attribute data. Furthermore, the spatial data includes digital elevation model (DEM), water distribution map, and land-use and soil maps. The attribute data includes the physical and chemical properties of soil, meteorological and hydrological information (including rainfall, temperature, wind speed, relative humidity, and net solar radiation.), observed runoff, and farmland management measures. The sources and main types of data collected are shown in *Table 1*. The DEM, land-use map, and soil maps are shown in *Figure 2a-c.*

The simulation accuracy of SWAT model depends largely on the description of the watershed characteristics of the input data. For runoff and sediment simulation, high-precision meteorological data can accurately describe the meteorological characteristics of the watershed and lead to better simulation results (Chen et al., 2016). Only one precipitation station exists near the study area. The China Meteorological Assimilation Driving Datasets for the SWAT model version 1.1 (CMADS V1.1) was introduced in this study to get the entire meteorological data for the study area. The climate data used in this study were downloaded from the official website (http://www.cmads.org).

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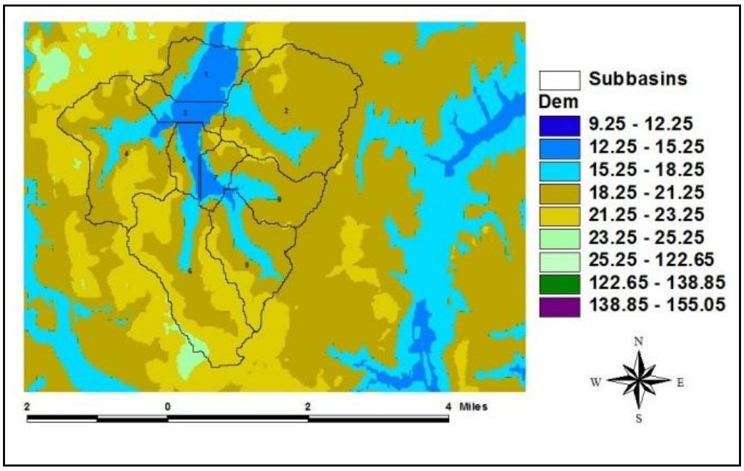

Figure 2a. *DEM of the study area*

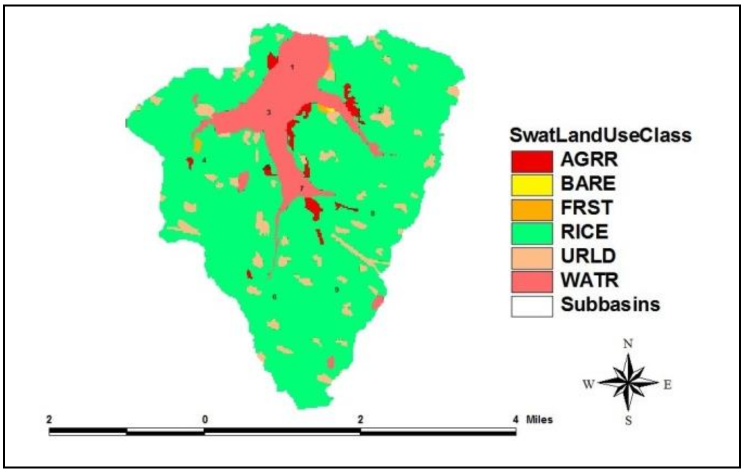

Figure 2b. *Land-use map of the study area (AGRR is dry land, BARE is bare land, FRST is forest and grass land, RICE is paddy land, URLD is rural residential land, and WATR is water area)*

