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# Sediment Yield Modeling Using SWAT Model: Case of Changjiang River Basin

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# Sediment Yield Modeling Using SWAT Model: Case of Changjiang River Basin

**Yao Liu and Hui Jiang**

National and Local Joint Engineering Laboratory of Hydraulic Engineering Safety and Efficient Utilization of Water Resources in Poyang Lake Basin, Nanchang Institute of Technology, NanChang 330099, China
Hui Jiang, jnhuily@163.com

**Abstract.** Soil erosion is posing a severe challenge to the productivity of land throughout the word, this alarming situation requires urgent interventions in order to preserve water and soil resources. This study presents an application of the model Soil and Water Assessment Tool(SWAT) to simulate daily and monthly water flow and sediment load from 1980 to 2012 in the Changjiang River basin, which is a sub-basin of the Poyang Lake basin, China. The sensitivity analysis is carried out by using the LH-OAT method. The model was calibrated and validated based on a comparison of simulated and measured runoff and sediment data of the Tankou and Dufengken hydrological station in Changjiang River. Indeed, for the monthly time step application, the relative error of the model to the runoff simulation was less than 10.21% in the calibration period and the validation period. The correlation coefficient(R2) and Nash-Suttcliffe(Ens) were higher than or equal to 0.91, and The relative error of the model to the sediment simulation was less than 26.0% in the calibration period and the validation period, R2 and Ens were higher than 0.76. The research indicates that SWAT model can be used to simulate the runoff and sediment, water loss and soil erosion are mainly caused by rainfall in flood season, and the sediment is up to 99.26% of the total year, and it has a good correlation among rainfall, runoff and sediment in flood period.

## 1. Introduction

Accelerated soil and water loss, which are caused by human activities and natural factors, seriously threaten land resources, water resources and ecological environment. According to the results of the second remote sensing survey of Ministry of Water Resources in China, the currently existing soil erosion area is 3.67 × 106km$^2$, accounting for 38.2% of the total land area (Li et al.2005). The studies of soil erosion and sediment migration are very important and significance (Gassman et al.2007), because soil erosion is a main component of non- point source pollution, it is one of the basic work to calculate the sediment yield and the sediment transport.

The process of sediment transport and deposition are nonlinearly related to influence factors spatially and temporally (White,2006). In recent years, the study of soil erosion is more common by using the remote sensing, geographic information system technology and the Universal Soil Loss Equation (USLE) model, some of the popular models such as the Modified USLE (MUSLE) and the Revised USLE (RUSLE) are increasingly being used. Soil and Water Assessment Tool (SWAT) is a physically based model, and commonly used in practice to simulate water and sediment fluxes in basins (Arnold et al.1998; Douglas-Mankin et al.2010). The extensive application of the SWAT model confirms that its distributed hydrological model can be applied to a number of environmental processes at different time and spatial scales, and SWAT model provides a powerful model for runoff simulation and the non-point source pollution simulations (Ouyang, et al. 2013; Wellen, et al. 2014). The distributed hydrological model divides the watershed into a number of meshes or representative basic units as calculating units, which reflects the differences with the factors of affecting soil erosion in the sub-basin by assigning parameters values to the calculation unit, so as to achieve a more accurate prediction purposes of runoff and sediment production in the entire basin. The SWAT model was used to study the runoff and sediment in different watersheds, to grade the soil erosion intensity, and to analyze the effects of different land use types on sediment yield (Rokhsare, et al.2008). SWAT model can be used for the suitability of different scales and regions, non-point source pollution simulation of water, sediment and agricultural pollutants, and the impact of land use/cover types change and climate change on the basin (Vermast, et al. 2016). They provide effective ways and methods for runoff and sediment simulation in different watersheds.

