Simulation on Change Law of Runoff, Sediment and Non-point Source Nitrogen and Phosphorus Discharge under Different Land uses Based on SWAT Model: A Case Study of Er hai Lake Small Watershed

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Abstract: The Er yuan watershed of Er hai district is chosen as the research area, the law of runoff and sediment and non-point source nitrogen and phosphorus discharges under different land uses during 2001 to 2014 are simulated based on SWAT model. Results of simulation indicate that the order of total runoff yield of different land use type from high to low is grassland, paddy fields, dry land. Specifically, the order of surface runoff yield from high to low is paddy fields, dry land, grassland, the order of lateral runoff yield from high to low is paddy fields, dry land, grassland, the order of groundwater runoff yield from high to low is grassland, paddy fields, dry land. The orders of sediment and nitrogen and phosphorus yield per unit area of different land use type are the same, grassland > paddy fields > dry land. It can be seen, nitrogen and phosphorus discharges from paddy fields and dry land are the main sources of agricultural non-point pollution of the irrigated area. Therefore, reasonable field management measures which can decrease the discharge of nitrogen and phosphorus of paddy fields and dry land are the key to agricultural non-point source pollution prevention and control.

1. Introduction
As the second largest Yunnan plateau lake and also the foundation of sustainable development of society and economy for Dali, Erhai is the mother lake of people of all nationalities in Dali. Due to the development of economy and society, water quality deterioration, total nitrogen (TN) and total phosphorous (TP) pollution have been getting worse in recent years. While effectively control of point pollution from factory and urban area, non-point source pollution (NPS) has become the most important pollution source of Erhai watershed. Proportion of NPS increase step-by-step$^{[1]}$. The pollution discharged from the three northern rivers is the main source of Erhai pollution, so it is very important to make the research on source control for protection of Erhai aquatic ecosystem$^{[2]}$.

SWAT model (Soil and Water Assessment Tool) is one of the distributed hydrological models which are applied widely in non-point source pollution research. SWAT model is a physically based model developed by the Blackland Research and Extension Center and the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) to predict the effect of land management.
practices on water, sediment and agricultural chemical yields in large, complex basins with varying soil type, land use and management conditions over long periods of time [3]. SWAT model can response to the changes of land use, weather, topography and soil data, the applicability and effectiveness of this model has been validated by numerous researches around the world [4-24].

Previous research has shown that land use is the main effect factor for soil yield and non-point source pollution discharge of the watershed [25-31]. Research results of the change law of soil yield and non-point source pollution discharge under different land uses can provide scientific advice for land use planning and management, which make it more effective in preventing non-point source pollution.

For now, there have been few case studies about the simulation of SWAT model in Erhai [32-35], but it is scarce for the study of change law of soil yield and non-point source pollution under different land uses.

The northern typical watershed is chosen to be the research area, and the distributed hydrological model is built based on SWAT model. The purpose of this research is to find the change law of soil yield and non-point source pollution discharge under different land uses, and then to provide scientific advice for the non-point source pollution control in Erhai watershed.

2. Research area

Mi qie River, Yong an River and Luo shi River are three northern branches of Er hai lake located in the middle of the Er yuan area, which constitute 57% of Erhai’s total runoff, as the main water sources of Er hai lake. The Er yuan watershed is chosen to be the research area for model construction and simulation due to its closed hydrological condition. The research area has an area of 125151 hm$^2$ and the detail location map is shown as Fig.1. This area provide most of the non-point source pollutants into Er hai lake, so it is typical enough [36]. This area is influenced by subtropical western monsoon climate with an average temperature of 15°C and an average annual rainfall of 747 mm. The highest rainfall usually occurs from May to October which constitutes 85% of the total annual rainfall, while winter season (November to April) is dry and cold.

![Fig.1 Spatial location of research area](image)

3. Model building and validation

3.1 Data Collection

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

| No. | Sources of data | Sources of data |
|-----|-----------------|-----------------|
| 1   | Digital elevation model (DEM) | Geospatial Data Cloud (http://www.gscloud.cn/) |
| 2   | Water distribution map | Drawn by authors of this paper based on the water distribution of the research area |
| 3   | Soil map | Big Data Center of Sciences in Cold and Arid Regions (http://bdc.casnw.net/yyzc/sj/250299.shtml) |
| 4   | Land use map | Computer Network Information Center of Chinese Academy of Science (http://www.cnic.cas.cn) |
| 5   | Meteorological data | Da Li meteorological station |
| 6   | Hydrological data | Lian Cheng station (observed data) |
| 7   | Water quality data | Collected by the authors of this paper through field observation experimentation |
| 8   | Farmland management measures | Field investigation based on research area |
| 9   | Pollution source information | Field investigation based on research area |