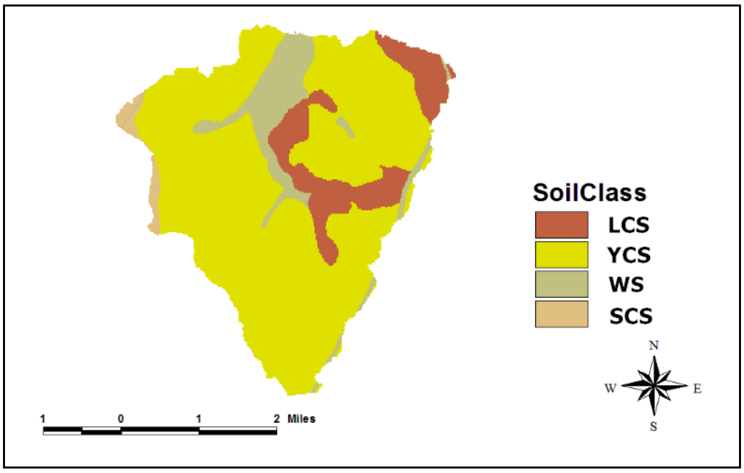

Figure 2c. *Soil map of the study area (LCS is lake clayey soil, YCS is yellow clayey soil, WS is water surface, and SCS is sand clayey soil)*

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Table 1. *Sources and types of data collected for the SWAT model*

No.	Data type		Temporal/spatial resolution	Source
1	Spatial data	Digital elevation model (DEM), 25 m	Grid format, 30 m/grid	Geospatial Data Cloud of China (http://www.gscloud.cn/)
2		Water distribution map	Shape format	Drawn by the authors of this manuscript based on the water distribution of the study area
3		Soil map	At the scale of 1:100,000, compiled in 2009	Nanchang County Agricultural Bureau
4		Land-use map	At the scale of 1:100,000, compiled in 2009	Computer Network Information Center of Chinese Academy of Science (http://www.cnic.cas.cn)
5	Attribute data	Meteorological data, daily	Daily data	China Meteorological Assimilation Driving Datasets for the SWAT Model (CMADS) (calculated temperature, solar, wind data between 2008 and 2014), Jiangxi Irrigation Experimental Center (observed precipitation data between January 1, 1978 and November 30, 2011)
6		Hydrological data	Daily runoff yield	Jiangxi Irrigation Experimental Center (observed data between May to October in 2011)
7		Farmland management measures	Daily data during crop growth period	Field investigation based on the study area (observed data in 2011)

The farmland management measures are also important information for runoff and sediment yield research in the study area. Double-cropping rice is cultivated in most of the study area. The growing period of early rice is April to July and that of late rice is July to October. Irrigation and drainage measures of double-cropping rice are gained by farm surveys. The surveyed data are shown in *Table 2*.

Table 2. *Irrigation and drainage measures*

	Date	Measures
Early rice	April 14	Irrigation, 50 mm
	April 23	Irrigation, 50 mm
	May 18	Drainage
	May 22	Irrigation, 50 mm
	July 6	Drainage
Late rice	July 18	Irrigation, 50 mm
	July 26	Irrigation, 50 mm
	July 31	Irrigation, 50 mm
	August 7	Irrigation, 50 mm
	August 19	Drainage
	September 3	Irrigation, 50 mm
	September 21	Irrigation, 50 mm
	October 31	Drainage

All data were prepared for the model setup

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SWAT model setup

Model construction

In this study, the spatial data in *Table 1* were loaded into the SWAT model, and the distributed hydrological model based on the study area was constructed. Nine sub-basins were calculated based on the DEM and river network distribution of the study area, and then 51 hydrological response units (HRUs) were subdivided based on the spatial distribution of the land-use type, soil type, and slope. The results are shown in *Figure 3* and *Table 3*.

The meteorological data were loaded into the SWAT model after HRU subdivision. Then, a distributed hydrological model based on the SWAT model was constructed in the study area.

Table 3. *Area of sub-basins and HRUs in the study area*

Sub-basins	Number of HRUs	Area (ha)	Area percentage (%)
1	4	253.59	8.23
2	8	685.23	22.25
3	6	122.63	3.98
4	6	571.78	18.56
5	7	127.43	4.14
6	2	623.55	20.24
7	10	105.14	3.41
8	5	232.73	7.56
9	3	358.12	11.63
Total	**51**	**3080.20**	**100**