In the Poyang Lake basin, SWAT model was applied to Fuhe Basin for the runoff simulation, which is the second-largest tributary of Poyang Lake, four main sensitivity parameters(CN2, GWQMN, RCHRG_DP, ESCO)were obtained from sensitivity analysis module( Wang, et al. 2009). Cui et al.(2014)applied the model to assess the sensitivity of the watershed hydrological response to changes in extreme climate conditions caused by the uncertainty of the future climate in Fuhe river basin. Both studies confirmed the ability of the model to reproduce the hydrological cycle and give satisfactory results. Ma et al.(2015) applied the model to simulate the more parameters including the runoff, silt and diffuse source nitrogen(N) and phosphorus(P) pollution loading of seven hydrological stations of Poyang Lake Basin. Then Liu et al.(2015) applied the model to simulate and analyze water quantity and water quality under the land use scenarios through the SWAT model in Changjiang River basin, and explored a relation with the land use of tributary Changjiang basin and the water pollution of environment. According to the above observations and other reports (Kaur et al.2003; Tripathi et al.2005; Prabhanjan 2011), it can be concluded that SWAT model is one of the promising models for runoff and sediment yield modeling.

In this context, and for the purpose of developing a decision tool for optimal management of water and soil resources in Changjiang River , which is an important sub-basin of Poyang Lake Basin, this study is interested in the simulation of water flow rates and sediment yields throughout the basin. The model SWAT, used in this study, was applied over the period 1989-2010 in Changjiang River Basin; The agreement between simulated and observed time series at the Dufengken and Tankou hydrological station was tested using performance indicators, such as Relative Error (Re), the correlation coefficient ($R^2$), Nash-Suttcliffe (Ens). This paper is composed of the following parts: following a main introduction of the study area (section 2) and the data and modeling(section 3), section 4 is devoted to the results obtained and their discussion, and conclusions in this study is presented in section 5.

## 2. Study Area

Changjiang River locates in the Poyang Lake Basin and the northeastern part of Jiangxi Province, is a Raohe north branch of the five rivers in Jiangxi Province. Changjiang River originates among Dahongling, Diaomuling and many other mountains in Qimen County in Anhui Province, and flows into the Poyang Lake with the Le'an River from the Qimen County into the territory of Jiangxi Province. A total area of Changjiang River Basin is 6260 $km^2$, of which 1894$km^2$ in Anhui Province. The landform type is eroded hills and sloping soil wash plain by mountainous area, hilly area to alluvial plain area from upstream to downstream. The basin is tilted from northeast to southwest, and mostly ancient metamorphic rocks, rock stratum is strong and mild erosion, river bed is stable by the composition of rock, pebbles and gravel. Changjiang River Basin is a subtropical climate, abundant rainfall, adequate light, and long frost-free period. According to hydrological data, the mean annual rainfall in the upstream of Dufengken hydrological station in Changjiang is 1800mm, mean annual runoff is 4.81 billion $m^3$.

