ORIGINAL ARTICLE

Simulation of spatial and temporal distribution on dissolved non-point source nitrogen and phosphorus load in Jialing River Watershed, China

Lei Wu · Tian-Yu Long · William J. Cooper

Abstract Jialing River, which covers a basin area of 160,000 km^2 and a length of 1,280 km, is the largest tributary of the catchment area in Three Gorges Reservoir Area, China. In recent years, water quality in the reservoir area section of Jialing River has been degraded due to land use and the rural residential area induced by non-point source pollution. Therefore, the semi-distributed land-use runoff process (SLURP) hydrological model has been introduced and used to simulate the integrated hydrological cycle of the Jialing River Watershed (JRW). A coupling watershed model between the SLURP hydrological model and dissolved non-point source pollution model has been proposed in an attempt to evaluate the potential dissolved non-point source pollution load; it enhances the simulation precision of runoff and pollution load which are both based on the same division of land use types in the watershed. The proposed model has been applied in JRW to simulate the temporal and spatial distribution of the dissolved total nitrogen (DTN) and dissolved total phosphorus (DTP) pollution load for the period 1990–2007. It is shown that both the temporal and spatial distribution of DTN and DTP load are positively correlated to annual rainfall height. Land use is the key factor controlling the distribution of DTN and DTP load. The source compositions of DTN and DTP are different, where average DTN pollution load in descending order is land use 67.2%, livestock and poultry breeding 30.5%, and rural settlements 2.2%; and for DTP, livestock and poultry breeding is 50%, land use 48.8%, and rural settlements 1.2%. The contribution rates of DTN and DTP load in each sub-basin indicate the sensitivity of the results to the temporal and spatial distribution of different pollution sources. These data were of great significance for the prediction and estimation of the future changing trends of dissolved non-point source pollution load carried by rainfall runoff in the JRW and for studies of their transport and influence in the Three Gorges Reservoir.

Keywords SLURP hydrological model · Jialing River Watershed · Non-point source pollution · Dissolved nitrogen and phosphorus · Spatial and temporal distributing simulation

L. Wu · T.-Y. Long
Key Laboratory of the Three Gorges Reservoir Area Ecological Environment, Ministry of Education, Chongqing University, 400045 Chongqing, People's Republic of China
e-mail: longty128@yahoo.com.cn

L. Wu (✉) · T.-Y. Long
Faculty of Urban Construction and Environmental Engineering, Chongqing University (B Campus), No.174, Sha Zheng Street, Sha Pingba District, 400045 Chongqing, People's Republic of China
e-mail: conquer2006@126.com

W. J. Cooper
Department of Civil and Environmental Engineering, Urban Water Research Center, University of California, Irvine, CA 92697-2175, USA

Introduction

After impoundment of the Three Gorges Reservoir in China, the hydrological situation in the Yangtze River and Jialing River had undergone fundamental changes, and potential eutrophication appears along the Yangtze River and tributaries because of favorable hydrodynamic and nutritious environment conditions (Deng 2007). Degradation of water quality caused by nitrogen (N) and phosphorus (P) can be partly attributed to agricultural productions; therefore, diffuse N and P losses from urban

storm water and agricultural runoff are the leading reasons for the increase of N and P concentrations in ground and surface waters and have already been an environmental concern over recent years (Buczko and Kuchenbuch 2010). Jialing River is the largest tributary of the Three Gorges Reservoir; human activities within the watershed cause a cumulative increase in N and P load for water bodies; non-point source (NPS) N and P pollution has become the major N and P background inputs of the Three Gorges Reservoir. Water quality monitoring data show that the average N concentrations of Beibei hydrological station in the export of JRW from 2004 to 2005 ranged from 1.07 to 4.16 mg L^{-1}, while during the dry period the range was between 1.07 and 2.39 mg L^{-1} and during the rainy season the range was within 1.18–3.18 mg L^{-1} (Zheng et al. 2008); and the average P concentrations ranged from 0.03 to 0.7 mg L^{-1}, while during the dry period the range was between 0.03 and 0.056 mg L^{-1} and during the rainy season the range was within 0.07–0.20 mg L^{-1} (Cao et al. 2008). Besides, water quality monitoring data from the National Water Resources Bulletin show that water quality in the JRW was taken on a Grade III level (suitable for centralized drinking water, surface water source protection zone, general fish protection areas and swimming areas) from 2000 to 2007. These data exhibit highly eutrophic conditions for the occurrence of algae growth due to nutrient over-enrichment; abnormal proliferation phenomenon of algae bloom in tributaries continuously breaks out; and this phenomenon shows an increasing trend recently. The eutrophication status of Jialing River is directly related to water environmental safety of Chongqing City as well as the whole Three Gorges Reservoir Area. Therefore, research on control and management of NPS pollution in the JRW has been of vital significance and value for water resources protection and water environmental safety.

NPS pollution (polluted runoff entering waterways from diffuse land-based activities) is the leading cause of water quality degradation to river waters (Pew Oceans Commission 2003), which includes runoff from agricultural to forestry land, storm water runoff from urban areas to discharges from on-site sewage disposal systems (such as septic tanks). NPS pollution is generally affected by soil, topography, climate, hydrology, land-use types, and other factors (Ou and Wang 2008). As rainwater or snow melt washes over the land, it picks up pollutants (e.g., sediments, nutrients, organic matter, bacteria, oils, metals and other toxic chemicals) and transports them to coastal creeks, rivers, bays and estuaries. Currently, field studies and modeling techniques are two useful approaches in evaluating NPS pollutant loadings. Nevertheless, due to significant spatial variations, it is very difficult to monitor on site. Simulating is an important way to study the formation processes of NPS pollution (Easton et al. 2008; Kuisi et al.