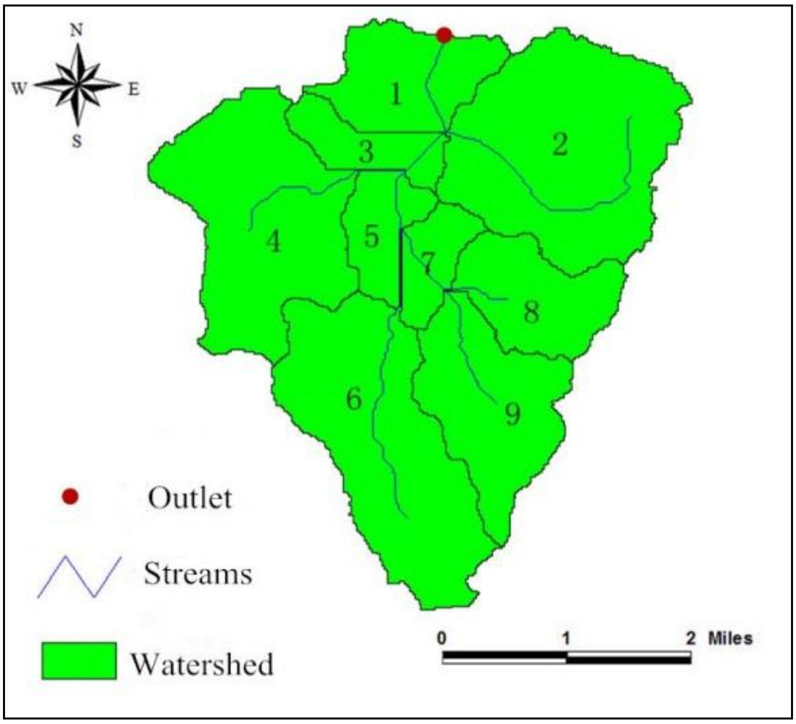

Figure 3. *Sub-basins of the study area*

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Model calibration and evaluation

Model calibration was based on the optimization of the parameter values by adjusting the simulated runoff and sediment yield data at the outlet of the basin with observed data. That is to say, the parameters of runoff and sediment yield in the SWAT model were adjusted to a reasonable range to get accurate simulation results in this study.

Some parameters called sensitive parameters can have an evident impact on the results of model simulation. These parameters were adjusted to a reasonable value for better simulation results. On the basis of some studies on the sensitivity analysis of SWAT model (Me et al., 2015; Yang et al., 2013), the main sensitive parameters of runoff and sediment yield adjusted in this study are shown in *Table 4*.

Table 4. *Main parameters of runoff and sediment yield in the SWAT model*

	Parameter	**Description**
Runoff parameter	CN_2	SCS runoff curve calculating parameter
	ESCO	Soil evaporation compensation coefficient
	EPCO	Crop transpiration compensation coefficient
	SOL-AWC	Soil available water capacity
	REVAPMN	Water table threshold for shallow groundwater re-evaporation
	GW-REVAP	Groundwater re-evaporation coefficient
	GWQMN	Runoff coefficient of shallow groundwater
Sediment parameter	USLE_C	Minimum value of vegetation coverage factor
	USLE_P	Soil and water conservation factor of USLE equation
	USLE_K	Soil erosion coefficient of USLE equation
	CH_EROD	Channel scour coefficient
	CH_COV	Channel coverage coefficient
	SPCON	Linear coefficient of sediment transport
	SPEXP	Index coefficient of sediment transport

The relative error (R_e), correlation coefficient (R^2), and Nash–Sutcliffe efficiency (Ens) were used to evaluate the model performance. The formulas used for calculating these indexes are as follows:

$$R_e = \frac{Q_p - Q_0}{Q_0} \times 100\% \qquad \text{(Eq.1)}$$

$$R^2 = \left[\frac{\sum_{i=1}^{n} (Q_0 - \overline{Q_0})(Q_P - \overline{Q_P})}{\sqrt{\sum_{i=1}^{n} (Q_0 - \overline{Q_0})^2 \sum_{i=1}^{n} (Q_P - \overline{Q_P})^2}} \right]^2 \qquad \text{(Eq.2)}$$

$$Ens = 1 - \frac{\sum_{i=1}^{n} (Q_0 - Q_P)^2}{\sum_{i=1}^{n} (Q_0 - \overline{Q_0})^2} \qquad \text{(Eq.3)}$$

where Q_p is the simulation value, $\overline{Q_P}$ is the average simulation value, Q_0 is the observed value, $\overline{Q_0}$ is the average observed value, and n is the number of observed data. The

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evaluation standard indexes of model simulation efficiency are shown in *Table 5*. Generally, the model performances are identified to be good enough to apply in actual numerical simulation if R_e < 10%, R^2 > 0.79, and Ens > 0.59.