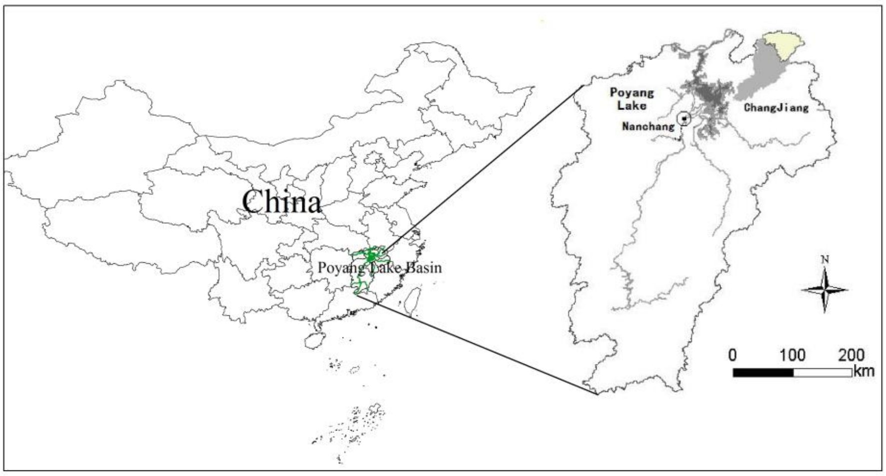


**Figure 1.** The location of Changjiang River Basin, China

## 3. Material and Methods

### *3.1 Creation of Database*

*A. Hydrologic Features Data.* The digital elevation model (DEM) was established with splicing and neighborhood analysis of the sub-frame GDEM data using the Arcgis9.2 software technology, the resolution was 30m (Figure 2a), and then a series of hydrological features were extracted by using the Hydrology Model of the Arcgis9.2 Toolbox based on the DEM model, which mainly includes: the flow direction and flow length, flow accumulation and flow network of the surface water, and watershed boundary and sub-watershed partition. Through the extraction of basic hydrological features and hydrological analysis, it is possible to outline the flow process of water flow and carry out a series of hydrological process analysis and visualization. All data have the same geographic coordinates and projections in the SWAT model, and the latitude and longitude units of the geographic coordinates are transformed into the length units(m). In this study, the ALBERS authalic conical projection is chosen as the parameter of the projection transformation, the spatial data are transformed into the same coordinate system, which can provide the basis for the superposition analysis and simulation of spatial data.

*B. Meteorological Data.* Rainfall is the main driving force of the model, the spatial distribution of rainfall stations has a great influence on the accuracy of model simulation and prediction. Figure 2b shows six rainfall sites as well as Tankou, Huantan, shendu, Jingdezhen, Poyang, and Leping rainfall sites. Climate input data of six rainfall sites in the model includes daily precipitation, maximum temperature, minimum temperature, solar radiation, wind speed and relative humidity.

*C. Soil Data.* The spatial distribution data of soil types are from Department of Agriculture of Jiangxi Province. The boundary data of the acquired vector data is cut with the boundary of the study area as the mask to obtain the spatial distribution of the soil mapping. Soils data were reclassified by the establishment of soil index file with the projection of the SWAT model required by the soil raster map. The soil types and its distribution are shown in Figure 2c, where brown soil accounted for 66.08% of the total area, paddy soil accounted for 23.81% of the total area, yellow soil accounted for 4.93% of the total area, red soil, moisture soil, submergienc paddy soil, gleyed paddy soil, mountain meadow soil and other types accounted for 5.2% of the total area.

*D. Land Use Data.* The land use types are especially important for the application of SWAT model to simulate the sediment change of the river basin, and the coding of the land use type is the basis for the hydrological simulation. In this study, the land use types in 1983 and 2012 were selected, and the the land use types data were classified by Landsat TM satellite remote sensing images, which were classified by ERDAS IMAGES 9.3 software. With field survey using GPS equipment, various remote sensing interpretation method as well as unsupervised, supervised and object-oriented classification improved the accuracy of remote sensing image recognition. According to the national classification standard and the actual situation of the study area, seven types such as forest land, grassland, paddy field, dry land, water area, town and construction land, grassland were shown in Figure 2d.