The data in table 1 are analyzed and treated and loaded into SWAT model and the distributed hydrological model based on research area is constructed. And then the 34 sub basins and 174 hydrological response units (HRUs) are calculated based on the DEM and river network distribution of the research area. The results are shown in figure 2(d).
3.2 Model Performance Evaluation

The parameters of runoff, sediment yield and water quality in SWAT model should be adjusted to reasonable range. We use relative error (Re), correlation coefficient ($R^2$) and Nash-Sutcliffe efficiency (Ens) to evaluate model performance. The calculation formulas of these indexes are shown as follows:

$$Re = \frac{Q_p - Q_0}{Q_0} \times 100\%$$  \hspace{1cm} (1)

$$R^2 = \frac{\Sigma_{i=1}^{n}(Q_0 - Q_0) \Sigma_{i=1}^{n}(Q_p - Q_p)}{\Sigma_{i=1}^{n}(Q_0 - Q_0)^2 \Sigma_{i=1}^{n}(Q_p - Q_p)^2}$$  \hspace{1cm} (2)

$$Ens = 1 - \frac{\Sigma_{i=1}^{n}(Q_0 - Q_p)^2}{\Sigma_{i=1}^{n}(Q_0 - Q_0)^2}$$  \hspace{1cm} (3)

Where, $Q_p$ is the simulation value, $Q_0$ is the average simulation value, $Q_0$ is the observed value, $Q_p$ is the average observed value, n is the number of observed data. The evaluation standard of model simulation efficiency of these indexes are shown in Table 2. Generally, the model performances are identified to be good enough to apply in actual numerical simulation if the Re<10%, $R^2$>0.79 and Ens>0.59.

| Standard   | Relative Error $Re$ (%) | Correlation Coefficient $R^2$ | Nash-Sutcliffe Efficiency (Ens) |
|------------|-------------------------|-------------------------------|--------------------------------|
| Excellent  | -5~+5                   | 1.00–0.95                     | 1.00–0.80                      |
| Good       | ±5~±10                  | 0.94–0.80                     | 0.79–0.60                      |
| Medium     | ±10~±20                 | 0.79–0.70                     | 0.59–0.40                      |
3.3 Model Calibration and Validation
The required runoff, sediment and water quality observed data for model calibration and validation are gained through field observation experimentation during flood season. The field observation points are set in accordance with the results of subcatchments calculation.

The monthly runoff data collected from 2001 to 2004 in Lian Cheng hydrologic station are designated as the calibration period for runoff discharge and the monthly data collected from 2005 to 2006 are designated as the validation period for runoff discharge. The results of runoff parameters adjusting are shown in figure 3(a-b). The evaluation index value of runoff simulation of Liancheng is shown in table 3. model performance is satisfactory while all of the parameters value are above the good standard, which are Re<10%, R^2>0.79 and Ens>0.59. Therefore , the model constructed in this paper is good enough to be used to finish the runoff simulation research.

![Fig.3 The calibration and the verification results of runoff parameters](image)

| Items     | Period of Record | Re/| R^2  | Ens  |
|-----------|------------------|----|------|------|
| Calibration | 2001-2004        | 5.54 | 0.87 | 0.74 |
After the runoff parameters calibration, the water quality parameters (mainly refer to the TN and TP calculating parameters) is to be calibrated next. Water quality observed data during 2013 of Jiang Wei River station (N25.96ºE100.13º) which is located in the south of research area are designated for water quality parameters calibration. In consideration of the lack of water quality observed data, we assumed that the SWAT model constructed in this paper would have a good validation result if the calibration result was perfect according to previous literature[37]. Therefore, the SWAT model in this paper is calibrated only based on existing observed water quality data. The results of water quality parameters adjusting are shown in figure 4(a-b). The evaluation index value of water quality simulation is shown in table 4. The results indicate that the model performance is good enough because most of the parameters value are above the good standard, excepting the relative error(Re) of TP is slightly over 10%. Therefore, the model constructed in this paper is good enough to be used to finish the water quality simulation research. So far, the distributed hydrological model of research area based on SWAT model is constructed entirely and scientifically.

