Estuarine, Coastal and Shelf Science 86 (2010) 387–394

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Comparative study of two models to simulate diffuse nitrogen and phosphorus pollution in a medium-sized watershed, southeast China

Jinliang Huang*, Huasheng Hong

Environmental Science Research Center, Xiamen University, No. 422 South-siming Road, Xiamen 361005, Fujian Province, PR China

ARTICLE INFO

Article history:
Received 12 November 2008
Accepted 2 April 2009
Available online 16 April 2009

Keywords:
non-point source pollution
watershed modeling
grid-based GIS
AnnAGNPS

ABSTRACT

The aim of this study was to compare and assess two models to calculate diffuse nitrogen and phosphorus emissions in a selected watershed. The GIS-based empirical model and the physically-based AnnAGNPS model were evaluated for comparative purposes. The methodologies were applied for the Jiulong River watershed, covering 14,700 km^2, located in southeast China, with intensive agricultural activities. The calculated loadings by AnnAGNPS model was checked by the measured values at the watershed outlet, whereas the calculated nitrogen and phosphorus emission by GIS-based empirical model spatially provided the potential values in terms of sub-watersheds, districts/counties, and land use type. Both models gave similar levels of diffuse total nitrogen emissions, which also fit well with previous estimates made in the Jiulong River watershed. Comparatively, the GIS-based empirical model gave sound results of source apportionment of non-point source pollution (NPS) from the available input data and critical source areas identification of diffuse nitrogen and phosphorus pollution. The AnnAGNPS model predicted reasonable nitrogen loading at the watershed outlet and simulated well for NPS management alternatives under changing land use conditions. The study indicated that the GIS-based empirical model has its advantage in extensive studies as a decisions support tool for preliminary design since it is easily applied to large watersheds with fewer data requirements, while AnnAGNPS has its advantage in detailed emission assessment and scenario development.

1. Introduction

Non-point source pollution (NSP), especially resulting from agricultural activities, has been identified as a significant source of water quality pollution (USEPA, 2002). Nitrogen (N) and phosphorus (P) from excessive N and P fertilizer use can be discharged into the receiving water when rainfall events and irrigation practices occur, which can induce the eutrophication phenomenon in receiving water and losses of biodiversity in the aquatic ecosystem. Therefore knowledge of N and P emissions from different pathways and sources is a key issue concerning the protection of water quality and sustainable watershed management practices (Kovacs, 2006).

Environmental models provide an efficient way for quantitatively evaluating pollutant loadings from NSP, natural processes in watershed scale and aids for control and management of NSP (Pullar and Springer, 2000; Borah and Bera, 2003). Environmental models, greatly developed since the 1980s, have provided possible solutions with the capability of modeling NSP processes exactly, including processes of rainfall-runoff, soil losses, nutrients, and sediment transportation. Unfortunately, in many cases data regarding water quality, stream flow, climate variables, etc., in catchments were found to be insufficient or inappropriate for the purpose of modeling or accurate direct estimation of loadings (Letcher et al., 2002), which is especially a big problem and challenge for the application of NSP models in China.

Model selection depends mainly on the goal of the simulation, the scale of the studied area, the availability of data, the expected accuracy, and the temporal and financial costs (Grizzetti et al., 2005; Kovacs, 2006; Kliment et al., 2008). Due to their simplicity, transparency, and good available input data, empirical models including the USLE and SCS-CN are widely used to roughly evaluate long-term average estimates of soil loss or runoff volume of large regions up to the size of large river basins (Sivertun and Prange, 2003; Shi et al., 2007). However, this approach does not attempt to model processes such as surface flow, deposition, sediment, and nutrient transport and retention. On the other hand, in medium-sized areas (10^2–10^4 km^2), semi-empirical models are often applied combining physically based and empirically-derived simulation algorithms (Borah and Bera, 2003). These are often referred to as

* Corresponding author.
E-mail address: jlhuang@xmu.edu.cn (J. Huang).