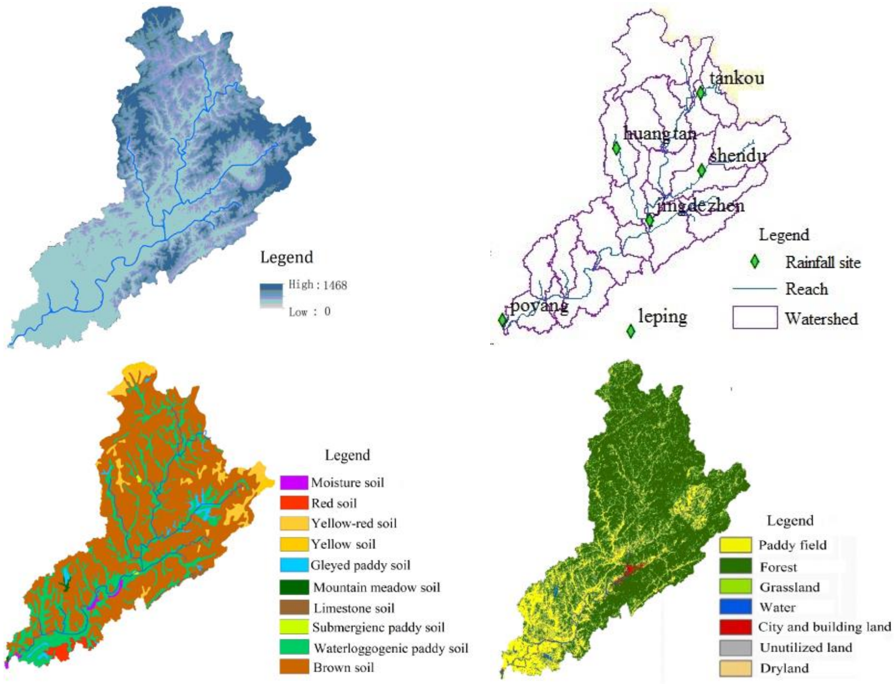


**Figure 2.** The prepared input data in Changjiang River basin. a)the digital elevation model and water system; b) rainfall sites; c) Spatial distribution of soil type map; d) Land use distribution maps

*3.2 Modeling*

SWAT simulation of the basin hydrological process is divided into the water cycle of the land surface (ie, runoff and slope concentration) and the water cycle of river confluence. The former controls the input of water and sand of the main river channel in each sub-basin, the latter determines the transport movement of water, sand and other substances from the river network to the basin exit. A multi-hydrological response unit partitioning method is used to set two thresholds as well as land use threshold and soil area threshold in this simulation. The setting of the threshold avoids the generation of very small hydrological response units due to the subtle distribution of land use or soil, excessive hydrological response units reduce the efficiency of the simulation. The simulation is set to 5%, the study area is divided into 376 hydrological response units. The runoff is calculated separately in each hydrological response unit, and then calculates every parameter in the basin, and the simulation accuracy can be improved. According to the research needs, the digital river networks are discretized and extracted on the basis of the DEM data, and the basin exit points and upstream water are manually added (Figure 3).

The hydrological data are based on the data of the Tankou and Dufengken hydrological stations in the Changjiang River Basin, and the water level, flow data, meteorological data and sediment data are daily datasets. In this paper, the model is executed for 33 years from 1980 to 2012 year. The data from 1989 to 1998 were used to calibrate for the data of Tankou hydrological station, and the data from 1991 to 2010 were used to calibrate for the data of hydrological station in Dufengken hydrological station. Based on the runoff calibration, the sediment parameters are adjusted, and then the sediment is calibrated.

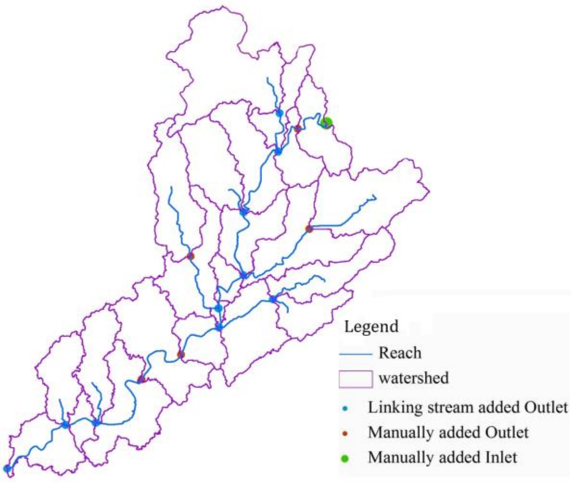


**Figure 3.** Partition mapping of sub-basin in Changjiang River Basin

*3.3 Accuracy Assessment Criteria*

The efficiency level of model reflects the adaptability in the study area. In this paper, three indicators as well as Relative Error(Re), the correlation coefficient($R^2$), Nash-Suttcliffe(Ens) were selected to evaluate the applicability of the model. Re can be described follows:

$$Re=\frac{Q_p-Q_o}{Q_o}\times 100\% \tag{1}$$

In which, $Q_P$ is estimated value, $Q_o$ is measured value. If Re is positive, it shows that the model simulation or prediction value is too large compared with the measured value. If Re is negative, the model simulation or prediction value is smaller than the measured value. The closer the Re is to 0, the more reliable the simulation result is. $R^2$ is computed by linear regression method (Jiang et al.2016). Formula 2 of Nash-Suttcliffe is shown (Nash and Sutcliffe,1970):

$$Ens = 1-\frac{\sum_{i=1}^{n}(Q_o-Q_p)^2}{\sum_{i=1}^{n}(Q_o-\bar{Q})^2} \tag{2}$$

Where, Q is the measured average value; n is the number of measured data. When $Q_o$ is equal to $Q_P$, Ens is equal to 1. The closer to the Ens value of 1 , the higher analog reliability will get.