Table 5. *Evaluation standard of model simulation efficiency*

Standard	**Relative error (R_e, %)**	**Correlation coefficient (R^2)**	**Nash–Sutcliffe efficiency (*Ens*)**
Excellent	–5 to + 5	1.00–0.95	1.00–0.80
Good	± 5 to ± 10	0.94–0.80	0.79–0.60
Medium	± 10 to ± 20	0.79–0.70	0.59–0.40
Awful	> 20 or < –20	< 0.70	< 0.40

For runoff parameters, the observed runoff data at the outlet of the study area from May to October 2011 were used for model calibration and evaluation. Especially, the meteorological data of CMADS were used for model simulation to increase the accuracy of model simulation. In addition, the daily runoff data during the period 2008–2011 were simulated, choosing 2008–2010 as the warm-up period of SWAT model simulation. Some studies showed that the warm-up could make better simulation results for SWAT model simulation (Li et al., 2013; Nyeko, 2015; Wang et al., 2017, 2015). *Figure 4* shows the comparisons between the observed and simulated runoff yield of the study area outlet during the model calibration and validation period. *Table 6* shows the performance of SWAT model during the calibration and validation periods. The optimum values of the calibrated runoff parameters are shown in *Table 7*.

Table 6. *Evaluation standard of model simulation efficiency*

	Re (%)	***R^2***	***Ens***
Calibration period	15.5	0.88	0.74
Validation period	12.4	0.90	0.78

Table 7. *Optimum value of calibrated runoff parameters for the SWAT model*

Name	**Paddy land**	**Dry land**	**Rural residential land**	**Bare land**	**Grass land**
CN2	70	85	86	90	78
ESCO	0.3	0.6	0.7	0.5	0.5
EPCO	0.7	0.8	0.5	0.5	0.8
SOL-AWC	0.18	0.13	0.14	0.16	0.18
REVAPMN	450	450	450	450	450
GW-REVAP	0.2	0.2	0.2	0.2	0.2
GWQMN	1	1	1	1	1

For sediment parameters, the model was calibrated by experience according to the related studies due to the lack of observed data (Qiu et al., 2012; Wang and Cui, 2011; Xu et al., 2008; Zhang et al., 2003). The optimum value of the calibrated sediment parameters is shown in *Table 8*.

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Table 8. *Optimum value of calibrated sediment parameters for the SWAT model*

