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ORIGINAL PAPER

Small-scale watershed extended method for non-point source pollution estimation in part of the Three Gorges Reservoir Region

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Abstract Non-point source (NPS) pollution has been increasingly recognized as a major contributor to the declining quality of aquatic environment in recent years. Because of the data shortage, the non-point source loads estimation in the large-scale watershed is always difficult in most developing countries. In this study, small-scale watershed extended method (SWEM) was introduced with a case study in the middle part of Three Gorges Reservoir Region (TGRR). Small-scale watershed extended method is the method which uses physical-based models in some small typical catchments of the targeted large watershed, and then the parameters obtained from those small catchments are extended to the surrounding area until the non-point source pollution loads in the entire watershed or region are obtained. The selected small catchments should have sufficient data. Here, the middle part of the Three Gorges Reservoir Region, about 12,500 km^2, was chosen as the targeted region for the case study. In this region, considering the data availability, Xiaojiang River was screened as a typical watershed and was simulated with Soil and Water Assessment Tool model through accurate parameter calibration and validation. And then the parameter group obtained in Xiaojiang River Watershed was extended to the entire study area to quantify the total non-point source pollution loads. After which, the spatio-temporal characteristics of the non-point source pollution in the middle part of the Three Gorges Reservoir Region were analyzed, as well as the pollution from each tributary and different under layer surface conditions. The small-scale watershed extended method provides a practical approach for non-point source pollution loads estimation in the large-scale watershed or region.

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Introduction

Non-point source (NPS) pollution has been increasingly recognized as a severe threat to the declining quality of aquatic environment in recent decades (Humenik et al. 1987; Trauth and Xanthopoulos 1997; López-Flores et al. 2003; Ongley et al. 2010). NPS inputs, especially from agricultural activity, have resulted in large amounts of nitrogen (N) and phosphorous (P) (Chang et al. 2004) being input into aquatic environments, which cause a wide range of problems, such as toxic algal blooms, oxygen depletion and loss of biodiversity. In addition, nutrient enrichment seriously degrades aquatic ecosystems and decreases the quality of water used for drinking, industry, agriculture, recreation and other purposes (Potter et al. 2004; Farenga and Daniel 2007).

Many models have been developed for the NPS pollution loads estimation since the quantification is critical to guide decision makers before plans are implemented (Gburek and Pionke 1995; Santhi et al. 2006; Hunter and Walton 2008; Bach et al. 2010). Generally, the NPS simulation models can be classified into empirical models that are developed through field experiment or literature review to extract the relevant parameters. The export coefficient model (ECM) is based on the idea that the nutrient loads exported from a watershed, which are the sum of the losses from individual sources, such as land use, livestock and rural living (Omernik 1976; Johnes 1996; Bowes et al. 2005). It has been widely applied in flat and small catchments. Ding et al. (2010) developed this model into improved export coefficient model (IECM) by considering the impact of the spatial heterogeneity of rainfall and terrain on NPS pollution. It was demonstrated that the IECM provided better results than ECM when applying in the large-scale watersheds. Besides, Chinese scholars developed overall estimate method (OEM) for NPS pollution loads estimation in the large-scale watershed (Cheng et al. 2006; Hao et al. 2006). The essence of OEM is a binary-structure model, which considers both natural and anthropogenic factors, combining the empirical and physical calculation. However, this generalized linear model is set up for frame watershed planning level and the expression of nutrients loss in channel processes is still relatively weak.

In order to get more accurate results, many physical-based models have been successfully developed for NPS pollution simulation, including Soil and Water Assessment Tool (SWAT) (Arnold et al. 1993; Gassman et al. 2007), SWRRB (Williams et al. 1985; Esen and Uslu 2008), ANSWERS (Beasley et al. 1980; Singh et al. 2006), HSPF (Bicknell et al. 2001; Ribarova et al. 2008), AGNPS (Young et al. 1989; Cho et al. 2008), etc. These physical-based models can well characterize the NPS pollution process and provide more precise results. When applying these physical models in the large-scale watershed, the best way is whole watershed precision calculate method (WWPCM), which estimates NPS pollution load with physical-based models in all small catchments within the watershed, then the total NPS pollution loads of the whole watershed can be attained. However, values of a large number of parameters cannot be obtained from field data and must instead be determined through model calibration. Therefore, the demand for parameters and computation efficiency due to the complexity of the models hinder the application to some extent (Singh et al. 2005), especially in developing countries with a shortage of the observed data.

Based on this situation, it is expected that the small-scale watershed extended method (SWEM) can provide a good support for NPS pollution loads estimation in the large-scale watersheds in spite of insufficient data. SWEM is the method which adopts SWAT or other physical-based models in several typical small catchments of a large watershed, and then the parameters of these typical catchments are extended to the surrounding areas until the NPS pollution loads in the whole watershed can be attained. This method can be implemented as long as the selected small catchments have sufficient data.

The Three Gorges Reservoir Region (TGRR) is located in the upper reach of Yangtze River, covered an area of 54,000 km^2. Along with the rapid population growth and economic development in this region since 1980s, the ecological environment has changed rapidly because of excessive cultivation and over-fertilizing, leading to serious NPS pollution problems (Lu and Higgitt 2001; Chen et al. 2007, 2008). As a potential threat for the aquatic environment in Yangtze River, it is imperative to quantify and control the NPS pollution in this region to maintain sustainable development. In this study, SWEM is adopted to estimate the NPS pollution loads in the middle part of the TGRR, which covered an area of ~12,500 km^2. The objective of this study is to validate the applicability of SWEM and quantify the NPS pollution in this area, which will be helpful for the decision makers in control and management. And the extension research all over the TGRR will be carried out after this pilot study. It is expected that it will also provide a practical way for developing countries to conduct NPS pollution loads estimation and support the aquatic environment management in the large-scale watershed or region.