0272-7714/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecss.2009.04.003

conceptual models (Beven, 2001) and enable continuous long-term predictions of runoff, soil erosion, sediment transport and other hydrological processes in larger river basins and their sub-areas (Kliment et al., 2008). Examples of conceptual erosion models include AnnAGNPS (Bingner and Theurer, 2003), HSPF (Bicknell et al., 1996) and SWAT (Arnold et al., 1998). The application of this model was limited by the data availability for model calibration and validation.

Since 1990, many researchers have focused on the evaluation and identification of pollutant loadings, critical source areas, and management practices of NSP for controlling NSP by integrating GIS with empirical environmental models at the watershed scale (Tim et al., 1992; Heidtke and Auer, 1993; Wong et al., 1997; Sivertun and Prange, 2003; Guo et al., 2004; Markel et al., 2006; Kovacs and Honti, 2008). Physically-based models such as SWAT and AnnAGNPS were used to simulate the complex processes of NPS, quantify the N and P loadings and management alternatives of NPS (Francos et al., 2001; Baginska et al., 2003; Tripathi et al., 2003; Yuan et al., 2003; Das et al., 2006; Kliment et al., 2008). However, comparative study on the application of both of these methods, namely, integrating GIS with empirical models, and physically-based models (AnnAGNPS) on the same watershed in China, was seldom conducted.

This paper presents the evaluation of two different models used for a predominantly agricultural watershed located in southeast China, to calculate diffuse nitrogen and phosphorus emissions/sources of contaminants in the Jiulong estuary.

2. Materials and methods

2.1. Description of study watershed

Jiulong River watershed, the second largest watershed in Fujian Province covering 14.7 thousand km^2 (116°46′55″–118°02′17″ E, 24°23′53″–25°53′38″ N), is situated in southeast China (Fig. 1). It has a subtropical monsoon climate. North river and West river are the two biggest branches of the Jiulong river, whose annual stream flow discharge into the Jiulong river estuary and coastal water is 8.2 billion m^3(Punan station) and 3.7 billion m^3 (Zhedian station), respectively. More than 5 million residents from Xiamen, Zhangzhou and Longyan city take Jiulong river as their water source for drinking as well as industrial and agricultural use. Administratively, it is mainly comprised of eight counties/districts, namely Zhangzhou, Xinluo, Zhangping, Hua'an, Changtai, Pinghe, Longhai, and Nangjing.

2.2. Description of AnnAGNPS model

The Annualized Agricultural Non-Point Source (AnnAGNPS) pollutant model is a continuous model for predicting surface runoff, suspended load and nutrients from medium-sized river basins in daily steps. The model is an improved version of the event model AGNPS (Young et al., 1989). Major improvements for the AnnAGNPS include a routing system, which enables continuous simulation, and the adoption of RUSLE (Renard, 1991; Bingner and Theurer, 2003). Simulated processes include direct runoff, infiltration, evapotranspiration, soil erosion and suspended sediment transport, agricultural activities, and plant growth. A modified SCS runoff curve number (CN) method estimates daily surface runoff (SCS, 1985). Soil loss is estimated using the RUSLE equation accompanied by a sediment delivery ratio depending on the time of flow concentration (Bingner and Theurer, 2003). The pollutant loading surface runoff module simulates chemical transport of particulate and soluble forms of phosphorus and nitrogen, organic carbon and pesticides using routines derived from the CREAMS model (Knisel, 1980).

2.3. GIS-based empirical model

The GIS-based empirical model is one method of integrating Grid-based GIS with three empirical equations: Soil conservation service curve number (SCS-CN), universal soil loss equation (USLE), and nutrient losses equations (Fig. 2). Nutrient losses in forms of particulate N (PN) and particulate P (PP) discharge from NSP are calculated as follows:

$$LS_{kt} = a \cdot CS_{kt} \cdot X_{kt} \quad (1)$$

where LS_{kt} in kg hm^{-2} is the nutrient losses in particulate form; a is a constant; CS_{kt} in mg kg^{-1} is the N and P concentration in the top soil layer; and X_{kt} in t hm^{-2} yr^{-1} is the average annual soil loss.