Name	USLE_C	USLE_P	USLE_K	CH_EROD	CH_COV	SPCON	SPEXP
Value	0.5	0.2	0.15	0.15	0.6	0.005	1.2

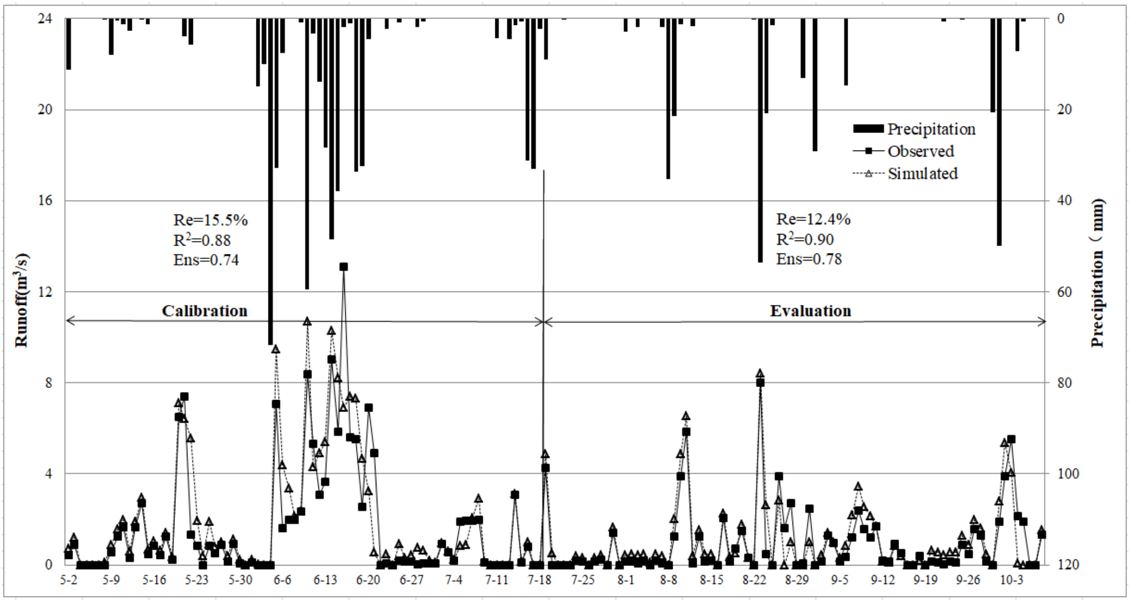

Figure 4. *Comparisons between the observed and simulated daily runoff during the calibration and validation period*

The SWAT model simulated value reflected the actual changes in the runoff yield, and the SWAT model could be used for runoff simulation in the study area. Hence, the distributed hydrological model of the study area based on the SWAT model was successfully constructed.

Results

Runoff and sediment yield variations in response to precipitation

Statistical analysis of precipitation data

In this study, the annual precipitation data of the study area during 1978–2010 were used for frequency calculation and the characteristic hydrological years were identified. The empirical frequency is calculated using the equation as follows:

$$P = \frac{m}{n+1} \quad \text{(Eq.4)}$$

where P is the empirical frequency of the annual precipitation of a particular year, m is the number in order from largest to smallest of the precipitation (*Table 9*), n is the total number of annual precipitation data.

Table 9 shows the precipitation and the result of empirical frequency calculation. As shown in *Table 9*, the multi-year average precipitation was 1523.19 mm.

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Table 9. *Precipitation and the result of frequency calculation*

Year	Precipitation (mm)	No.	Frequency (P, %)	Year	Precipitation (mm)	No.	Frequency (P, %)
2010	2317	1	2.94	1997	1468.2	18	52.94
1995	2296	2	5.88	2001	1459.9	19	55.88
2002	2120.1	3	8.82	1992	1404.8	20	58.82
2005	2063.5	4	11.76	1989	1400.3	21	61.76
1999	1884.4	5	14.71	1987	1376.6	22	64.71
2006	1856.4	6	17.65	2008	1362.9	23	67.65
1993	1784.3	7	20.59	1996	1342.4	24	70.59
1998	1748.1	8	23.53	1979	1295.3	25	73.53
2003	1720.6	9	26.47	1985	1241.2	26	76.47
2000	1680.1	10	29.41	1990	1228.2	27	79.41
1983	1670.7	11	32.35	1988	1221.9	28	82.35
1980	1583.7	12	35.29	1986	1211.8	29	85.29
1994	1517.2	13	38.24	2009	1086.1	30	88.24
1984	1501.2	14	41.18	2007	1045.3	31	91.18
2004	1485	15	44.12	1978	986.9	32	94.12
1981	1483.4	16	47.06	1991	940.9	33	97.06
1982	1481	17	50.00	Average	1523.19	Cv	0.23

The variation coefficient and ocular estimation method was used to draw theoretical frequency curve of the annual precipitation data, the best-fitted theoretical frequency curve was drawn when the coefficient of variation (Cv) was 0.23, as shown in *Figure 5*. The characteristic hydrological years were chosen with the frequency of 5%, 20%, 50%, 70%, and 95% according to the theoretical frequency curve. According to *Table 1*, the soil map and land-use map were compiled in 2009, so 2002 (8.82%), 2006 (17.65%), 2004 (44.12%), 2008 (67.65%), and 2009 (88.24%) were chosen as the corresponding years, which are close to 2009 and will decrease the impact of land-use and soil change on simulation results in SWAT model.