Materials and methods

SWAT model

As mentioned above, the SWEM adopts the physical-based model in the typical watersheds to attain the appropriate parameters, and then extends the parameters to the entire region to obtain the total NPS pollution loads. In this study, SWAT model was selected for SWEM application due to its satisfied applicability (Gassman et al. 2007). SWAT is a physically based, continuously distributed model (Arnold et al. 1993). It operates on a daily time step and is designed to predict the impact of management practices on hydrology, sediment and water quality in an ungauged watershed. An interface between SWAT and Arcinfo GIS allows the model to be run on a geographical information system that contains a digital elevation model (DEM), a land-use map, a soil map and a stream network map. In SWAT, a watershed is delineated into multiple sub-watersheds, which are then further subdivided into hydrologic response units (HRUs) that include homogeneous slope, land-use and soil characteristics. Estimated flow, sediment yield and nutrient loads for each subbasin are then routed through the river system.

The SWAT Calibration and Uncertainty Programs (SWAT-CUP), developed by expand for EAWAG, Neprash Cooperation and Texas A&M University, was adopted for parameter calibration and validation (Abbaspour 2008). This calibration package links four procedures for calibration, validation and uncertainty analysis of SWAT models. Since previous studies have showed that Sequential Uncertainty Fitting version 2 (SUFI2) method is very efficient in calibration of large watersheds (Abbaspour et al. 2007; Akhavan et al. 2010), the SUFI2 method, which also considers the parameter uncertainty to some extent

(Abbaspour et al. 2004, 2007), was selected for calibration. The Nash–Sutcliffe efficiency coefficient, E_{NS}, can be used to assess the degree of fit between the observed data and the simulated data (Nash and Sutcliffe 1970), with 1.0 being the highest possible value indicating best fit.

$$E_{\mathrm{NS}} = 1 - \frac{\sum_{i=1}^{n}\left(Q_{\mathrm{sim},i} - Q_{\mathrm{mea},i}\right)^2}{\sum_{i=1}^{n}\left(Q_{\mathrm{mea},i} - \overline{Q}_{\mathrm{mea}}\right)^2} \quad (1)$$

where $Q_{\mathrm{mea},i}$ is the observed data, $Q_{\mathrm{sim},i}$ is the simulated data, $\overline{Q}_{\mathrm{mea}}$ is the mean value of the observed data and n is the simulation time.

Site description and data availability

The TGRR covers an area of more than 54,000 km^2, including part of Sichuan, Hubei Provinces and Chongqing Municipality. In this study, the middle part of the TGRR, about 12,500 km^2, was clipped as the study area for NPS pollution loads estimation by SWEM. The location of the study area is shown in Fig. 1, as well as the elevation (Fig. 1a) and land-use map (Fig. 1b).

In this area, there are 11 first level tributaries larger than 100 km^2, namely Huangjinhe (HJ River), Ruxihe (RX River), Dongxihe (DX River), Hexihe (HX River), Rangduhe (RD River), Wuqiaohe (WQ River), Zhuxihe (ZX River), Xiaojiang (XJ River), Tangxihe (TX River), Modaoxi (MD River) and Changtanhe (CT River). Considering the data availability, XJ River was screened as the typical one for SWAT simulation to obtain the accurately calibrated and validated parameter group. The watershed covers a drainage area of 5,498 km^2, with an average annual stream flow volume of 1.6 billion m^3. The average temperature is 10.8–18.0 °C and the annual precipitation is around 1,200 mm. In this study, the watershed is divided into 63 subbasins by SWAT. The location is shown in Fig. 1c and the data used in this study are listed in Table 1.

Results and discussion

Sensitivity analysis

Soil and Water Assessment Tool model contains large quantities of parameters. Sensitivity analysis is used to screen the most sensitive parameters to enhance the efficiency in calibration and validation. Morris qualitative screening method was adopted for sensitivity analysis. These parameters were assumed to have a uniform distribution and to be independent of each other, and the analysis results are listed in Table 2. It can be seen that for the