## 4. Results and Discussion

*4.1 Sensitivity analysis*

The Latin hypercube and one-factor-at-a-Time (LH-OAT) method was proposed by Morris in 1991, and developed by Griensven and Bauwens 2003. A combination of latin hypercube (LH) sampling method and one-factor-at-a-Time (OAT) method was used in the sensitivity analysis of the new method, and the advantages of both methods are evoluted. The model runs only one parameter value changes at a time, and the change in the sensitivity of a particular input parameter value does not depend on the selection of other parameter values of the model. This method can effectively obtain the main parameter factors which affect the model results, and the usability of the model is greatly improved. The LH-OAT method divides the parameter sensitivity level into four levels, for example, parameter sensitivity value up to 1.0 is very high, parameter sensitivity value between 0.2 and 1.0 is high, parameter sensitivity value between 0.05 and 0.2 is medium, parameter sensitivity value down to 0.05 is low.

The sensitivity analysis was carried out for both runoff and sediment, such as the LH sampling interval set to 10, the OAT variation parameter is 0.05, and the random population is 2003. Tankou, Dufengken sites made a sensitivity analysis on the study area. the runoff and sediment parameter sensitivity results of the

Dufengken stations show respectively Table 1 and Table 2.

**Table 1.** The sensitivity results of runoff parameter in the Dufengken stations

| Parameters | Parameter Description | Sensitivity Sort | LH-OAT Value | Sensitivity Grade |
|---|---|---|---|---|
| CN2 | Soil conservation service runoff curve number | 1 | 2.43 | Very high |
| GWQMM | Shallow groundwater depth threshold value | 2 | 1.09 | |
| RCHRG_DP | Deep aquifer permeability coefficient | 3 | 0.84 | High |
| ESCO | Soil evaporation compensation factor | 4 | 0.27 | |
| SOL_Z | Soil depth | 5 | 0.20 | |
| SLOPE | Mean gradient | 6 | 0.18 | Medium |
| SOL_AWC | Soil available water | 7 | 0.12 | |
| SOL_K | Soil transmissivity | 8 | 0.09 | |
| GWREVAP | Underground water reevaporation coefficient | 9 | 0.08 | |
| CANMX | Maximum canopy pondage | 10 | 0.04 | Low |
| ALPHA_BF | Alpha coefficient of base flow | 11 | 0.03 | |
| GW_DELAY | Groundwater hysteresis coefficient | 12 | 0.02 | |
| CH_K2 | River effective transmissivity | 13 | 0.01 | |
| SURLAG | Surface runoff hysteresis coefficient | 14 | 0.01 | |
| REVAPMN | Shallow groundwater reevaporation coefficient | 15 | 0.003 | |

**Table 2**. The high sensitivity results of sediment parameter in the Dufengken stations

| Parameters | Parameter Description | Sensitivity Sort | Sensitivity Grade |
|---|---|---|---|
| CN2 | Soil conservation service runoff curve, curve number | 1 | Very high |
| SPCON | Sediment transport linear coefficient | 2 | |
| SURLAG | Surface runoff hysteresis coefficient | 3 | High |
| SLOPE | Mean gradient | 4 | |
| SOL_ORGN | Soil organic N initial concentration | 5 | |
| SOL_Z | Soil depth | 6 | |
| USLE_P | Soil and water conservation measures factor | 7 | |
| BIOMIX | Biology mixing efficiency coefficient | 8 | |
| SLSUBBSN | Mean slope length | 9 | |
| CH_N | Manning coefficient of main channel | 10 | |

*4.2 Calibration and validation*

*A. Calibration and validation of runoff.* The runoff was calibrated and verified at month scale. According to the results of runoff sensitivity analysis, nine parameters with very high sensitivity and high sensitivity were selected, namely CN2, GWQMN, RCHRG_DP, ESCO, SOL_Z, SLOPE, SOL_AWC, SOL_K and GWREVAP as the main adjustment parameters of runoff calibration. The simulated runoff was calibrated and verified using the historical data of the Tankou hydrological station (1989-1998) and the Dufengken hydrological station (1989-2010). The simulated and measured values of the monthly runoff depth in the hydrological station such as Dufengken are shown in Figuer 4 and Figuer 5. The results of the evaluation monthly are shown in Table 3.