Analysis of runoff and sediment variation response to precipitation change

At first, the annual yield of runoff and sediment of characteristic hydrological years was analyzed. The results are shown in *Table 10* and *Figure 6*. The runoff and sediment yields increased with an increase in precipitation. The correlation coefficient of runoff yield and precipitation was 0.94, whereas that of the sediment yield and precipitation was 0.85. Hence, a strong positive correlation was observed between the runoff yield and precipitation, as well as between sediment yield and precipitation.

Table 10. *Precipitation and the result of frequency calculation*

Year	2002	2006	2004	2008	2009
P (%)	5	20	50	70	95
Precipitation (mm)	2120.1	1856.4	1485	1362.9	1086.1
Runoff ($m^3 s^{-1}$)	1.90	1.76	1.22	1.28	1.09
Sediment (ta^{-1})	438.02	490.47	291.04	267.93	207.93

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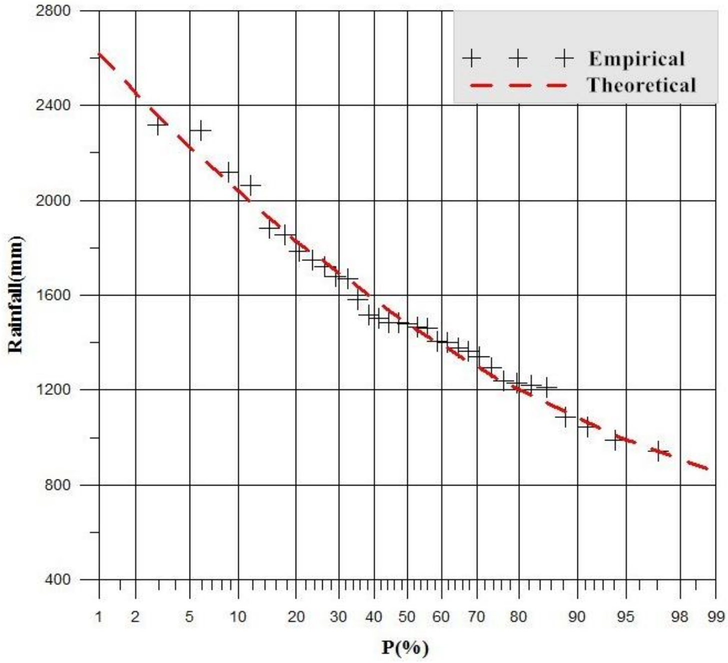


Figure 5. *Theoretical frequency curve of precipitation*

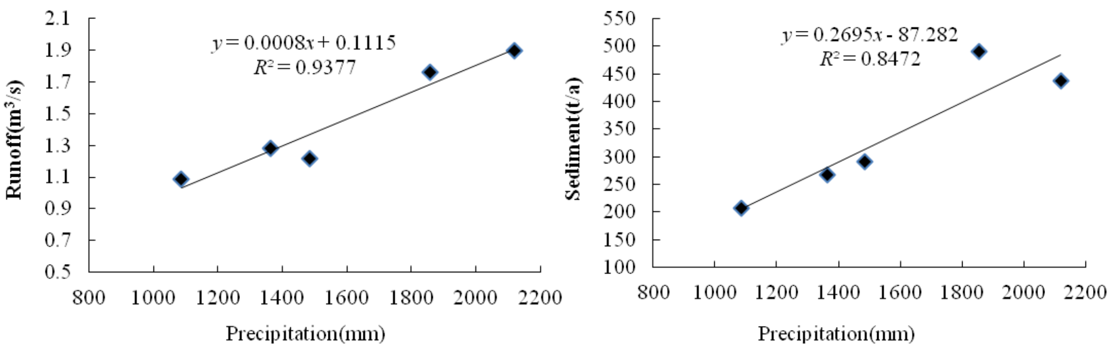
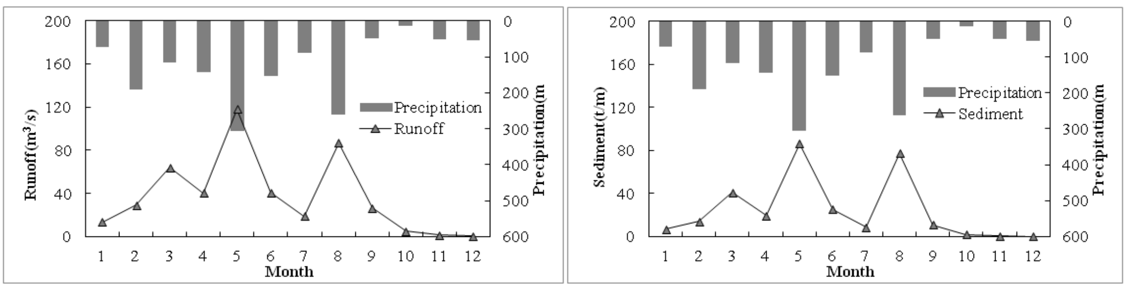