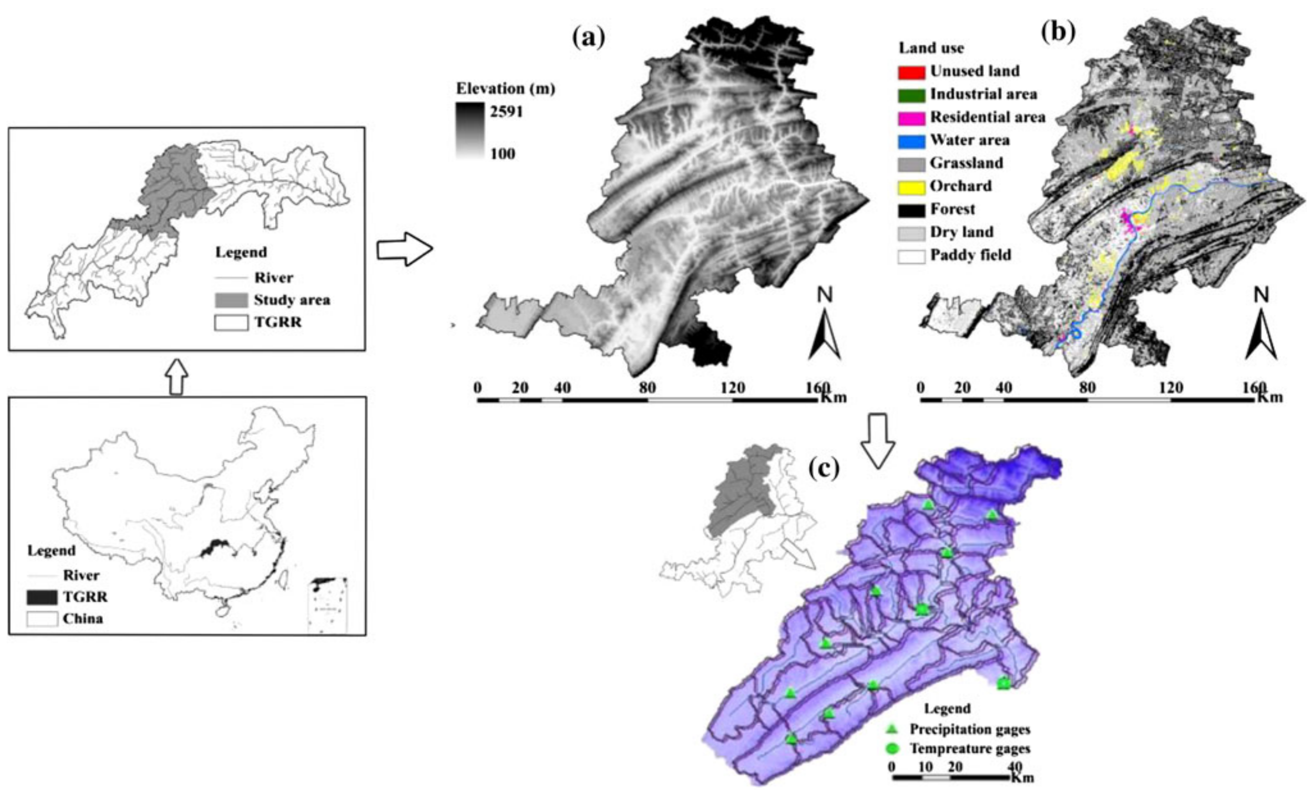

Fig. 1 Elevation (**a**), land use (**b**) of the middle part of the TGRR and the location of XJ Watershed (**c**)

Table 1 Data type scale and data description

Data type	Scale	Data description	Source
Digital elevation model	1:250,000	Elevation, overland and channel slopes and lengths	Institute of Geographical and Natural Resources Research, Chinese Academy of Sciences; National Geomatics Center of China
Land use	1:100,000	Land-use classifications	Institute of Geographical and Natural Resources Research, Chinese Academy of Sciences
Soil properties	1:1,000,000	Soil physical and chemical properties	Institute of Soil Science, Chinese Academy of Sciences
Weather	8 stations	Precipitation	China Meteorological Administration; Local Bureau of Meteorology
Hydrology and water quality			Local hydrographical station and environmental monitoring station
Social economical data		Population, livestock rearing, fertilizer application	Field investigation; statistics yearbook

Table 2 Parameter sensitivity analysis of SWAT model in XJ Watershed

Variable	Parameter	Description	Lower limit	Upper limit	Rank
Flow	*SOL_AWC*	Available water capacity of the soil layer	0	1	1
	SOL_K	Saturated hydraulic conductivity of the first layer	−20	30,000	2
	ESCO	Soil evaporation compensation coefficient	0	1	3
	GWQMN	Threshold water level in the shallow aquifer for the base flow	0	5,000	4
	CN2	SCS moisture condition II curve number for pervious areas	−25	19	5
	CANMX	Maximum canopy storage	0	10	6
	SOL_Z	Depth from soil surface to the bottom of the layer	−25	25	7
N	*SOL_ORGN*	Initial humic organic nitrogen in the soil layer	0	10,000	1
	NPERCO	Nitrate percolation coefficient	0	1	2
	SOL_NO3	Initial NO_3 concentration in the soil layer	0	100	3
P	*SOL_ORGP*	Initial humic organic phosphorus in the soil layer	0	400	1
	PPERCO	Phosphorus percolation coefficient	10	18	2
	PHOSKD	Phosphorus soil partitioning coefficient	100	200	3
	RCHRG_DP	Deep aquifer percolation fraction	0	1	4
	SOL_LABP	Initial labile (soluble) phosphorous concentration in the surface layer	−25	25	5

stream flow, *SOL_AWC*, *SOL_K* and *ESCO* were the three most sensitive parameters, and the following sensitive parameters were *GWQMN*, *CN2*, *CANMX* and *SOL_Z*. For the nitrogen, the most sensitive parameters were *SOL_ORGN*, *NPERCO* and *SOL_NO3*. For the phosphorous, *SOL_ORGP*, *PPERCO* and *PHOSKD* were identified as the most sensitive parameters.

CN2 has been reported to be the most important parameters in stream flow simulation (Van Griensven et al. 2006), but it exhibited a relatively low sensitivity in this study, which was similar to the study conducted by Francos et al. (2003). This may be due to the *CN2* updating feature of SWAT. For the nitrogen and phosphorous, the initial concentration in the soil and the percolation coefficient were both identified to be in high degree of sensitivity. This showed some common features with other studies. However, the overall results illustrated that the parameter sensitivity displays region-specific properties, and the results of one catchment cannot be generalized to another identically.