2009; Mitja 2010). Hydrological process simulation directly determines the estimated accuracy of dissolved NPS pollution (Janza 2010). Therefore, the semi-distributed land-use runoff process (SLURP) hydrological model (Kite 2002) was introduced and used to simulate the hydrological cycle of surface flow and interflow in the watershed. SLURP hydrological model, with the physical mechanism and high simulation accuracy, is a watershed model based on geological features data of Digital Elevation Model (DEM) and land-use types. The selection of SLURP hydrological model for the simulation study of dissolved NPS pollution is mainly based on two principal aspects: firstly, SLURP hydrological model has a physical mechanism which simulates the formation processes of the hydrological cycle about the surface runoff and interflow, and it is suitable for large- and medium-sized mountain basin. It has previously obtained good simulation results in mountain basins in Canada, America, and China (Haberlandt et al. 2001; Zhang et al. 2005; Krysanova et al. 2007; Long et al. 2009). Besides, the model parameters have clear physical meaning and they can be derived from site monitoring directly, or calibrated and optimized by the observed runoff values of watershed export. Secondly, the SLURP hydrological model uses land-use types as the basic research unit. It is easy to combine with the pollution model, which is also based on land-use types for analyzing and simulating dissolved NPS pollution load from surface runoff to interflow, and to form a coupling dissolved NPS pollution model. Above all, it improves the simulation accuracy of surface runoff and interflow, and it also enhances estimation precision of dissolved NPS pollution load within the watershed.

Through the construction of an environmental database in JRW, the SLURP hydrological model and the dynamic pollution load model were fully coupled with each other based on runoff and land-use types. The contribution ratio of various pollution sources, pollution categories and the critical sources area were quantitatively calculated; and the corresponding best control and management measures for NPS pollution were put forward. Therefore, the objective of this study was to explore and improve the simulation precision of dissolved NPS pollution load through the coupling of SLURP hydrological model and NPS pollution load model, and to provide scientific foundation as the government on national policies for protecting and restoring river water quality due to NPS pollution in Three Gorges Reservoir Area through wise management.

Study area

The Jialing River, which originates from the southern foot of Qinling Mountain, is one of the main tributaries in the north shore of the Yangtze River. Jialing River mainly includes tributaries of Bailong River, Qujiang, western Han

River (upstream of Jialing River), and Fujiang. The four major rivers converge near Hechuan in Chongqing, and finally empty into the Yangtze River in Chaotianmen, Chongqing (Fig. 1). JRW is across four provinces (municipalities) including Shanxi, Gansu, Sichuan, and Chongqing. Statistical yearbooks show that the population distribution of the watershed is very uneven; the highest density is 600–700 person km^{-2} and most of the region is at the range of 100–300 person km^{-2} (Fig. 2). The JRW is located between 102°33′ and 109°00′ E longitude and 29°40′ and 34°30′ N latitude. The general elevation of the northeast and northwest edge in the watershed ranges from 1,500 to 3,000 m above mean sea level, showing a slow slope to the Sichuan Basin. The climate of the watershed is sub-tropical monsoon type with an average annual temperature of 16–18°C; the average annual precipitation is

about 1,098 mm (Fig. 3); and almost 70–90% of the total annual rainfall occurs during the monsoon period (May–September). The average annual potential evaporation amount of Beibei hydrological station, which is the control station of watershed export, is 709.4 mm; and the average annual runoff amount is 65.9 billion m^3. Soils in this basin mainly consist of purple soil, brown soil and yellow–brown soil, where purple soil is mainly in the middle and downstream of the watershed. It accounts for 40% of the watershed area; brown soil is mainly in the upstream of Bailong River basin; and yellow–brown soil is mainly in the upper reaches of Qujiang River basin, with a little in the upstream of the Fujiang River basin.

Materials and methods

Basic data sources

The parameters included in the watershed environmental modeling include a digital elevation (DEM) map, meteorology data (dew point temperature, relative humidity, precipitation, wind speed, sun hours), water quality, runoff, soil properties and land-use data (Fig. 4). Socio-economic conditions include population, livestock and poultry breeding, fertilizer application data, and administrative divisions (Table 1).

SLURP hydrological model

Principles of the SLURP model

The SLURP hydrological model (Kite 2002) is a basin model which takes day as a time step and simulates the hydrological cycle from precipitation to runoff including

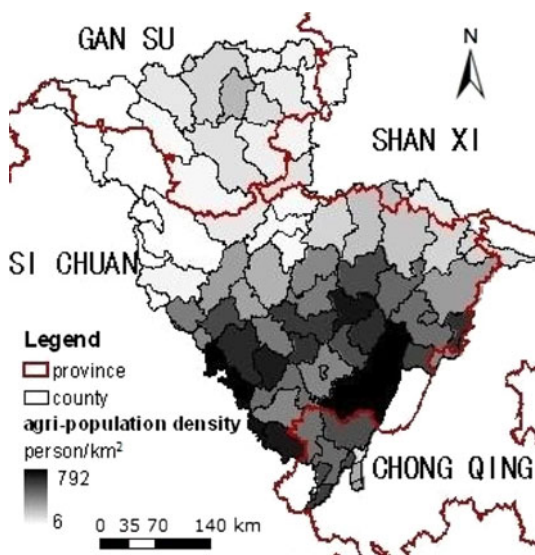**Fig. 1** Digital elevation, river, sub-basins of Jialing River Watershed

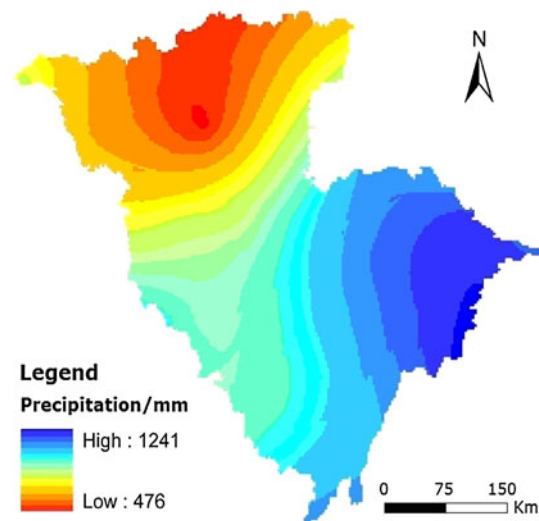**Fig. 2** Distribution map of agri-population density

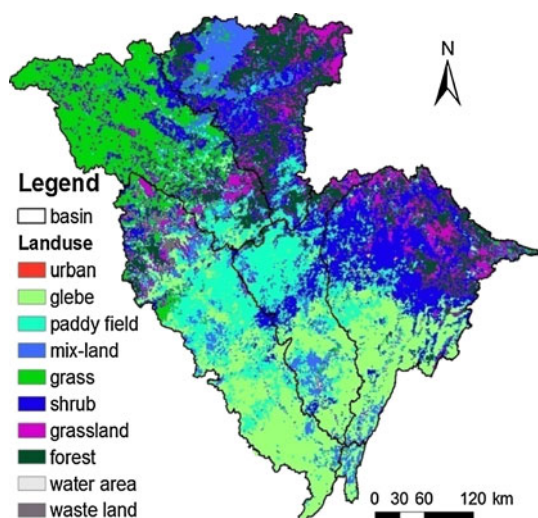**Fig. 3** Annual precipitation map in Jialing River Watershed