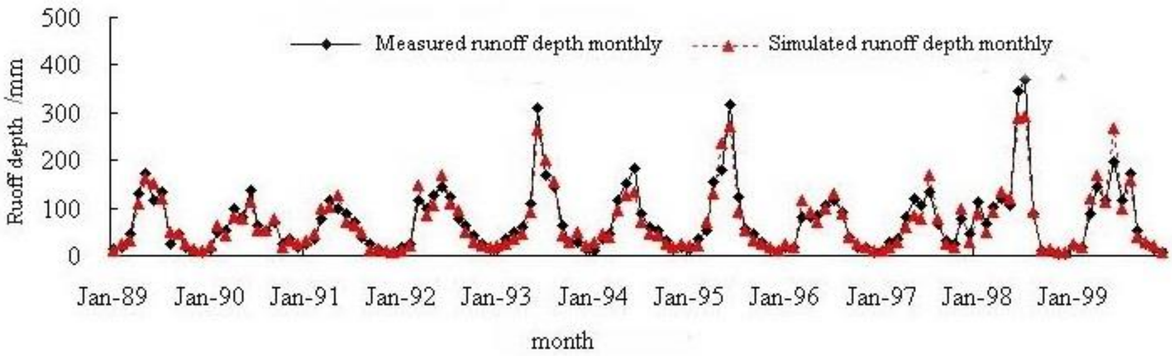


**Figure 4.** The runoff depth fitting curve of Dufengken hydrological station monthly in calibration period

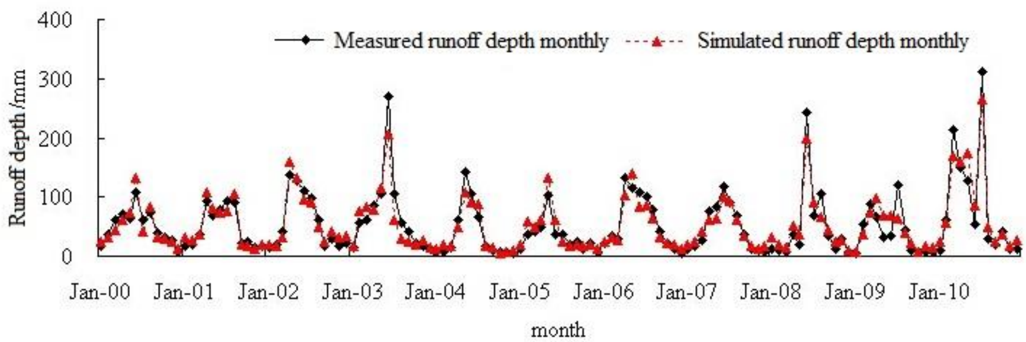


**Figure 5.** The runoff depth fitting curve of Dufengken hydrological station monthly in validation period

**Table 3**. Evaluation indicator values of calibration and validation of runoff monthly

| Hydrological Station | Period | Re（%） | $R^2$ | Ens |
|---|---|---|---|---|
| Tankou | Calibration: 1989-1993 | 6.47 | 0.95 | 0.93 |
| | Validation:1994-1998 | -3.81 | 0.96 | 0.92 |
| Dufengken | Calibration: 1989-1999 | 6.06 | 0.91 | 0.91 |
| | Validation:2000-2010 | -5.29 | 0.94 | 0.92 |

*B. Calibration and validation of Sediment.* On the basis of runoff calibration, the sediment was calibrated and validated. Based on the historical data of daily sediment concentration in Dufengken hydrological station from 2001 to 2010, the sediment was calculated monthly. The sediment of the site was calibrated and validated monthly between 2001 and 2010. The SWAT model uses the corrected universal soil loss equation (Rusle) to calculate the sediment erosion, sediment erosion is affected by the soil erosion factors and vegetation cover and operating management factors, and the vegetation cover and operating management factors are closely related to the surface vegetation fraction, leaf crown coverage, so the above parameters will become the main adjustment parameters. The monthly sediment is obtained and compared with the measured sediment, Figure 6 and Figure 7 are shown. The accuracy of runoff is more than the simulated sediment erosion using the SWAT model, The reason is that the migration of sediment is carried by runoff, and the error is accumulated and amplified.