Based on the sensitivity analysis, the most sensitive parameters were screened for calibration and validation to determine the most reasonable values.

Calibration and validation

The observations in the outlet of XJ Watershed were used for calibration and validation. In detail, the monthly observed data of runoff, nitrate and TP during 2004–2005 were used for calibration, and the observations in 2006 were used for validation. The calibration and validation results are shown in Fig. 2. For the stream flow, the E_{NS}

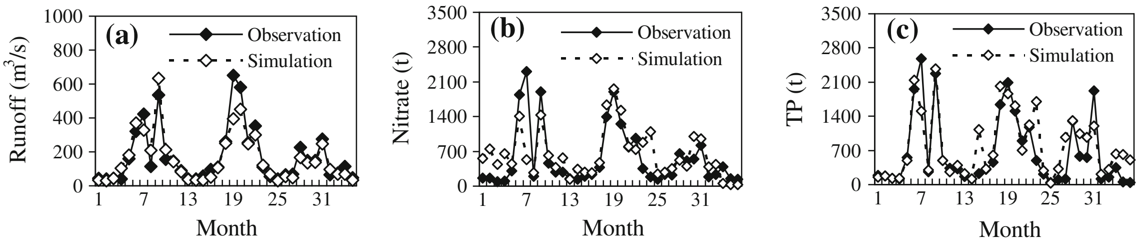

Fig. 2 Calibration and validation of runoff (**a**), nitrate (**b**) and TP (**c**) in XJ Watershed

values in the calibration and validation periods were 0.81 and 0.53, respectively. For the water quality variables, the E_{NS} values in calibration period and validation period were 0.52 and 0.41 for nitrate, 0.60 and 0.47 for TP, respectively. It can be seen that there were relatively apparent deviations between the observation and simulation in several months. This may be due to the uncertainty from the observation. The observed value based on one or two samples collected in each month may not well represent the average monthly value, especially when the precipitation changed much within 1 month. It should also be noted that the deviation in 2006 was more obvious; this can be explained by that the water storage of Three Gorges Reservoir in 2006 resulted in large areas of backwater region, and the particular hydraulic condition in backwater region would have greatly disturbed the natural stream flow and nutrients transportation. Therefore, the deviations were caused. Fortunately, according to the similar research, the calibration and validation results were acceptable (Gassman et al. 2007).

Extended simulation

With the calibrated parameters, the extended simulation for NPS pollution by SWAT was conducted in the middle part of the TGRR. The entire region was delineated into 161 subbasins and the simulating period was 2001–2009. To verify the reasonability of the simulation, the simulating results of those 11 tributaries were compared with the observations. Unfortunately, the observed sediment and nutrients were not available. Thus, considering the data availability, only the stream flow was used for comparison. The mean annual observed stream flow, collected from the year book of hydrology, was used to compare with the simulating results. Equation 2 expressed the linear fit relations, and it was found that the correlation coefficient between the observed and simulated stream flow was as high as 0.96 (Eq. 2), indicating the satisfied applicability of SWEM in TGRR.

$$y = 0.7263x - 1.7705 \quad R^2 = 0.9585 \tag{2}$$

where y is the simulated runoff (m^3/s) and x is the observed runoff (m^3/s).

Based on the simulation, the mean annual spatio-temporal distributions were analyzed. Figure 3 showed the spatial distribution of the runoff depth, sediment yield and nutrient exports in the middle part of the TGRR. It can be seen that the runoff depth and NPS pollution loads showed apparent spatial heterogeneity. For the runoff depth (Fig. 3a), the values were between 61.9 and 469.5 mm, and the spatial distribution exhibited some correlation with the elevation (Fig. 1a). In the areas of higher elevation, the runoff depth is relatively smaller, whereas in the areas of lower elevation, the runoff depth is relatively higher. This may lie in two main reasons. On one hand, in the areas of higher elevation, the percentage of forest and grassland is much higher than that of agricultural land. The curve number of forest or grassland is smaller than agricultural land, which can effectively conserve the water. While in the areas of lower elevation, the land-use type is generally dominated by agricultural land, in which the water loss is easy to induce with larger curve number. On the other hand, this is also attributed to the accumulation effect from upland to lowland. Therefore, the spatial distribution pattern of runoff showed some correlation with that of the elevation.

For the sediment yield (Fig. 3b), the load intensities ranged from 0.1 to 60.2 t/ha among those subbasins. In the SWAT model, the sediment yield was derived from Modified Universal Soil Loss Equation (MUSLE), and the main impact factors were surface runoff, peak flow, soil erodibility factor, coverage factor, cover and management factor, support practice factor, topographic factor, etc. Under the integrated influence, the exhibited macro effect indicated that the sediment yield was much associated with land-use types. According to the land-use map (Fig. 1b), we can see that the sediment yield was relatively serious in agricultural land, especially dry land. The dry land is disturbed by human activity, in which the frequent planting and harvesting makes the soil erosion easy to induce. Moreover, in the study area, down slope cultivation has been a common practice for decades. Although down slope cultivation is considered to be easier for plowing fields, it also facilitates the downward movement of water during cultivation. Therefore, the down slope cultivation promotes