Fig. 4 Land use distribution map in Jialing River Watershed

the effects of reservoirs, dams, regulators, water extractions and irrigation schemes. The model initially divides a basin into hydrological sub-basins and then divides each sub-basin into its component land covers using topographic analysis programs. Each land cover region is a hydrological response unit, and different units are corresponding to different model parameters. SLURP model uses the topographic analysis package TOPAZ (Topographic Parameterization) to derive the topographic and land cover inputs (Garbrecht and Campbell 1997). The SLURPAZ interface (Lacroix and Martz 1997) processes the physiographic outputs from TOPAZ together with RASTER for land cover data and routing data to generate a SLURP command file. It also processes climate station coordinates in order to

generate a SLURP weights file and SLURP evaporation files. The model simulates the vertical water balance at each element of the sub-basin/land cover matrix using daily meteorological data which include precipitation, temperature, relative humidity, wind speed and sun hours, thus the discrete point meteorological data are transformed into surface meteorological data using spatial interpolation method of isohyetal method described in Linsley et al. (1975). Finally, runoffs from each matrix element are routed through each sub-basin to the basin outlet taking account of reservoir regulation, diversions, groundwater extractions, and water exports from the basin.

Validation of parameters optimization and simulation

Two methods are used to evaluate the simulation effects of parameter optimization for SLURP hydrological model: Nash–Sutcliffe coefficients (Nash and Sutcliffe 1970) and the relative error.

1. The expression of Nash–Sutcliffe coefficient E_{ns} is Eq. 1,

$$E_{ns} = 1 - \frac{\sum_{i=1}^{n} (Q_{obs} - Q_{sim})^2}{\sum_{i=1}^{n} (Q_{obs} - Q_{avg})^2} \quad (1)$$

where Q_{obs} is the measured value, Q_{sim} is the simulated value; Q_{avg} is the average of all measured values, $E_{ns} \leq 1$, the more E_{ns} value is close to 1, the better the model simulation is.

2. The expression of relative error is Eq. 2,

$$D(\%) = 100 \times \frac{Q_{sim} - Q_{obs}}{Q_{obs}} \quad (2)$$

Table 1 Environmental data in Jialing River Watershed

Data type	Format	Description	Source
Digital elevation model (DEM)	RASTER	90 m spatial resolution DEM data of the upper reaches in Yangtze River	China Earth system science data sharing network http://www.geodata.cn/
Administrative division	VECTOR	Sichuan, Shanxi, Gansu, Chongqing (2000)	
Land use	RASTER	Urban, glebe, paddy field, grassland, shrub, woodland, etc.	
Soil attribute data	DBF	Total nitrogen (TN) and total phosphorus (TP)	Chinese Academy of Sciences, Nanjing Institute of Soil http://www.issas.ac.cn/
Meteorological data	DBF	Daily values of precipitation, temperature, sun hours, wind speed and relative humidity (1960–2007)	China Meteorological Data Sharing Service Network http://www.geodata.cn/
Water quality	EXCEL	TN and TP concentration data of Beibei hydrological station (1996–2007)	Chongqing Environmental Quality Report http://www.cjw.com.cn/
Runoff amount	EXCEL	Time series of daily observed values of runoff amount in Beibei hydrological station (1997–2007)	China Hydrology and Water Resources Scientific Data Sharing Network http://www.hydrodata.gov.cn/
Economic conditions	DBF	Population, livestock and poultry breeding, fertilizer application (1990–2007)	Statistical yearbooks and reports

where D is the relative error, Q_{obs} is the measured value, Q_{sim} is the simulated value; this parameter is also a simple reflection of the relationship between the average observed values and the average simulated values during the simulation period, when D is negative, it indicates that the simulated value is lower than the observed value.

The measured values of runoff amount at Beibei hydrological station from 1997 to 2000 were applied to calibrate and optimize model parameters. The optimization results of model parameters were verified by the measured runoff amount from 2001 to 2007, the comparison of the simulated and observed monthly average runoff values was as shown in Fig. 5, the Nash–Sutcliffe coefficient of annual runoff amount was 0.87 during the verification period. The average relative error was −0.98%, the maximum relative error was −13.34%, and the Nash–Sutcliffe coefficients of average monthly and daily runoff amount were respectively 0.72 and 0.61, it indicated that the SLURP hydrological model had good simulation results in JRW. Therefore, the watershed annual runoff was simulated using the daily meteorological data from 1990 to 2007 in the watershed, and the final simulated results of annual surface runoff and interflow values from 1990 to 2007 were obtained from statistics. The comparison of simulated and observed annual runoff values was shown in Fig. 6, the average relative error was −2.8%, and the range of relative error was within −13.3 to 10.4%, the Nash–Sutcliffe coefficient was 0.79. The changing trends of the simulated annual runoff values were consistent with the observed ones. The simulation results in dry years were larger than the observed results, and the simulation results in wet years were smaller than the observed results. Overall, the simulated effects in extreme hydrological were slightly deficiency, but for such a complex, big climate variability and large-scale underlying surface of Jialing River Watershed, the simulation results were very satisfactory. It had laid an important foundation for accurately simulating watershed non-point source pollution load.
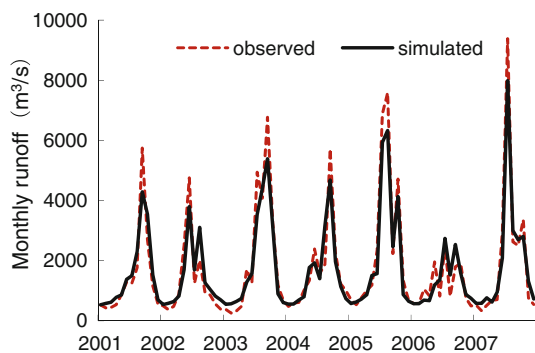