Nutrients in forms of dissolved N and dissolved P discharge from NSP are calculated as follows:

$$LD_{kt} = b \cdot CD_{kt} \cdot Q_{kt} \quad (2)$$

Where LD_{kt} in kg hm^{-2} is nutrient loadings in dissolved form; b is a constant; CD_{kt} in mg l^{-1} is nutrient concentration in surface runoff; Q_{kt} in millimeters is the runoff volume. kt means that specific diffuse pollutants (e.g. TN, TP) discharge from stormwater runoff on specific areas k (1 hm^2) at specific times t (year).

Nutrient losses equations were integrated with the grid-based geographic information system (GIS) to evaluate the contributors and sources apportionment of nitrogen and phosphorus loading from NSP in Jiulong River watershed. Potential diffuse nitrogen and phosphorus loadings via surface runoff were calculated. However, processes such as N and P enrichment ratio and overland delivery ratio of sediment were not considered in the nutrient losses equation in this study.

2.4. Data preparation for models

The most important input data format and types for GIS-based empirical model and AnnAGNPS model are shown in Table 1.

The values for variables in empirical models were mainly generated from GIS database and monitoring data in the field during storms. X_{kt} was obtained from applying USLE in GIS environment in the Jiulong River watershed (Huang, 2004); CS_{kt} was obtained from soil survey information in the Jiulong River watershed; CD_{kt} was obtained from data monitoring in five typical sub-watersheds of the Jiulong River watershed; Q_{kt} was obtained from the SCS-CN method mentioned above. CN was adjusted depending on the antecedent moisture condition (AMC) before each storm.

Combined with the results obtained from the CN method and USLE model, the empirical equations for calculating nutrient losses were provided to calculate the N and P loadings in forms of dissolved N and P, particulate N and P from each grid based on ARC/INFO software. The total N and total P loadings and sources for Jiulong River watershed can be calculated and evaluated based on each GRID in Jiulong River watershed. Sub-watersheds and counties/districts of Jiulong River watershed were separately used as the spatial unit to show the spatial variability of N and P loadings and analyze the major contributors of agricultural non-point source pollution for each county or district.

The input data set for AnnAGNPS is extensive and may consist of up to 33 sections of data including catchment physical characteristics (e.g. soil type, texture, particle distribution, pH, hydraulic conductivity, organic and inorganic N and P ratios in soil layers, land slope, slope length, steepness), detailed management practices and daily climatic records of minimum and maximum