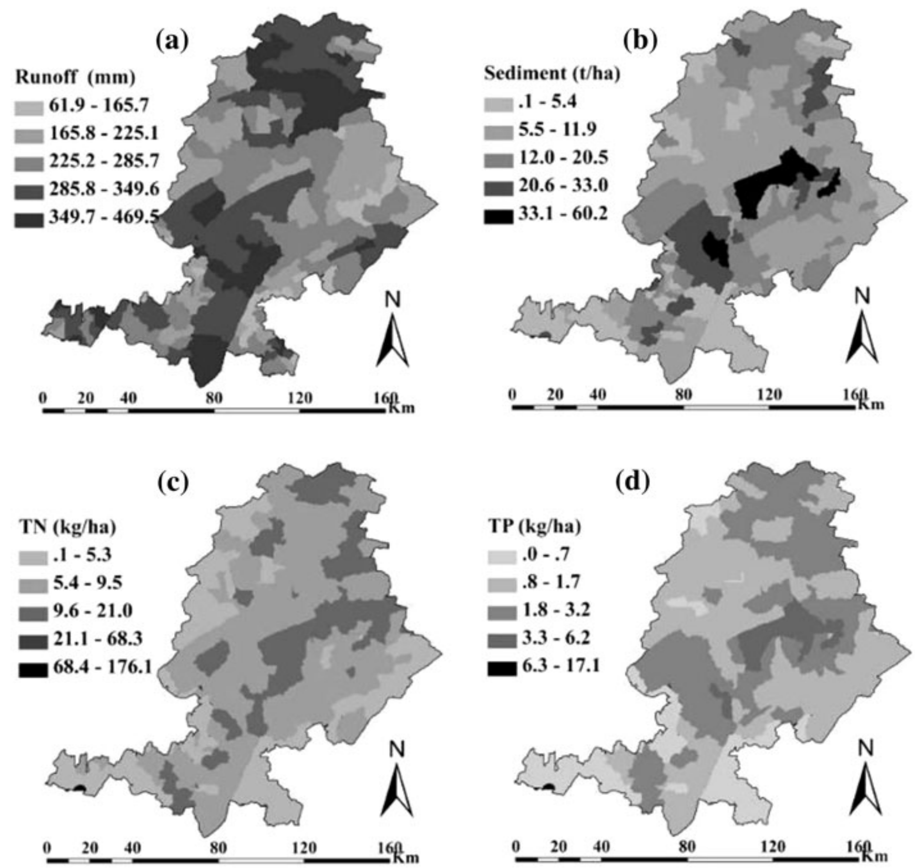

Fig. 3 Spatial distribution of runoff depth (**a**) sediment (**b**), TN (**c**) and TP (**d**) in the middle part of the TGRR

soil erosion in response to every rainfall event during the growing season.

With regard to the TN and TP (Fig. 3c, d), the load intensities ranged from 0.1 to 176.1 and 0.1 to 17.1 kg/ha, respectively. Since the phosphorous is chiefly existed in the sorption state and attached by the sediment, the distribution pattern exhibited much similarity with that of sediment yield. Based on the land use (Fig. 1b), the most polluted subbasins were also generally located in the agricultural lands, indicating the fertilization as the main contributor. The serious NPS pollution from agricultural lands is also attributed to the tillage pattern. It has been reported that regardless of the residual level, conventional tillage is less effective at reducing N in water and sediments than no-till systems (Mostaghimi et al. 1992). However, conventional tillage is just the primary tillage pattern in the TGRR. Therefore, to control the NPS management, improving the tillage pattern should be considered.

Figure 4 showed the temporal distribution of NPS pollution during 2001–2009 in the study region. From Fig. 4a, it may be found that the runoff showed much correlation with sediment. The runoff and sediment increased from 2001 to 2004, and then dropped from 2004 to 2006. In 2007, these two variables sharply increased, and then decreased after 2007. According to the rainfall, it also can be seen that the runoff and sediment exhibited apparent response relationship with rainfall, e.g., 2001 and 2006 were typical dry years, the runoff and sediment yield showed correspondingly low values. The response relationship was also identified between the rainfall and nutrients. Figure 4b showed the temporal variation of the TN and TP. The pollution loads varied with the rainfall, indicating the similar response relationship.

In this study, the NPS pollutions from each tributary were analyzed, aiming to support the watershed aquatic environment management.

The NPS pollution in different watersheds showed much difference (Table 3). For the sediment yield and nutrients, XJ River, TX River and MD River exported the most loads. This is much associated with the area of each watershed. However, the pollution load intensities were quite different with the above results. For the sediment yield, the watersheds with the highest load intensity were RD River, HX River and RX River. For the TN, the most polluted watersheds were WQ River, HX River and RX River. While with respect to the TP, TX River, HX River and WQ River exported the highest load intensity. It can be concluded that the NPS pollution load intensities exhibited large variations among different watersheds, and the load intensities of different pollutant types in the same