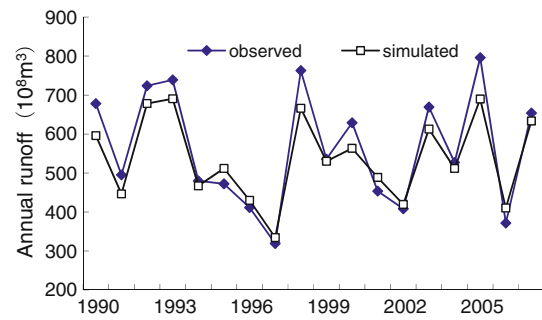**Fig. 5** Comparison of monthly average runoff during validation

Fig. 6 Comparison of annual runoff in 1990–2007 during simulation

Dissolved pollution load model of different land use types

DTN and DTP pollution model of different land use

The process of pollution is associated with hydrological runoff processes, N and P pollutants with water-soluble characteristics in the soil surface are dissolved and carried by surface runoff and interflow into the river stream to form non-point source pollution load, so the DTN and DTP output of different land use types changes with time and space due to the different of weather conditions, land use, soil texture, N and P contents of soil surface. Reference to the non-point source pollution load model about AGNPS (Borah et al. 2002), and SWAT (Easton et al. 2008) etc., the DTN and DTP output load models of different land use types in the watershed were determined as Eqs. 3–4 through the coupling of SLURP hydrological model and pollution load model,

$$Lt_{N,i} = \delta_N \cdot \sum_{j=1}^{n} \left(Q_{d,j,i} \cdot C_{N_{d,j}} + Q_{r,j,i} \cdot C_{N_{r,j}} \right) \qquad (3)$$

$$Lt_{P,i} = \delta_P \cdot \sum_{j=1}^{n} \left(Q_{d,j,i} \cdot C_{P_{d,j}} + Q_{r,j,i} \cdot C_{P_{r,j}} \right) \qquad (4)$$

where $Lt_{N,i}$, $Lt_{P,i}$ respectively represents non-point source DTN and DTP pollution load of the watershed export in i year, t; δ_N, δ_P respectively represents the DTN and DTP transport loss coefficient; $Q_{d,j,i}$, $Q_{r,j,i}$ respectively represents total amount of surface runoff and interflow in j-type land use in i year, m^3; $C_{N_{d,j}}$, $C_{N_{r,j}}$ and $C_{P_{d,j}}$, $C_{P_{r,j}}$ respectively represents the DTN and DTP concentration of surface runoff and interflow in j-type land use, mg L^{-1}; and n represents the number of land use types.

The determination of the DTN and DTP runoff concentration

Monitoring and analytical methods   The monitoring and assessment system of N and P pollution concentration from

surface runoff and interflow was carried out in Jialing project demonstration area. In accordance with the characteristics of hilly cropland of purple soil, the slope runoff plot with mensuration function was designed and built to test runoff and the corresponding N and P concentration (Fig. 7). The ISCO-6712 full-size portable sampler was installed in the mensuration pool so that it could automatically measure the water level changes in the process of rainfall runoff, the samples of surface runoff and interflow were collected from the runoff beginning to the end. The sampling frequency is the first dense and the following thinning. After setting sampling time, the ISCO-6712 water and sediment acquisition instrument automatically samples, and the concentration of TN and TP was determined by measuring. Average N and P concentrations of surface runoff and interflow were determined as the final N and P concentration of different land use. The monitoring time was from March 2006 to October 2007. The monitoring indexes include surface runoff, interflow, TN, DTN, TP, and DTP.

The determination of DTN and DTP concentration Through the construction of runoff field plots, N and P concentrations of the rainfall runoff were determined by monitoring N and P exports from various land use types, besides, reference to Hanjiang watershed (Shi et al. 2002) in Hubei province, China; Jiulongjiang watershed (Hong et al. 2008) in Fujian province, China; Chaohu watershed (Wang 2006) in Anhui province, China, etc., it is necessary to compare and perfect the specific runoff N and P concentration values of different land use types to estimate the pollutant loadings into water bodies. Due to the characteristics of cumulation in the dry season and leaching in the rainy season about the soil texture of hilly glebe in the reservoir area (Zhu et al. 2008; Chen et al. 2006; Hong et al. 2008; Liu et al. 2011), the dissolved N and P concentration value of interflow about the glebe was much higher than the concentration value of surface runoff, and other interflow concentrations of different land-use types almost take the same value as surface runoff. Table 2 lists

the N and P concentration values of surface runoff and interflow in different land use types.

The determination of transport loss coefficient

In the transport process of dissolved pollutants with surface runoff and interflow, it will generate transport loss by the vegetation retention, biochemical reactions, diffusion, infiltration, sediment adsorption, and deposition. For large-scale basin, the transport environments are complex and transport paths are quite length, transport losses account for a large proportion, they should not be ignored in the calculation of watershed export pollution loads. Therefore, the watershed transport loss coefficient δ is introduced to express the impacts of precipitation, runoff, and conflux on pollutants transport, it indicates that the intensity level of the pollutants transport from land surface to watershed export, it also means the ratio of the pollution load into the main river along with the rainfall runoff processes. Typically, pollutant transport loss coefficients are determined by monitoring pollutant exports from small catchments with a predominant land use or by using field plots to isolate individual land use contributions (Reckhow et al. 1980). However, there is a big issue in developing pollutant transport loss coefficients by field plot studies and using them to estimate pollution loadings at larger scales. The most important issue is the transport loss coefficients do not represent the average of conditions and practices within the entire catchment, the transport loss coefficients derived from small catchment and field plot scale studies cannot be confidently used in catchment-scale water quality modeling. This necessitates greater effort in determining transport loss coefficients and may result in larger uncertainties in load estimation. Therefore, the hydrological estimation method (Chen et al. 2003) was used to estimate the coefficient, the basic principles of the hydrological estimation method are: dissolved runoff pollution loads of watershed export are the sum of dissolved point source and non-point source pollution loads, the runoff in river way is equal to the sum of base flow and slope surface runoff. As the

Fig. 7 Design sketch of runoff pathway for runoff plot and local view of runoff plot
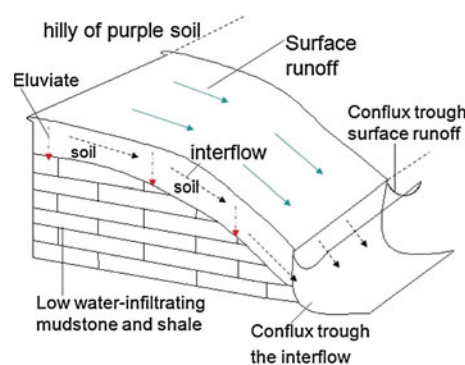
Table 2 DTN and DTP concentration of different land use types in Jialing River Watershed