![Figure 4](image)

**Table 4** The evaluation index value of TN and TP simulation
4. Simulation Results Analysis

4.1 Simulation of Runoff Yield under Different Land uses

In order to reduce the HRUs amount and the calculation effort, the land use type was reclassified by transforming the land use type with an proportion less than 10% of the total sub basin into other land use type with larger proportion during the HRU division of the SWAT model. The change of land use type of research area is shown in table 5.

Table 5 The change of area proportion of land use due to HRU division

| No. | Land use type   | Before Division | After Division |
|-----|----------------|-----------------|---------------|
|     |                | Area/hm² | Proportion (%) | Area/hm² | Proportion (%) |
| 1   | Paddy Field    | 16175.71   | 12.92          | 13786.13 | 11.02          |
| 2   | Dry Land       | 23294.28   | 18.61          | 22398.65 | 17.90          |
| 3   | Grass Land     | 83376.56   | 66.62          | 88968.32 | 71.09          |
| 4   | Urban Land     | 739.64     | 0.59           | 0        | 0              |
| 5   | Waters         | 1566.89    | 1.25           | 0        | 0              |

Generally, the law of non-point source pollution discharge is influenced and controlled by the hydrological cycle[38-39]. Therefore, if we want to analyze the law of sediment yield and non-point source nitrogen and phosphorus discharge under different land uses, we need to analyze the law of runoff yield first. Based on present agricultural management practices and land use pattern, the runoff yield from 2001 to 2014 is simulated. In this model, the water balance equation of HRU is shown as below:

\[
WYLD = SURQ + LATQ + GWQ - TLOSS
\]  \hspace{1cm} (4)

Where, WYLD is average annual runoff yield of HRU, SURQ is surface flow of HRU flow into main channel during time step, LATQ is the lateral flow, GWQ is the underground runoff, TLOSS is the losses of the runoff. The average annual runoff yield of different land uses is shown in figure 5.

Fig.5 The Simulation results of annual average runoff generation capacity of different land use

As seen in figure 5, the order for total runoff generation capacity of different land uses from strong
to weak is grass land, paddy field and dry land, while the order for surface runoff yield capacity from strong to weak is paddy field, dry land and grass land, for the lateral flow yield capacity is grass land, dry land and paddy field, for the groundwater runoff yield capacity is grass land, paddy field and dry land. The vegetation type and vegetation coverage of the surface can affect surface runoff and infiltration process significantly. The higher vegetation coverage is, the stronger rainfall infiltration capacity will be, and the less surface runoff production will be [40]. Consequently, the surface runoff yield capacity of grass land is the weakest, the underground runoff capacity is the strongest and the infiltration capacity is the strongest, due to the highest vegetation coverage. The paddy field can impound the rainfall and increase the infiltration capacity, as a result, paddy field has a high underground runoff yield capacity than dry land.

4.2 Simulation analysis of sediment yield, nitrogen and phosphorus discharge under different land uses

Based on the simulation results of the SWAT model, average annual sediment yield, nitrogen and phosphorus discharge are calculated, and the law of sediment yield and NPS nitrogen and phosphorus discharge under different land uses is analyzed. The sediment yield and TN and TP of different land use type is shown in table 6. With per area load of sediment, TN and TP of different land use type is shown in table 7. The contribution rate of different land use to yield of sediment yield, TN and TP is shown in figure 6.

### Table 6 Sediment yield and TN and TP of different land use type

| Items          | Area/10^4hm² | Sediment Yield/t | TN/t  | TP/t  |
|----------------|--------------|------------------|-------|-------|
| Dry Land       | 2.24         | 67256.88         | 1120.66 | 108.87 |
| Grass Land     | 8.90         | 590.92           | 126.31 | 11.14  |
| Paddy Field    | 1.38         | 18998.37         | 719.04 | 78.83  |

![Image](a) Sediment
![Image](b) TN
![Image](c) TP

Fig.6 contribution rate of different land use to yield of sediment yield, TN and TP

### Table 7 Per area load of sediment, TN and TP of different land use type

| Items          | Sediment Yield of Per Unit Area (kg/ hm²) | TN of Per Unit Area kg/ hm² | TN of Per Unit Area kg/ hm² |
|----------------|------------------------------------------|-----------------------------|----------------------------|
| Dry Land       | 3047.75                                  | 50.78                       | 4.93                       |
| Grass Land     | 6.65                                     | 1.42                        | 0.13                       |
| Paddy Field    | 1422.10                                  | 53.82                       | 5.90                       |