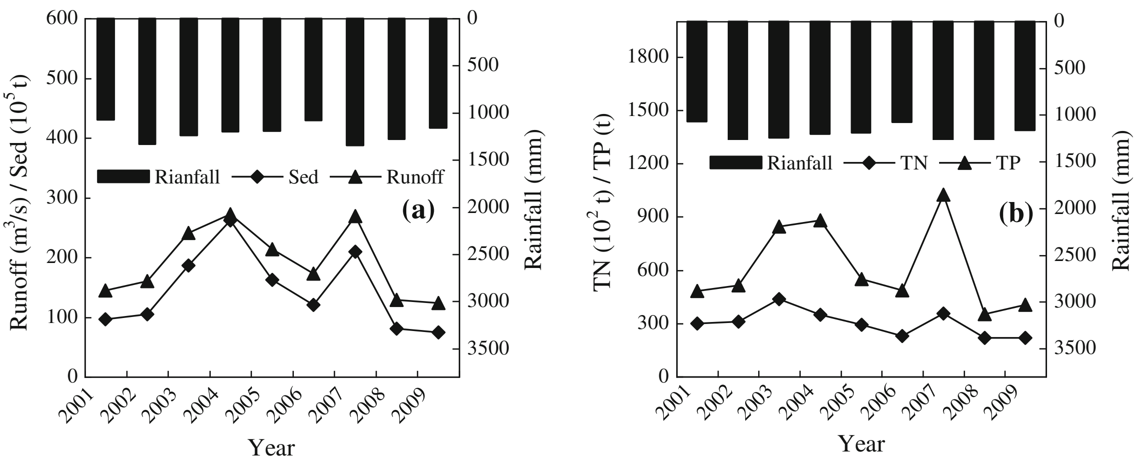

Fig. 4 Temporal distributions of rainfall, runoff, sediment (**a**), TN and TP (**b**) in the middle part of the TGRR

Table 3 Mean annual sediment and nutrients loads from the first level tributary (2001–2009)

Name	Area (km^2)	Load delivered into the TGRR			Load intensity		
		Sediment (10^4 t)	TN (t)	TP (t)	Sediment (t/ha)	TN (kg/ha)	TP (kg/ha)
HJ River	603.1	60.30	1,259.34	40.49	11.2	7.1	1.3
RX River	195.43	17.45	249.01	9.95	21.3	9.9	2.1
DX River	83.9	4.72	184.56	4.43	5.7	6.8	1.0
HX River	260.2	36.47	492.82	23.22	22.4	10.3	2.1
RD River	189.4	45.74	513.10	21.00	24.2	9.2	2.0
WQ River	111.2	15.51	399.77	13.66	13.9	10.4	2.0
ZX River	311.8	25.73	893.39	29.57	17.2	8.2	1.9
XJ River	4,696.5	811.19	14,675.66	257.27	11.6	7.4	1.7
TX River	1,741.0	281.48	7,460.67	178.84	13.5	9.3	2.1
MD River	1,454.9	130.21	3,760.70	76.43	10.6	7.1	1.6
CT River	361.7	49.69	902.69	23.66	8.1	5.3	1.3

watershed also differed much. Thus, management of different NPS pollutant types should be considered with the variations in regions. Generally, in those watersheds which exhibited relatively large pollution load intensities, the agricultural activities were more frequent in common. Simultaneously, the differences were also attributed to the different structure of land-use and soil types. Therefore, the NPS pollution different under layer surfaces were analyzed.

Table 4 showed the NPS pollution from different land-use types. For the sediment, dry land and forest were identified as the main contributors, exporting 61.09 and 20.68 % of the total sediment yield, respectively. Referring to the TN and TP, the main contributors were considered to be dry land and paddy field. This is mainly because of the nutrient abundance in the agricultural land rather than the forest. With regard to the load intensity, dry land and paddy field exported the highest load intensities for all types of NPS pollutants. The ranking sequence was found to be dry land > paddy field > forest > grassland. Although the forest exported large portion of sediment yield, the load intensity of forest was relatively low. Thus, agricultural land should be paid much attention in NPS management, and returning more agricultural land to forest and grass should be given priority.

Table 5 showed the NPS pollution from different soil types. It was found that purplish soils, yellow earths and paddy soils exported the most portions. With respect to the load intensities, there were some differences between the sediment and nutrients. The soil types which exported most sediment were paddy soils, skeletal soils and gleyed paddy soils. This is much associated with the soil properties. Those types of soils are generally categorized into hydrological soil group A or B, indicating the strong penetration and low soil compaction, which is vulnerable to wash away and cause soil erosion. While for the nutrients, paddy soils, yellow earths and purplish soils were found to have high

Table 4 Mean annual NPS pollution export from the primary land-use types (2001–2009)

Land use	Load						Load intensity		
	Sediment (10^4 t)	%	TN (t)	%	TP (t)	%	Sediment (t/ha)	TN (kg/ha)	TP (kg/ha)
Dry land	1,042.76	61.09	8,976.36	64.13	1,892.34	71.54	22.84	19.66	4.14
Paddy field	140.36	8.22	1,602.22	11.45	343.53	12.99	11.13	12.70	2.72
Forest	353.01	20.68	2,409.34	17.21	262.89	9.94	9.70	6.62	0.72
Grassland	164.89	9.66	1,004.79	7.18	145.19	5.49	6.30	3.34	0.55
Total	1,701.02	100	13,992.71	100	2,643.95	100	–	–	–

Table 5 Mean annual NPS pollution export from soil types (2001–2009)