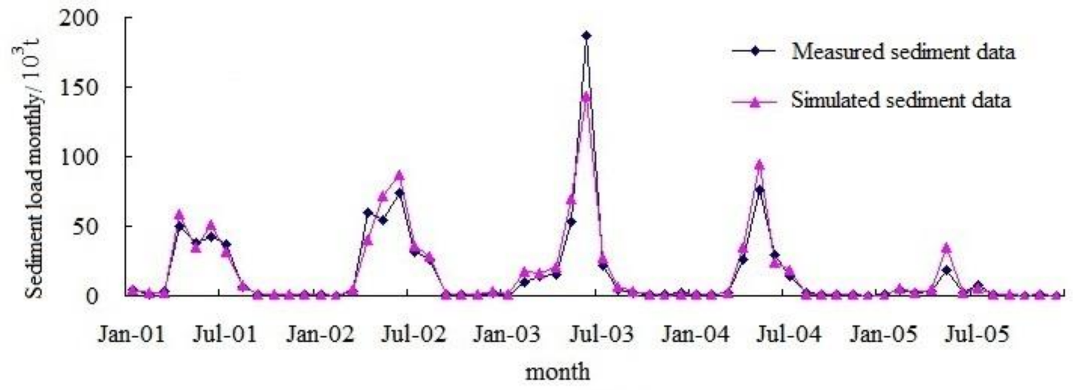


**Figure 6.** The sediment fitting curve of Dufengden hydrological station monthly in calibration period

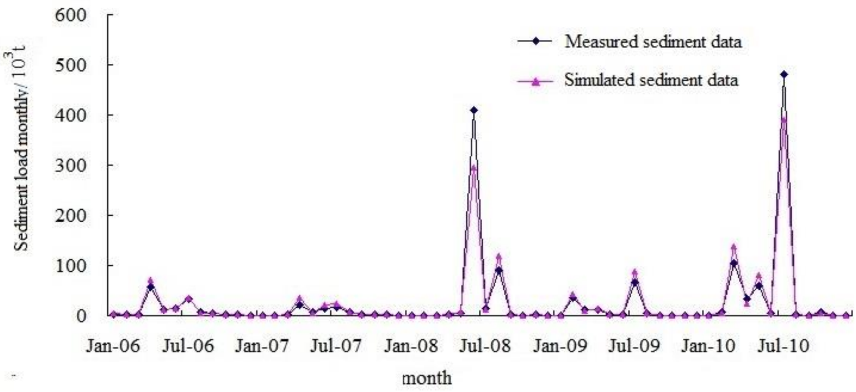


**Figure 7.** The sediment fitting curve of Dufengden hydrological station monthly in validation period

**Table 4.** Evaluation indicator values of calibration and validation of sediment monthly

| Station | Period | Re/% | $R^2$ | Ens |
|---|---|---|---|---|
| Dufengken | Calibration:（2001-2005） | 19.85 | 0.824 | 0.77 |
| | Validation:（2006-2010） | 26.15 | 0.765 | 0.75 |

*4.3 Temporal distribution of runoff and soil loss*

Based on the statistical analysis of the rainfall data from 1981 to 2012 in the study area, it is found that most of the rainfall is concentrated from April to August in this area, the rainfall in flood period account for 52.70% -80.13% of the annual rainfall, with an average proportion of 66.24%. According to the simulation results monthly of SWAT model, the statistical analysis of the flood season and the annual runoff and sediment output is carried out. The results are shown in Figure 8 and Figure 9.