As can be seen in table 6, the sediment yield and NPS TN and TP discharge in dry land is the largest. The grass land has the least sediment yield and NPS TN and TP discharge with the largest proportion. Figure 8 shows that the contribution rate of sediment yield and NPS TN and TP discharge
of dry land are all the largest, which are 77.4%, 57.0%, 54.8%, those of paddy field are slightly less than dry land. The total contribution rate of sediment yield and NPS TN and TP discharge of these two land use all surpass 90%. Grass land has the least contribution rate of all the NPS discharge with the rate of 0.7%, 6.4%, and 5.6% respectively for sediment, TN and TP.

According to table 7 we know that the orders of sediment, nitrogen and phosphorus yield per unit area of different land uses are the same, grassland > paddy fields > dry land. Based on chapter 4.1, grass land has the largest runoff yield but the least sediment yield and nitrogen and phosphorus discharge, that is to say there is no obvious positive correlation between the runoff yield and the non-point losses of nitrogen and phosphorus, and further explains that land use type is one of the determining factors for the sediment erosion and non point losses of nitrogen and phosphorus of the watershed. As the paddy field and dry land are the main source of the sediment erosion and non point source losses of nitrogen and phosphorus, prevention and control of sediment erosion and non-point source pollution in paddy field and dry land should be the key to the prevention and control of non-point source pollution in the research area.

It is of great significance to adjust the land use pattern in the basin to control and prevent the sediment erosion and the non point losses of nitrogen and phosphorus effectively.

5. Conclusions
In this study, the distributed hydrological model of research area was built based on SWAT model. The change law of soil yield and non-point source pollution discharge under different land uses was simulated and analyzed. Based on the results of the study, the following major conclusions were drawn:

(1) The distributed hydrological model of research area constructed based on SWAT model was able to simulate runoff, sediment and non point source of nitrogen and phosphorus discharge successfully.

(2) The order for total runoff generation capacity of different land uses from strong to weak is grass land, paddy field and dry land, while the order for surface runoff yield capacity from strong to weak is paddy field, dry land and grass land, for the lateral flow yield capacity is grass land, dry land and paddy field, for the groundwater runoff yield capacity is grass land, paddy field and dry land.

(3) The orders of sediment, nitrogen and phosphorus yield per unit area of different land uses are the same, grassland > paddy fields > dry land.

(4) As the paddy field and dry land are the main source of the sediment erosion and non-point source losses of nitrogen and phosphorus, prevention and control methods in paddy field and dry land for sediment erosion and non-point source pollution should be the key methods in research area. It is of great significance to adjust the land use pattern in the basin to control and prevent the sediment erosion and the non-point losses of nitrogen and phosphorus effectively.

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References
[1] HU Weiqiong, DUAN Songbi, Study on Erhai agricultural non-point source pollution control[J]. Yunnan Agriculture, 2017.5:75-77. (in Chinese)
[2] TANG Jia, LI Deping, JIANG Xu. Primary Study on Characteristics of Nitrogen and Phosphorus Losses in the Typical Small Watershed of the Northern Area of Erhai Lake[J]. JOURNAL OF DA LI UNIVERSITY, 2014.6:60-63. (in Chinese with English abstract)
[3] D.B. Phan, C.C. Wu and S. C. Hsieh, Land Use Change Effects on Discharge and Sediment
Yield of Song Cau Catchment in Northern Vietnam. Journal of Environmental Science and Engineering, 5(2011)92-101

[4] HAO Fanghua, CHENG Hongguang, YANG Shentian. Theory and application of non point source pollution model[M], Bing Jing, China Environmental Science Press, 2006. (in Chinese)

[5] Tanoh Jean-Jacques, Jean Patrice Jourda. Assessment of Sediment and Pollutants in Buyo Lake, Ivory Coast, Using SWAT (Soil and Water Assessment Tool) Model [J]. Journal of Chemistry and Chemical Engineering, 2013, 7:1054-1059.

[6] Barlund I, Kirkkala T. Examining a model and assessing its performance in describing nutrient and sediment transport dynamics in a catchment in southwestern Finland [J]. Boreal Environment Research, 2008, 13(3):195-207.

[7] Farida Dechmi, Javier Burguete, Ahmed Skhiri. SWAT application in intensive irrigation systems: model modification, calibration and validation[J]. Journal of Hydrology, 2012, 470-471(12): 227-238.