Land use	DTN (mg L^{-1})		DTP (mg L^{-1})		Land use	DTN (mg L^{-1})		DTP (mg L^{-1})	
	Runoff	Interflow	Runoff	Interflow		Runoff	Interflow	Runoff	Interflow
Urban	1.2	1.2	0.1	0.1	Shrub	0.9	0.9	0.05	0.05
Glebe	2.65	14.5	0.2	1.18	Grassland	1.25	1.25	0.09	0.09
Paddy field	3.1	3.1	0.12	0.12	Woodland	1.2	1.2	0.062	0.062
Mix-land	1.65	1.65	0.092	0.092	Water area	0	0	0	0
Meadow	1.85	1.85	0.105	0.105	Wasteland	0.35	0.35	0.023	0.023

generation of dissolved non-point source pollution load is mainly due to rainfall runoff, it can be similar to consider that non-point source pollution runoff load is equal to the slope surface runoff load, and the point source pollution load is equal to the base flow load. Thus, annual slope surface runoff load of watershed export is equal to the base flow load subtracted from the total runoff load. Through the analysis of the hydrological data and available in-stream water quality monitoring data from Beibei hydrological station in the JRW from 1996 to 2002, non-point source DTN and DTP load can be estimated by the way of hydrological estimation method, and then the watershed N and P transport loss coefficient δ was determined by definition. Through the curve fitting, it was found that there was a good exponential-type correlation between the transport loss coefficient δ and runoff modulus q, L km^{-2} s^{-1}, as it was shown in Eqs. 5–6,

$$\delta_N = 0.1426 \cdot e^{0.1377q}, \ \left(R^2 = 0.985\right) \quad (5)$$

$$\delta_P = 0.0531 \cdot e^{0.1495q}, \ \left(R^2 = 0.979\right) \quad (6)$$

Dissolved pollution load model of rural residential area

DTN and DTP load model of rural settlements

The pollution of rural settlements includes rural life pollution, livestock and poultry breeding pollution. According to the situation of rural residential area, the sewage coefficient method and the excretion coefficient method were respectively used to calculate the pollution load of rural life, together with the pollution load of livestock and poultry feedlot, so the pollution output model of rural settlements was determined as Eq. 7,

$$Ln_i = \sum_{j=1}^{m} P_{i,j} \cdot \rho_j \cdot \varphi_j \cdot \gamma_j \cdot \lambda_i \quad (7)$$

where Ln_i is the DTN and DTP pollution output load of rural settlements in the watershed in i year, t a^{-1}; $P_{i,j}$ is the number of j category pollution sources which refers to agricultural population or livestock and poultry, person or head; ρ_j is the excretion coefficient of the j category

pollution sources of livestock and poultry, t head^{-1} a^{-1}, and it also represents the sewage coefficient of rural life, kg person^{-1} a^{-1}; φ_j is the content coefficient of pollutants in the j category pollution sources of livestock and poultry (φ_j value of person takes 1), kg t^{-1} a^{-1}; γ_j is the producing pollution coefficient, %; λ_j is the coefficient into the river of pollutants, the coefficient into the river λ_j of N and P in rural settlements takes into account the values of National Environmental Protection Administration, TN: $\lambda_{N,i} = 0.3$; TP: $\lambda_{P,i} = 0.2$.

The determination of the sewage (excretion) coefficient and producing pollution coefficient

Reference to rural pollution studies of Chang-Shou Lake areas (Chen et al. 2008) and other reports (Trevisan et al. 2010), the sewage coefficient of rural life, and the producing pollution coefficient were determined in Table 3. In addition, according to GB18596-2001 "livestock and poultry breeding pollution discharge standards" issued and implemented by the State Environmental Protection Administration, the excretion coefficient, the content coefficient of pollutants and the producing pollution coefficient were determined as Table 4 using the "Fertilizer Practical Manual" for feces and urine of livestock and poultry (Gao et al. 2002; Wu 2005).

Results and discussion

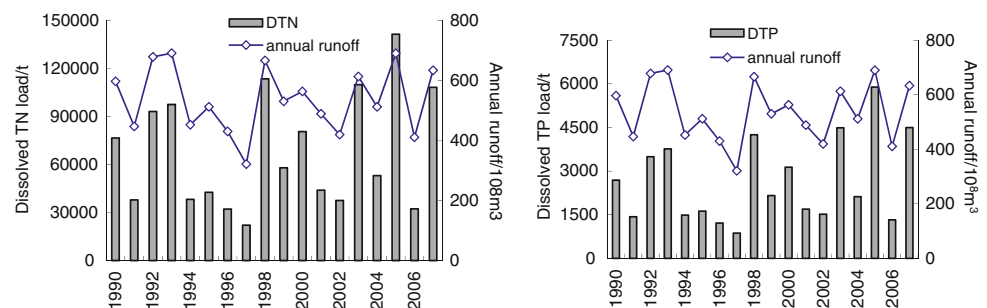The annual variability of DTN and DTP pollution load

With the increase of chemical fertilizer application and the expansion of livestock and poultry breeding, it can be seen from Fig. 8 that the non-point source DTN and DTP pollution load with the loss of rainfall runoff in the watershed takes on a slight upward trend in overall, annual changes have random fluctuations due to the hydrological impacts, and pollution load was particularly serious in individual years such as 1992, 1993, 1998, 2000, 2003, 2005, 2007 and so on, the reason for this was that the rainfall intensity was heavy during the 7 years' period; this led to generate

Table 3 The sewage coefficient of rural life and the producing pollution coefficient

Item	The sewage coefficient of rural life (kg person^{-1} a^{-1})		The producing pollution coefficient (%)	
	TN	TP	TN	TP
Value	0.31	0.04	14.5	2.55

Table 4 The excretion coefficient, the content coefficient of pollutants and the producing pollution coefficient