Soil type	Load						Load intensity		
	Sediment (10^4 t)	%	TN (t)	%	TP (t)	%	Sediment (t/ha)	TN (kg/ha)	TP (kg/ha)
Dark-brown earths	36.51	2.14	248.27	1.78	66.18	2.50	12.16	8.27	2.20
Skeletal soils	6.63	0.39	5.64	0.04	2.60	0.10	57.72	4.91	2.27
Calcium skeletal soils	0.16	0.01	1.24	0.01	0.72	0.03	4.94	3.85	2.24
Rendzina	4.79	0.28	19.90	0.14	2.59	0.10	25.73	10.70	1.39
Yellow-cinnamon soils	0.02	0.00	0.73	0.01	0.17	0.01	0.37	1.27	0.29
Yellow earth soils	5.58	0.33	154.88	1.11	18.80	0.71	5.04	14.00	1.70
Yellow earths	437.52	25.59	3,731.39	26.76	508.63	19.20	16.26	13.87	1.89
Yellow-brown earths	0.03	0.00	0.51	0.00	0.09	0.00	0.71	1.26	0.21
Yellow brown earth soils	5.87	0.34	29.46	0.21	6.09	0.23	12.11	6.08	1.26
Gleyed paddy soils	7.11	0.42	22.77	0.16	7.08	0.27	34.37	11.00	3.42
Paddy soils	547.04	31.99	1,000.21	7.17	269.74	10.18	65.88	12.04	3.25
Calcareous purple soils	35.29	2.06	250.81	1.80	57.13	2.16	9.43	6.70	1.53
Limestone soils	67.31	3.94	759.37	5.45	134.25	5.07	6.12	6.91	1.22
Acid purple soils	92.06	5.38	485.75	3.48	128.81	4.86	17.01	8.97	2.38
Submergic paddy soils	0.09	0.01	0.90	0.01	0.24	0.01	1.16	1.20	0.32
Brown earths	2.23	0.13	25.73	0.18	5.90	0.22	2.43	2.80	0.64
Purplish soils	440.55	25.76	7,065.16	50.66	1,432.91	54.08	8.03	12.88	2.61
Neutral purple soils	8.25	0.48	51.53	0.37	7.59	0.29	11.22	7.01	1.03
Hydromorphic paddy soils	12.90	0.75	91.55	0.66	0.00	0.00	30.99	21.99	2.73
Total	1,709.94	100	13,945.8	100	2,649.52	100	–	–	–

load intensities. The nutrient sources of soils mainly originated from the background value and fertilization amount. By comparing these two aspects, it can be concluded that the formula fertilization by soil testing should be carried on for NPS management.

Conclusion

In the middle part of the TGRR, the NPS pollution exhibited apparent tempo-spatial heterogeneity. The runoff depth showed some relation with the elevation, and the sediment yield was correlated with the coverage and land-use types. The nutrients exported more from areas covered by agricultural land. The runoff, sediment yield and nutrients showed good response relationship with rainfall during 2001–2009.

With respect to the first level tributaries in the region, the NPS pollution load intensities exhibited large variations among different watersheds, and the load intensities of different pollutant types in a watershed also differed much. RD River showed most serious pollution in the sediment yield. WQ River needs better protection from TN and TX River deserves more control and management in TP. According to the NPS pollution from different land-use types, the sediment and nutrients were mainly contributed by the agricultural land and forest. Referring to the soil types, the paddy soil, purplish soils and yellow earths exported much higher NPS pollution. Generally, the agricultural land should be paid much attention in NPS management and the formula fertilization by soil testing should be carried on.

Considering the data shortage in developing countries, SWEM is an effective method for NPS pollution loads estimation in the large-scale watersheds or regions. After the pilot study, the extension research all over the TGRR will be carried out.

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References

Abbaspour KC (2008) SWAT-CUP2: SWAT calibration and uncertainty programs—a user manual. Department of Systems Analysis, Integrated Assessment and Modelling (SIAM), Eawag, Swiss Federal Institute of Aquatic Science and Technology, Duebendorf

Abbaspour K, Johnson C, Van Genuchten MT (2004) Estimating uncertain flow and transport parameters using a sequential uncertainty fitting procedure. Vadose Zone J 3(4):1340–1352

Abbaspour KC, Yang J, Maximov I, Siber R, Bogner K, Mieleitner J, Zobrist J, Srinivasan R (2007) Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. J Hydrol 333(2–4):413–430

Akhavan S, Abedi-Koupai J, Mousavi SF, Afyuni M, Eslamian SS, Abbaspour KC (2010) Application of SWAT model to investigate nitrate leaching in Hamadan-Bahar Watershed. Iran Agric Ecosyst Environ 139(4):675–688

Arnold JG, Allen PM, Bernhardt G (1993) A comprehensive surface-groundwater flow model. J Hydrol 142(1–4):47–69

Bach M, Letzel M, Kaul U, Forstner S, Metzner G, Klasmeier J, Reichenberger S, Frede HG (2010) Measurement and modeling of bentazone in the river Main (Germany) originating from point and non-point sources. Water Res 44(12):3725–3733

Beasley DB, Huggins LF, Monke EJ (1980) ANSWERS: a model for watershed planning. Trans ASAE 23(4):938–944

Bicknell BR, Imhoff JC, Jobes TH, Kittle JLJ, Donigian ASJ (2001) Hydrological Simulation Program—Fortran (HSPF Version 12): user's manual. U.S. Environmental Protection Agency, Washington, DC

Bowes MJ, Hilton J, Irons GP, Hornby DD (2005) The relative contribution of sewage and diffuse phosphorus sources in the River Avon catchment, southern England: implications for nutrient management. Sci Total Environ 344(1–3):67–81

Chang M, McBroom MW, Scott Beasley R (2004) Roofing as a source of nonpoint water pollution. J Environ Manag 73(4):307–315