[8] Lam Q D, Schmalz B, Fohrer N. Modeling point and diffuse source pollution of nitrate in a rural lowland catchment using the SWAT model[J]. Agricultural Water Management, 2010, 97(2): 317-325.

[9] Santith C, Srinivasan R, Arnold J G, et al. A modeling approach to evaluate the impacts of water quality management plans implemented in a watershed in Texas[J]. Environmental Modeling and Software, 2005, 21(8): 114-1157.

[10] MiSeon Lee, GeunAe Park, MinJi Park, et al. Evaluation of non-point source pollution reduction by applying Best Management Practices using a SWAT model and QuickBird high resolution satellite imagery[J]. Journal of Environmental Sciences, 2010, 22(6): 826-833.

[11] Panagopoulos Y, Markropoulos C, Baltas E, et al. SWAT parameterization for the identification of critical diffuse pollution source areas under data limitations[J]. Ecological Modeling, 2011, 222(19): 3500-3512.

[12] DAI Junfeng, CUI Yuanlai. Distributed hydrological model for irrigation area based on SWAT-Model application[J] Journal of Hydraulic Engineering, 2009, 40(3):311-318. (in Chinese with English abstract)

[13] DAI Junfeng, CUI Yuanlai. Distributed hydrological model for irrigation area based on SWAT-Principle and method[J] Journal of Hydraulic Engineering, 2009, 40(2):145-152. (in Chinese with English abstract)

[14] Zhang Zhanyu, Si Han, Kong Lili. Migration of non-point source nitrogen and phosphorus in small watershed based on SWAT model[J]. Transactions of the Chinese Society of Agricultural Engineering, 2013, 29(2):93-100. (in Chinese with English abstract)

[15] Song L X, Liu D F, Xiao S B, et al. 2013. Study on non-point nitrogen and phosphorus load from Xiangxi River in the Three Gorges Reservoir area based on SWAT[J]. Acta Scientiae Circumstantiae, 33(1):267-275.

[16] CHEN Yuan, GUO Xiu-rui, CHENG Shu-i yuan, et al. On the applicability of SWAT model to the nonpoint source pollution in the watershed of the three-gorge reservior[J]. Journal of Safety and Environment, 2012, 12(2):146-152. (in Chinese with English abstract)

[17] Liu Bo, Xu Zongxue. Simulation of non-point source pollution in the Shahe Reservoir catchment in Beijing by using SWAT model[J]. Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE), 2011, 27(5): 52-61. (in Chinese with English abstract)

[18] TONG Xiaoxia, CUI Yuan-lai, ZHAO Shu-jun, et al. Simulation on Change Law of Agricultural non-point Pollution Based on Modified SWAT Model: A Case Study of Fangxi Lake Small Watershed of Ganfu Plain Irrigation District[J], Journal of Yangtze River Scientific Research Institute, 2015, 3(32):89-94. (in Chinese with English abstract)

[19] DENG Ou-ping, SUN Si-yang, Lv Jun. Nitrogen Non-Point Source Pollution Identification Based on ArcSWAT in Changle River[J]. Environmental Science. 2013, 34(4):1284-1290. (in Chinese with English abstract)
Qiao Weifang, Niu Haipeng, Zhao Tongqian. Temporal Spatial Distribution of Agricultural Non-point Source Pollution in the Danjiangkou Reservoir Watershed Based on SWAT Model[J]. Resources and Environmental in the Yangtze Basin, 2013, 34(4): 1284-1290. (in Chinese with English abstract)

Wu Yiming. Study on Non-point Source Pollution of Xitiao lake Watershed in Anji County, Zhejiang Province Based on SWAT Modeling. Hangzhou, Zhejiang University, 2013. (in Chinese with English abstract)

ZHENG Jie, LI Guang-yong, HAN Zhen-zhong, et al. Application of modified SWAT model in plain irrigation district[J]. Hydraulic Engineering, 2011, 42(1): 88-97. (in Chinese with English abstract)

Li Shuo, Lai Zhengqing, Wang Qiao, et al. Distributed simulation for hydrological process in Plain river network region using SWAT model[J]. Transactions of the Chinese Society of Agricultural Engineering, 2013, 29(6): 106-112. (in Chinese with English abstract)