Sorts	The excretion coefficient (t head^{-1} a^{-1})	The content coefficient of pollutants (kg t^{-1} a^{-1})		The producing pollution coefficient (%)	
		TN	TP	TN	TP
Cattle feces	8,711.2	27.3	8.61	5.68	5.5
Cattle urine	4,055.6	19.45	1.46	25	25
Pig feces	1,367.6	2.34	1.36	1.085	0.177
Pig urine	1,719	2.17	0.34	25	25
Sheep feces	474	2.28	0.45	5.3	5.2
Sheep urine	158	0.94	0.08	20	20
Poultry feces	32.1	0.275	0.115	1.19	1.16

Fig. 8 Comparison of DTN, DTP load and annual rainfall runoff in Jialing River Watershed from 1990 to 2007

the large amount of DTN and DTP load, so the annual changes of DTN and DTP pollution load had close linear correlation with annual rainfall runoff. Through the comparative analysis between runoff and pollution load from 1990 to 2007, the runoff in 1990 was only less than 4% in 2007, but DTN and DTP loads in 2007 had increased by 38%, it was indicated that the increase of source strength about N and P pollution in the watershed was also an important reason for the increase of DTN and DTP pollution load.

The sources composition of DTN and DTP pollution load

The comparisons of source composition for DTN and DTP pollution load are shown in Fig. 9. The pollution sources were mainly from land use and rural life, together with livestock and poultry breeding, it also could be seen that although the annual variabilities of DTN and DTP pollution load were large, the composition ratio of all sources was relatively stable in 1 year. As far as the average case was concerned, the composition ratio of TN in descending order was land use (67.2%), livestock and poultry (30.5%),

and rural life (2.2%); while TP was livestock and poultry (50%), land use (48.8%), and rural life (1.2%). The composition ratio indicated that the DTN and DTP load were mostly from land use, livestock and poultry breeding, where TN pollution loads of the both respectively accounted for about 2/3 and 1/3, and TP pollution loads of the both roughly accounted for equal 1/2. Thus, lowering the loss of agricultural fertilizers and the pollutants discharge of livestock and poultry breeding was the major measures to control the generation of dissolved non-point source pollution.

The spatial distribution of DTN and DTP pollution load

Spatial analysis techniques were used to estimate the spatial distribution of pollution load (Lourenco and Landim 2010). The spatial distribution maps of non-point source DTN and DTP pollution load in JRW were respectively generated with the help of GIS technology. As a result of the broadly similar distribution each year, this study only listed the year of 2007, as it was shown in Fig. 10. The analysis indicated that the key source distribution of non-point source DTN and DTP pollution load primarily

Fig. 9 Comparison of DTN and DTP loads from different sources composition in Jialing River Watershed from 1990 to 2007
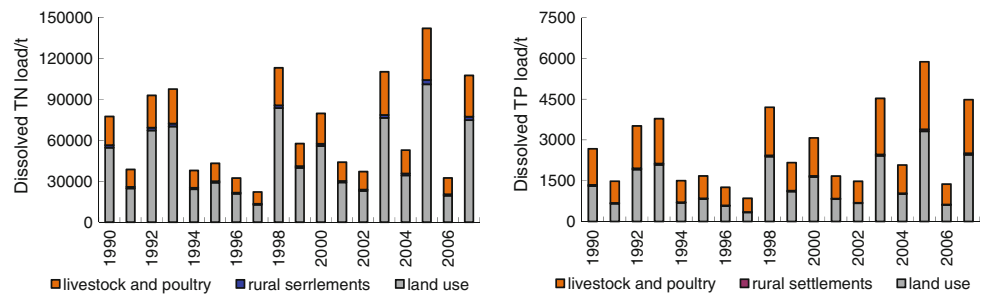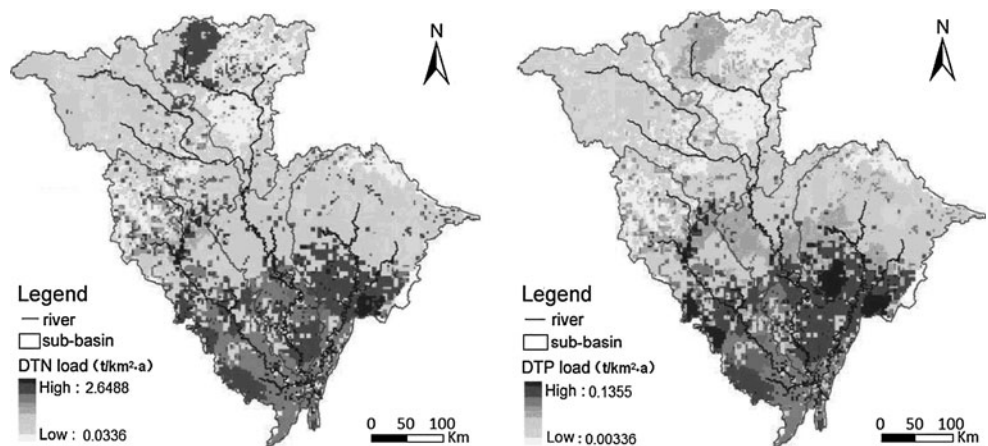

Fig. 10 Spatial distribution of DTN and DTP load of Jialing River Watershed in 2007

depended on the distribution of land use types, and it was followed by the distribution of livestock and poultry breeding. The critical source areas occurred to DTN and DTP pollution were mainly centralized in the downstream of the middle and lower reaches of Qujiang, the lower reaches of Jialing River, the middle and lower reaches of Fujiang River, and the upper reaches of the western Han River. The primary reasons were mainly high agricultural population density, intensive cultivation of agricultural land, and large-scaled livestock and poultry breeding. For the whole watershed, the DTN load got an average value of 1.12 t km^{-2} a^{-1}, and DTP load achieved an average value of 0.051 t km^{-2} a^{-1}. Therefore, the spatial distribution of DTN and DTP pollution load is mainly related to the distribution of farmland, the distribution of livestock and poultry breeding, and the situation of local soil loss.