Chen LD, Huang ZL, Gong J, Fu BJ, Huang YL (2007) The effect of land cover/vegetation on soil water dynamic in the hilly area of the loess plateau, China. Catena 70(2):200–208

Chen X, Yan Y, Fu R, Dou X, Zhang E (2008) Sediment transport from the Yangtze River, China, into the sea over the Post-Three Gorge Dam Period: a discussion. Quat Int 186(1):55–64

Cheng HG, Yue Y, Yang ST, Hao FH, Yang ZF (2006) An estimation and evaluation of non-point source (NPS) pollution in the Yellow River Basin. Acta Scientiae Circumstantiae 26(3):384–391 (in Chinese)

Cho J, Park S, Im S (2008) Evaluation of Agricultural Nonpoint Source (AGNPS) model for small watersheds in Korea applying irregular cell delineation. Agric Water Manag 95(4):400–408

Ding XW, Shen ZY, Hong Q, Yang ZF, Wu X, Liu RM (2010) Development and test of the Export Coefficient Model in the Upper Reach of the Yangtze River. J Hydrol 383(3–4):233–244

Esen E, Uslu O (2008) Assessment of the effects of agricultural practices on non-point source pollution for a coastal watershed: a case study Nif Watershed, Turkey. Ocean Coast Manag 51(8–9):601–611

Farenga SJ, Daniel N (2007) Making a community information guide about nonpoint source pollution. Sci Scope 30(5):12–15

Francos A, Elorza FJ, Bouraoui F, Bidoglio G, Galbiati L (2003) Sensitivity analysis of distributed environmental simulation models: understanding the model behaviour in hydrological studies at the catchment scale. Reliab Eng Syst Saf 79(2):205–218

Gassman P, Reyes M, Green C, Arnold J (2007) The Soil And Water Assessment Tool: historical development, applications, and future research directions. Trans ASABE 50(4):1211–1250

Gburek WJ, Pionke HB (1995) Management strategies for land-based disposal of animal wastes: hydrologic implications. Lewis, Boca Raton

Hao FH, Yang ST, Cheng HG, Bu QS, Zheng LF (2006) A method for estimation of non-point source pollution load in the large-scale basins of China. Acta Scientiae Circumstantiae 26(3):375–383 (in Chinese)

Humenik F, Smolen M, Dressing S (1987) Pollution from nonpoint sources. Environ Sci Technol 21(8):737–742

Hunter HM, Walton RS (2008) Land-use effects on fluxes of suspended sediment, nitrogen and phosphorus from a river catchment of the Great Barrier Reef, Australia. J Hydrol 356(1–2):131–146

Johnes PJ (1996) Evaluation and management of the impact of land use change on the nitrogen and phosphorus load delivered to surface waters: the export coefficient modelling approach. J Hydrol 183(3–4):323–349

López-Flores R, Quintana XD, Salvadó V, Hidalgo M, Sala L, Moreno-Amich R (2003) Comparison of nutrient and contaminant fluxes in two areas with different hydrological regimes (Empordà Wetlands, NE Spain). Water Res 37(12):3034–3046

Lu XX, Higgitt DL (2001) Sediment delivery to the Three Gorges 2: local response. Geomorphology 41(2–3):157–169

Mostaghimi S, Younos TM, Tim US (1992) Crop residue effects on nitrogen yield in water and sediment runoff from two tillage systems. Agric Ecosyst Environ 39(3–4):187–196

Nash J, Sutcliffe J (1970) River forecasting using conceptual models, 1. A discussion of principles. J Hydrol 10:282–290

Omernik JM (1976) The influence of land use on stream nutrient levels. U.S. Environmental Protection Agency, Washington, DC

Ongley ED, Xiaolan Z, Tao Y (2010) Current status of agricultural and rural non-point source pollution assessment in China. Environ Pollut 158(5):1159–1168

Potter KM, Cubbage FW, Blank GB, Schaberg RH (2004) A watershed-scale model for predicting nonpoint pollution risk in North Carolina. Environ Manag 34(1):62–74

Ribarova I, Ninov P, Cooper D (2008) Modeling nutrient pollution during a first flood event using HSPF software: Iskar River case study, Bulgaria. Ecol Model 211(1–2):241–246

Santhi C, Srinivasan R, Arnold JG, Williams JR (2006) A modeling approach to evaluate the impacts of water quality management plans implemented in a watershed in Texas. Environ Model Softw 21(8):1141–1157

Singh J, Knapp HV, Arnold JG, Demissie M (2005) Hydrological modeling of the Iroquois River watershed using HSPF and SWAT. J Am Water Resour Assoc 41(2):343–360

Singh R, Tiwari KN, Mal BC (2006) Hydrological studies for small watershed in India using the ANSWERS model. J Hydrol 318(1–4):184–199

Trauth R, Xanthopoulos C (1997) Non-point pollution of groundwater in urban areas. Water Res 31(11):2711–2718

Van Griensven A, Meixner T, Grunwald S, Bishop T, Diluzio M, Srinivasan R (2006) A global sensitivity analysis tool for the parameters of multi-variable catchment models. J Hydrol 324(1–4):10–23

Williams JR, Nicks AD, Arnold JG (1985) Simulator for water resources in rural basins. J Hydraul Eng ASCE 111(6):970–986

Young RA, Onstad CA, Bosch DD, Anderson WP (1989) AGNPS: a nonpoint-source pollution model for evaluating agricultural watersheds. J Soil Water Conserv 44(2):168–173