Figure 6. *Correlation diagram of runoff and precipitation, as well as sediment and precipitation*

Then, 2004 was chosen as the typical year (P = 50%), and the monthly yield of runoff and sediment were simulated. The results are shown in *Figure 7*. The runoff and sediment had the same tendency of changes with precipitation variation.



(a) (b)

Figure 7. *Monthly runoff and sediment variation response to precipitation changes*

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Runoff and sediment yield under different land use type

During sub-basin calculation, the land-use area threshold setting method was used to reduce the calculation amount of SWAT model and the HRU amount of the study area. Therefore, the land-use type was readjusted to another type if the area percentage was less than the area threshold. In this study, 1% was used as the land-use area threshold. The changes in the land-use area before and after HRU calculation are shown in *Table 11*.

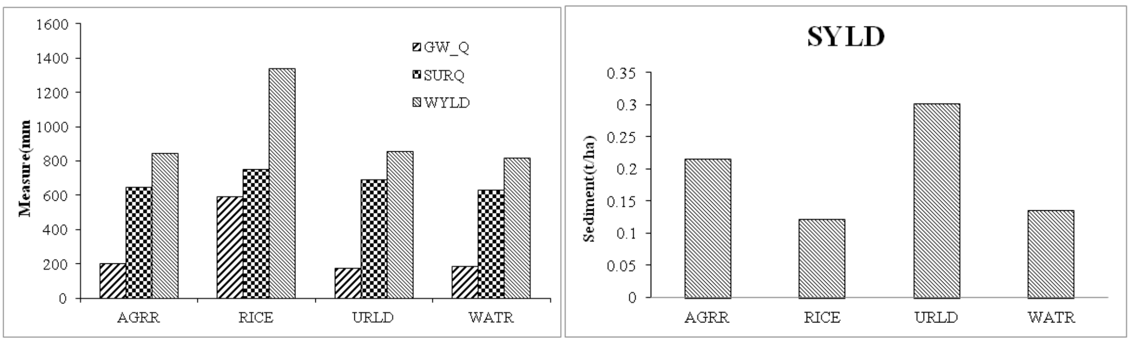
Table 11. *Land-use area changes before and after HRU calculation*

Type	Before		After	
	Area (ha)	**Percentage (%)**	**Area (ha)**	**Percentage (%)**
AGRR (dry land)	52.67	1.71	73.30	2.38
RICE (paddy land)	2441.67	79.27	2442.60	79.30
URLD (rural residential land)	188.20	6.11	186.40	6.05
WATR (water area)	389.03	12.63	377.90	12.27
FRST (forest and grass land)	7.39	0.24	0	0
BARE (bare land)	1.23	0.04	0	0
Total	3080.20	100	3080.20	100

Then, the per unit area yield of runoff and sediment of different land-use types in 2004 was calculated. The results are shown in *Figure 8*.

As illustrated in *Figure 8a*, the order of per unit area yield of total runoff from high to low was paddy land, rural residential land, dry land, and water area. Specially, the total yield from paddy land was much more than that from other land-use types in the study area. Likewise, the ground water runoff from paddy land was also much more than that from other land-use types in the study area. Further, the surface runoff yields from different land-use types were almost the same.

As illustrated in *Figure 8b*, the order of sediment yield from high to low was rural residential land, dry land, water area, and paddy land.