The contribution rates of DTN and DTP load in each sub-basin

According to the spatial distribution maps (Fig. 10) of non-point source DTN and DTP pollution load in JRW, DTN and DTP pollution load and its contribution rates of sub-basins had been statistically analyzed. Taking the year of 2007 as an example, it could be seen from the statistical results in Table 5 that the annual load modulus of DTN and

DTP were respectively 0.6925 and 0.0288 t km^{-2} a^{-1}. The sub-basin contribution rates of non-point source DTN pollution load in descending order were as follows: Fujiang sub-basin (28.6%), Qujiang sub-basin (26.4%), the middle and lower reaches of JRW (17.0%), the upper reaches of JRW (14.2%), Bailong River sub-basin (12.6%) and the export zone of JRW (1.2%). Furthermore, the sub-basin contribution rates of non-point source DTP pollution load were as follows: Qujiang sub-basin (29.8%), Fujiang sub-basin (28.9%), the middle and lower reaches of JRW (16.6%), the upper reaches of the JRW (11.3%), Bailong River sub-basin (10.1%) and the export zone of JRW (1.3%). These data reveal that the contribution rate of DTN and DTP load in each sub-basin is not only correlated to the area of sub-basin, but also associated with the distribution of different land use and the amount of livestock and poultry breeding within the watershed.

Simulation results verification

The simulation results verification was performed to evaluate the differences between the simulated and observed values from Beibei hydrological station located at the outlet of the JRW. According to the observed data of water quality in outlet of the watershed from 2003 to 2007, annual dissolved non-point source pollution load of

Table 5 DTN and DTP load of each sub-basin and the corresponding contribution ratios in 2007

Sub-basin	Area (km²)	Annual load modulus (t km⁻² a⁻¹)		Annual load (t a⁻¹)		Contribution rate (%)	
		DTN	DTP	DTN	DTP	DTN	DTP
Bailongjiang sub-basin	28,080	0.4851	0.0162	13,620.3	453.6	12.6	10.1
Upper reaches of JLW	32,028	0.4785	0.0159	15,325.3	508.8	14.2	11.3
Middle and lower reaches of JLW	20,780	0.8848	0.0402	18,386.2	835.4	17.0	18.6
Qujiang sub-basin	38,302	0.7442	0.0350	28,505.3	1,341.5	26.4	29.8
Fujiang sub-basin	35,668	0.8658	0.0365	30,882.2	1,301.8	28.6	28.9
Export zone of JLW	1,285	1.0474	0.0452	1,345.9	58.1	1.2	1.3
Sum (average)	156,142	0.6925	0.0288	108,134	4,499.6	100.0	100.0

watershed export had been estimated as the observed DTN and DTP load values using the hydrological estimation method (Chen et al. 2003), and the estimated values were quite consistent with the simulated values of non-point source pollution load in the watershed export through the analysis of the relative error of Eq. 2. The comparisons of the simulated and estimated values of DTN and DTP pollution load from 2003 to 2007 were shown in Table 6. The analysis results of relative error indicated that simulation results of the model were ideal and the established model was reasonable and capable of simulating pollution load accurately in the watershed.

Conclusions

To study the spatial and temporal variations of dissolved non-point source pollution in JRW, the SLURP hydrological model, a semi-distributed hydrological model with physical mechanism, was introduced to substitute the Soil Conservation Service-runoff Curve Number (SCS-CN) empirical model which was commonly used in the simulation study of non-point source pollution. The surface runoff and interflow of the JRW was simulated and validated according to calibration and optimization of hydrology parameters, based on this, the transport loss coefficient of the watershed was taken into account to establish dissolved non-point source nitrogen and phosphorus load model. The development of the coupling watershed model between

dissolved non-point source pollution load model and SLURP hydrological model has been of great significance for improving the simulation precision of non-point source pollution load. Therefore, the temporal and spatial distribution of dissolved non-point source pollution load from land use, rural settlements and livestock and poultry breeding was simulated according to the established DTN and DTP pollution model. Simulation results showed that the annual average non-point source DTN and DTP loads in JRW entered into the Three Gorges reservoir were respectively 67,670 and 2,648 t from 1990 to 2007, where land use output was mainly from agricultural intensive cultivation area such as the glebe, paddy fields and mixed land in middle and down reaches of the JRW; the output of rural settlements was primarily from counties with intensive agricultural population, livestock, and poultry breeding.

The temporal distribution of non-point source DTN and DTP pollution load in the watershed were mainly affected by variations of rainfall and runoff; they were also affected by source strengthen of pollution, along with the increase of farmland fertilizer, livestock and poultry breeding, the non-point source DTN and DTP pollution load would be gradually increasing. Besides, by comparing the spatial distribution maps of non-point source pollution load and land use, together with agricultural population density, it was found that the pollution sources of DTN and DTP load mainly came from the farmland areas, rural residential areas and intensive livestock and poultry breeding areas. Pollutants from both fertilizer application and native

Table 6 Comparison of the estimated and simulated values of DTN and DTP load in the outlet of Jialing River Watershed

Year	DTN simulated value (t)	DTN estimated value (t)	DTN relative error (%)	DTP simulated value (t)	DTP estimated value (t)	DTP relative error (%)
2003	111,837.1	103,857.40	7.68	4,186.91	3,981.40	5.16
2004	41,998.7	40,657.30	3.30	1,320.35	1,153.70	14.44
2005	151,324.1	168,547.50	−10.22	5,490.94	6,214.80	−11.65
2006	27,294.4	24,358.70	12.05	1,026.03	976.90	5.03
2007	108,111.2	113,254.60	−4.54	4,120.79	4,386.20	−6.05

sources are transported to the water courses and ultimately the reservoir as a consequence of gully, stream bank, and surface erosion. Control measures in risk areas should be considered as management options for controlling the impacts of TN and TP on water bodies (Mostafizur Rahman and Bakri 2010). For this situation, pollution prevention efforts should be focused on the control of pollution sources at the local level, especially improvements to land use planning and zoning practices to protect river water quality, in other words, the measures should be designed to minimize the creation of polluted runoff rather than attempting to clean up already contaminated water. Land use practices recommended in the non-point source management measures include preserving natural vegetation, avoiding development within sensitive habitats and erosion-prone areas and limiting impervious surfaces (such as pavement, decking and roof tops) to the maximum extent practicable. In addition, eco-fertilizer technology and soil and water conservation measures should be implemented to control the increase of non-point source DTN and DTP pollution from cropland; at the same time, feces and urine from livestock to poultry breeding should be reasonably processed for harmless. In short, water pollution control and management of surface water is a complex and comprehensive process, "Joint Governance of Water Body and Land Surface" should be the only fundamental way to control water pollution effectively.