**Figure 8.** Percentage of runoff depth and sediment in flood season(from April to Auguest)

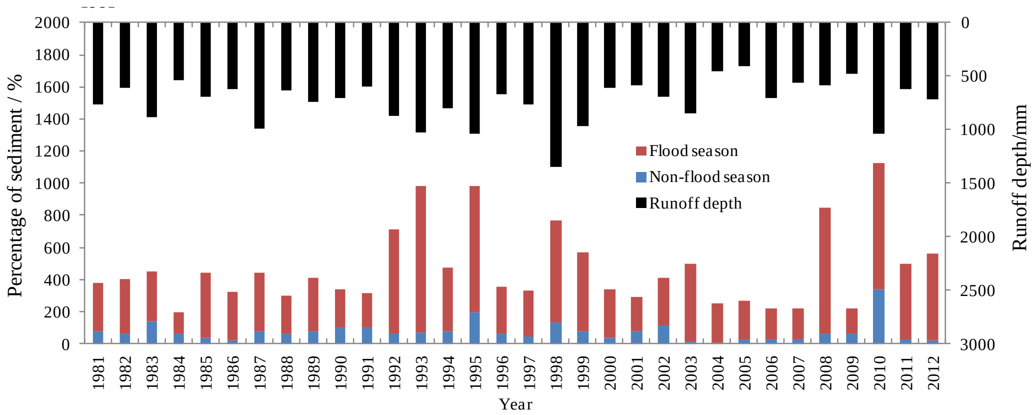


**Figure 9.** Mean precipitaion, mean runoff depth and mean sediment load monthly from 1981 to 2012

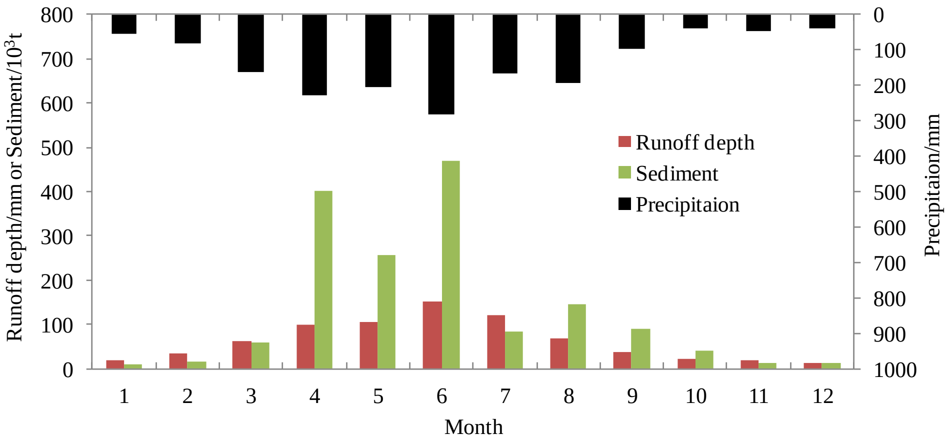


Figure 8 and Figure 9 show that the inter-annual variation is basically sandy years from 1981 to 2012, plentiful sediment years are mainly during the period of flood water years, lower sediment years are mainly in the dry season. Runoff of flood season account for 33.85 ~ 76.72% of the total year in 32 years, and sediment is 67.04 ~ 99.26%. Water loss and soil erosion are mainly caused by rainfall in flood season, and the sediment is up to 99.26% of the total year. That is, the sediment is mainly concentrated in the flood season with the high intensity precipitation, the relationship among rainfall, runoff and sediment is high in flood period.

## 5. Conclusion

In this paper, the Changjiang River Basin in Jiangxi Province is selected as the study area, and the sensitivity analysis is carried out by using the LH-OAT method. The model is calibrated based on the measured runoff and sediment data of the Tankou and Dufengken hydrological station. The relative error of the model to the runoff simulation is less than 10.21% in the calibration period and the validation period. $R^2$ and Ens are higher than or equal to 0.91, and The relative error of the model to the sediment simulation is less than 26.0% in the calibration period and the validation period, $R^2$ and Ens are higher than 0.76, which indicates that SWAT model can be used to simulate the runoff and sediment in the study area.

## 6. Acknowledgments

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