(a) (b)

Figure 8. *Runoff and sediment yield of per unit area from different land-use types in 2004.* ***a*** *Per unit area yield of runoff (GW_Q is groundwater, SURQ is surface runoff, WYLD is total runoff).* ***b*** *Per unit area yield of sediment (SYLD is total yield of sediment)*

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Discussion

Based on the SWAT model with CMADS data, observed data from Jiangxi Irrigation Experimental Center, and field observation, the distributed hydrological model of the study area was constructed and the runoff and sediment yield variations under different precipitation and land-use conditions were simulated and analyzed.

For model calibration and evaluation, the observed runoff yield data were used to finish runoff parameter calibration. The sediment yield parameters were calibrated based on the results of other studies in different study areas due to the lack of observed data. For further study, the sediment simulation would be more accurate if the observed sediment data in the study area are used for model calibration.

At first, the observed annual precipitation data from 1978 to 2011 were used to finish frequency calculation and characteristic hydrological year identification. The runoff yield and sediment yield of characteristic hydrological years were simulated. A strong positive correlation was observed between the annual runoff yield and annual precipitation, as well as between sediment yield and precipitation, such results are also available from other studies (Li and Gao, 2015; Ruan et al., 2017; Zhu et al., 2015).

Then, 2004 was chosen as the typical year (50%), and the monthly yield of runoff and sediment was simulated. Runoff and sediment had the same tendency of changes with precipitation variation. Specifically, a small spike for runoff, as well as for sediment, was observed in March with the decrease in precipitation, while a sharp decrease appeared in April with a relatively high increase in precipitation. That is to say, precipitation variation was not the only influencing factor for runoff and sediment changes. Several studies explored the influencing factors for runoff and sediment yield in different watersheds around the world (Jiang et al., 2008; Nguyen et al., 2017; Perry, 2015; Tong et al., 2018; Xiang et al., 2012; Alibuyog et al., 2009). Some other studies also indicated that the land-use type was one of the most important influencing factors for runoff and sediment yield variation (Gyamfi et al., 2016; Huang and Lo, 2015; Zhang et al., 2010).

In this study, the per unit area yields of runoff and sediment in 2004 of different land-use types were calculated.

The total runoff, surface runoff, and ground water runoff yield of different land-use types were analyzed. No significant difference was found in surface runoff yields from different land-use types. However, the underground runoff yields from different land-use types varied greatly. The ground water runoff from paddy land was also much more than that from other land-use types in the study area. This might be attributed to the fact that the paddy land is irrigated during the growing period of double-cropping rice, and the underground water maintains a relatively high level for a long time. Therefore, it is not comprehensive to only consider the surface runoff in the simulation of watershed runoff. The difference between surface runoff and subsurface runoff may increase, and hence the change and difference in runoff can be assessed from the time and space scale in the future studies.

The order of per unit area yield of total sediment from high to low was rural residential land, dry land, water area, and paddy land. The sediment yields from the rural residential land and dry land were much more than that from paddy land and water area. Thus, the rural residential land and dry land should be the major focus of soil erosion control and soil conservation.

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Conclusions

A distributed hydrological model was constructed in this study based on the SWAT model with CMADS data in the Fangxi Lake Watershed, a typical irrigation district in the Poyang Lake basin. The SWAT model was calibrated with observed runoff data. The results showed that the model was accurate enough for runoff and sediment yield simulation in the study area.

The runoff and sediment yield variations under different precipitation and land-use conditions were analyzed. The correlation coefficient of annual runoff yield and precipitation was 0.94, whereas that of annual sediment yield and precipitation was 0.85. Therefore, a positive correlation was observed between the annual runoff yield and precipitation, as well as between annual sediment yield and precipitation. When the monthly yield of runoff and sediment of typical year (2004) was simulated, the runoff and sediment yields had the same tendency of changes with precipitation variations. Then, the per unit area yield of runoff and sediment of different land-use types in 2004 was calculated. The order of per unit area yield of total runoff from high to low was paddy land, rural residential land, dry land, and water area. The order of per unit area yield of total sediment from high to low was rural residential land, dry land, water area, and paddy land. These findings figured out that the rural residential land and dry land are the main source of soil erosion.

However, several limitations in this study merit further research and investigation. The space distribution law of runoff and sediment should be taken into consideration in further studies. In addition, the transfer law of underground runoff and sediment in underground water under different rainfall and land-use conditions should be the focus of these studies.

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