References

Borah DK, Demissie M, Keefer LL (2002) AGNPS-based assessment of the impact of BMPs on nitrate-nitrogen discharging into an Illinois water supply lake. Water Int 27(2):255–265

Buczko U, Kuchenbuch RO (2010) Environmental indicators to assess the risk of diffuse nitrogen losses from agriculture. Environ Manage 45:1201–1222

Cao CJ, Qin YW, Zheng BH (2008) Phosphorus nutrient characteristics and its source analysis of the major rivers in the Three Gorges Reservoir storage. Environ Sci 29(2):310–315

Chen YY, Hui EQ, Jin CJ (2003) Hydrological estimation method of non-point source pollution load. Res Environ Sci 16(1):10–13

Chen KL, Zhu XD, Zhu B (2006) Load and output character on non-point nitrogen from purple soil farmlands in hilly area of central Sichuan basin. J Soil Water Conserv 20(2):54–58

Chen JC, Liu SY, Peng XY (2008) Study of rural living sewage pollution and its comprehensive prevention measures in Chang-Shou Lake. Agric Environ Dev 6:94–98

Deng CG (2007) Eutrophication study of Three Gorges Reservoir area. China Environmental Science Press, Beijing

Easton ZM, Fuka DR, Walter MT (2008) Re-conceptualizing the soil and water assessment tool (SWAT) model to predict runoff from variable source areas. J Hydrol 348:279–291

Gao XZ, Shen T, Zheng Y (2002) Fertilizer practicality manual. China Agro-science Press, Beijing

Garbrecht J, Campbell J (1997) TOPAZ: an automated digital landscape analysis tool for topographic evaluation drainage identification, watershed segmentation and sub-catchment parameterization, TOPAZ user manual. USDA-ARS, Oklahoma

Haberlandt U, Klöcking B, Krysanova V, Becker A (2001) Regionalisation of the base flow index from dynamically simulated flow components—a case study in the Elbe River Basin. J Hydrol 248(1–4):35–53

Hong HS, Hang JL, Cao WZ (2008) Agricultural non-point source pollution mechanism and control research in Jiu-long River Watershed. Science Press, Beijing

Janza M (2010) Hydrological modeling in the karst area, Rizana spring catchment, Slovenia. Environ Earth Sci 60:463–472

Kite G (2002) Manual for the SLURP Hydrological Model Version 12.2. Canada NHRI, NHRI Publ

Krysanova V, Hattermann F, Wechsung F (2007) Implications of complexity and uncertainty for integrated modeling and impact assessment in river basins. Environ Model Softw 22(5):701–709

Kuisi MA, Al-Qinna M, Margane A, Aljazzar T (2009) Spatial assessment of salinity and nitrate pollution in Amman Zarqa Basin: a case study. Environ Earth Sci 59:117–129

Lacroix M, Martz LW (1997) Integration of the TOPAZ landscape analysis and the SLURP hydrologic models. Proceedings of Scientific Meeting. Canadian Geophysical Union, Banff, Alberta, p 208

Linsley RK, Kohler MA, Paulhus JHL (1975) Hydrology for engineers, 2nd edn. McGraw-Hill, New York

Liu XH, He BL, Li ZX, Zhang JL, Wang L, Wang Z (2011) Influence of land terracing on agricultural and ecological environment in the loess plateau regions of China. Environ Earth Sci 62:797–807

Long TY, Wu L, Liu LM, Li CM (2009) Simulation of dissolved nitrogen pollution in Xiaojiang River Basin of Three Gorges Reservoir. Chongqing Daxue Xuebao, Ziran Kexueban 32(10):1181–1186

Lourenco RW, Landim PMB (2010) Mapping soil pollution by spatial analysis and fuzzy classification. Environ Earth Sci 60:495–504

Mitja J (2010) Hydrological modeling in the karst area, RiA3/4ana spring catchment, Slovenia. Environ Earth Sci 61:909–920

Mostafizur Rahman AKM, Bakri DA (2010) Contribution of diffuse sources to the sediment and phosphorus budgets in Ben Chifley Catchment, Australia. Environ Earth Sci 60:463–472

Nash JE, Sutcliffe JV (1970) River flow forecasting through conceptual models part-a discussion of principles. J Hydrol 10(3):282–290

Novotny V (1999) Diffuse pollution from agriculture-a worldwide outlook. Water Sci Technol 39(3):1–13

Ou Y, Wang XY (2008) Identification of critical source areas for non-point source pollution in Miyun reservoir watershed near Beijing China. Water Sci Technol 58:2235–2241

Pew Oceans Commission (2003) America's living oceans: charting a course for sea change. A Report to the Nation. Pew Oceans Commission, Arlington, VA

Reckhow KH, Beaulac MN, Simpson JT (1980) Modeling phosphorus loading and lake response under uncertainty: A manual and compilation of export coefficients. U.S. Environmental Protection Agency, Clean Lake Section, Washington, DC EPA 440/5-80-011, 214 pp

Shi ZH, Cai CF, Ding SW (2002) Research on nitrogen and phosphorus load of agricultural non-point sources in middle

and lower reaches of Hanjiang River based on GIS. Acta Scientiae Circumstantiae 22(4):473–477

Trevisan D, Dorioz JM, Poulenard J, Quetin P, Combaret CP, Merot P (2010) Mapping of critical source areas for diffuse fecal bacterial pollution in extensively grazed watersheds. Water Res 44:3847–3860

Wang XH (2006) Study on non-point source pollution of nitrogen and phosphorus drainage evaluating and it's controlling on in ChaoHu watershed. Dissertation, Hefei University of Technology, Hefei

Wang L, Yao WY, Liu LY (2008) Study evolvement of watershed sediment delivery ratio in China. Yellow River 30(9):36–45

Wu SX (2005) The spatial and temporal change of nitrogen and phosphorus produced by livestock and poultry & their effects on agricultural non-point Pollution in China. China Academy of Agricultural Sciences, Beijing

Zhang D, Zhang WC, Zhu L (2005) Improvement and application of SWAT—a physically based, distributed hydrological model. Scientia Geographica Sinica 25(4):434–440

Zheng BH, Cao CJ, Qin YW (2008) Nitrogen nutrient characteristics and its source analysis of the major rivers in the Three Gorges Reservoir storage. Environ Sci 29(1):1–6

Zhu B, Wang T, Kuang FH (2008) Characteristics of nitrate leaching from hilly cropland of purple soil. Acta Scientiae Circumstantiae 28(3):525–533