HUANG Qinghua, ZHANG Wanchang. Improvement and Application of GIS-based distributed SWAT Hydrological Modeling on High Altitude, Cold, Semi-arid Catchment of Heihe River Basin, China[J]. Journal of Nanjing Forestry University (Natural Sciences Edition), 2004, 28(2): 222-261. (in Chinese with English abstract)

HAO Fang-hua, CHEN Li-quin, LIU Chang-ming, et al. Impact of Land Use Change on Runoff and Sediment Yield [J]. Journal of Soil and Water Conservation, 2004, 18(3): 5-8. (in Chinese with English abstract)

Huang, J., Li, Q., Huang, L., Zhang, Z., Mu, J., Huang, Y., 2013a. Watershed-scale evaluation for land-based nonpoint source nutrients management in the Bohai Sea Bay, China. Ocean Coast. Manag. 71, 314–325.

Bu, H., Meng, W., Zhang, Y., Wan, J., 2014. Relationships between land use patterns and water quality in the Taizi River basin, China. Ecol. Indic. 41, 187–197.

Ye, Y., He, X., Chen, W., Yao, J., Yu, S., Jia, L., 2014. Seasonal water quality upstream of Da huo fang Reservoir, China-the effects of land use type at various spatial scales. CLEAN – Soil Air Water 42, 1423–1432.

Ahearn Dylan S, Sheibley Richard W, Dahlgren Randy A, et al. Land use and land cover influence on water quality in the last free-flowing river draining the western Sierra Nevada, California[J]. Journal of Hydrology, 2005, 313(3): 234-247.

Griffith Jerry A, Martinko Edward A, Whistler Jerry L, et al. Interrelationships among landscapes, NDVI, and stream water quality in the US Central Plains[J]. Ecological Applications, 2002, 12(6): 1702-1718.

Lee Sang-Woo, Hwang Soon-Jin, Lee Sae-Bom, et al. Landscape ecological approach to the relationships of land use patterns in watersheds to water quality characteristics[J]. Landscape and Urban Planning, 2009, 92(2): 80-89.

LI Man man, HAN Hui ling, LIU Xiao ying, et al. Study on Optimal Sub-division Scheme of Watershed Using SWAT Model-A Case Study in Erhai Basin, Yunnan Province[J]. Chinese Journal of Agrometeorology, 2012, 33(2): 185-189. (in Chinese with English abstract)

TANG Hai-feng, YANG Kun. The Simulation Research on Non-point Source Pollution in Erhai Lake Watershed by Using GIS and SWAT Model[J]. Journal of Anhui Agriculture, 2012, 40(11): 6747-6750. (in Chinese with English abstract)

ZHAI Yue, SHANG Xiao, SHEN Jian, et al. Application of SWAT Model in Agricultural Non—Point Source Pollution Investigation in Lake Erhai Watershed[J]. Research of Environmental Sciences, 2012, 6(25): 666-671. (in Chinese with English abstract)

PENG Bin, YANG Kun, LI Jian, et al. Response of Run of to Land Use Change in Erhai Basin Based on SWAT and GIS[J]. Journal of Yangtze River Scientific Research Institute, 2015, 43(2): 7-17. (in Chinese with English abstract)

ZHAO Hai-chao, WANG Sheng-rui, JIAO Li-xin, et al. Characteristics of Temporal and Spatial
Distribution of Nitrogen Loading in Erhai Lake in 2010[J]. Research of Environmental Sciences, 2013, 4:389-395. (in Chinese with English abstract)

[37] Wang Jianpeng, Cui Yuanlai. Modified SWAT for rice-based irrigation system and its assessment[J]. Transactions of the CSAE,2011,27(1):22-28. (in Chinese with English abstract)

[38] Li Ying, Wang Kang, Zhou Zuhao. Simulation of drainage and agricultural non-point source pollutions transport processes in paddy irrigation district in North-East China using SWAT[J]. Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE),2014,30(7):42-53. (in Chinese with English abstract)

[39] KONG Li-li, ZHANG Zhan-yu, ZHU Lei. Review of the trends in the study of non-point source nitrogen in hydrological processes on farmland over irrigation district. [J] Advances in Water Science, 2010,6(21):853-860. (in Chinese with English abstract)

[40] ZHAO Chun-hong, GAO Jian-en, SHAO Hui, et al. Numerical Simulation of Runoff Generation and Sediment Transport Processes Under Different Lands Use Patterns[J]. JOURNAL OF SICHUAN UNIVERSITY (ENGINEERING SCIENCE EDITION), 2013,2(42):38-46. (in Chinese with English abstract)