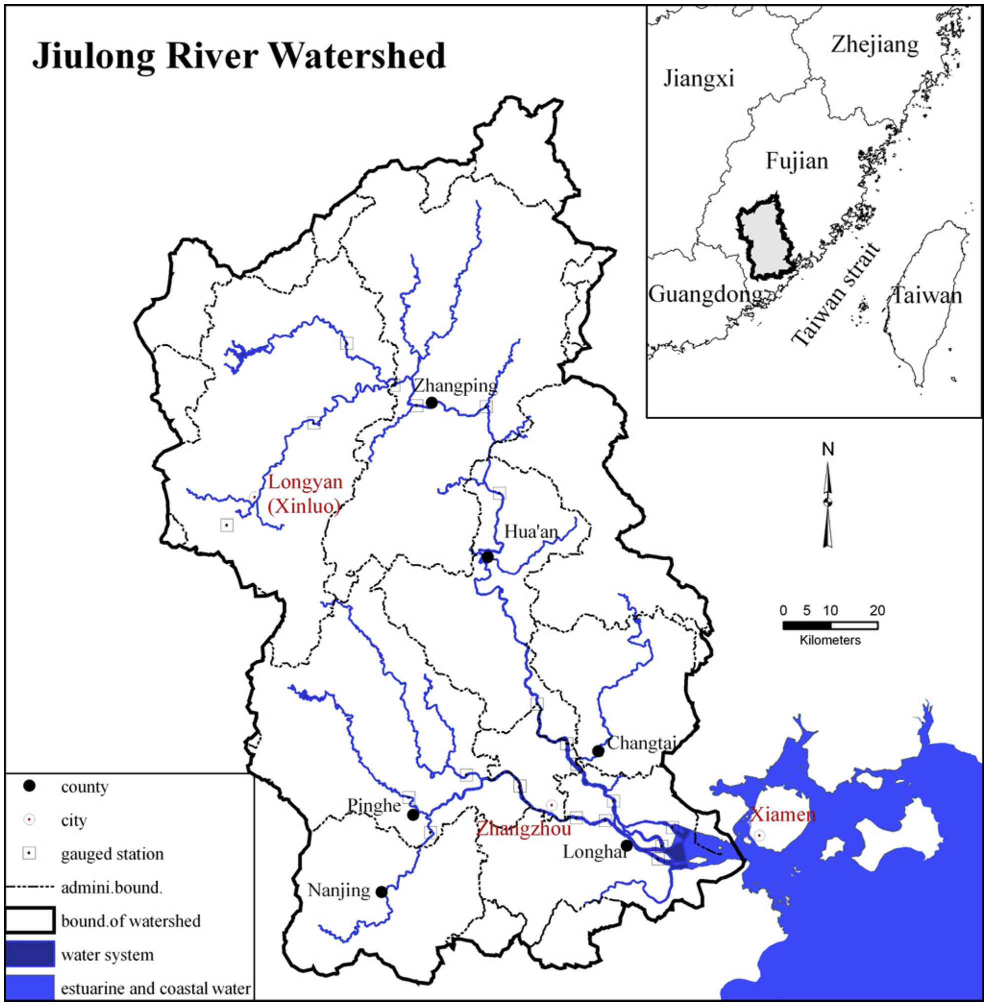

Fig. 1. Location of the study watershed.

temperatures, rainfall, dew point, sky cover and wind speed. The AnnAGNPS Input Editor was used to develop and modify the input data to the pollutant loadings model. Most of the input parameters were sourced from the measured data and where the data were not available, the parameters were estimated based on the literature and the reference data provided with the modeling system.

2.5. Watershed delineation

The AnnAGNPS model assumes that there is uniform precipitation for the whole watershed. But in fact, there is a large spatial variability for precipitation in the Jiulong River watershed. Hilly and mountainous areas occupy more than 60% of the Jiulong River watershed, which leads to spatial and temporal distribution of rainfall erosive power differing throughout Jiulong River watershed and during the year. In order to decrease uncertainty of the model associated with the natural geographical features of the watershed, the whole watershed is further divided into two big branches, namely North river and West river. AnnAGNPS is separately validated in two branches by the data regarding climate and land-use conditions in 2002–2003. The two biggest branch watersheds, i.e. North river and West river watersheds, were modeled by the AnnAGNPS model, and delineated into 2351 and 908 drainage areas (amorphous cells), respectively (Fig. 3).

The AnnAGNPS model was multi-site calibrated by trial-and-error process in four typical sub-watersheds of Jiulong River watershed, i.e., Tianbao (0.8 km^2), Xiandu (1.1 km^2), Xiazhuang (6.2 km^2) and Yanshi (3.5 km^2) from storm events during the period April to September, 2003. The calibrated model was further verified in the two biggest branches of Jiulong River watershed, namely West river and North river, by the data regarding climate and land-use conditions during the period of 2 years from January 2002 to December 2003. Then the nitrogen and phosphorus loading at the outlet of the watershed was predicted and the management alternatives for controlling NSP were simulated under changing land-use conditions.

The entire watershed was discretized into 1,470,000 grid cells each with cell size of 100 m $\times$ 100 m in the GIS-based empirical model. The GIS-based empirical model was applied in its original form.

3. Results and discussion

Two different watershed modeling tools were applied for the Jiulong River watershed for the period of 2002–2003.

3.1. Emissions of GIS-based empirical model

Diffuse TN and TP loadings in the study watershed vary among land-use types, which were used in this study to determine the pollution sources of NSP (Huang, 2004). As a result, the contribution of four pollution sources that led to agricultural non-point

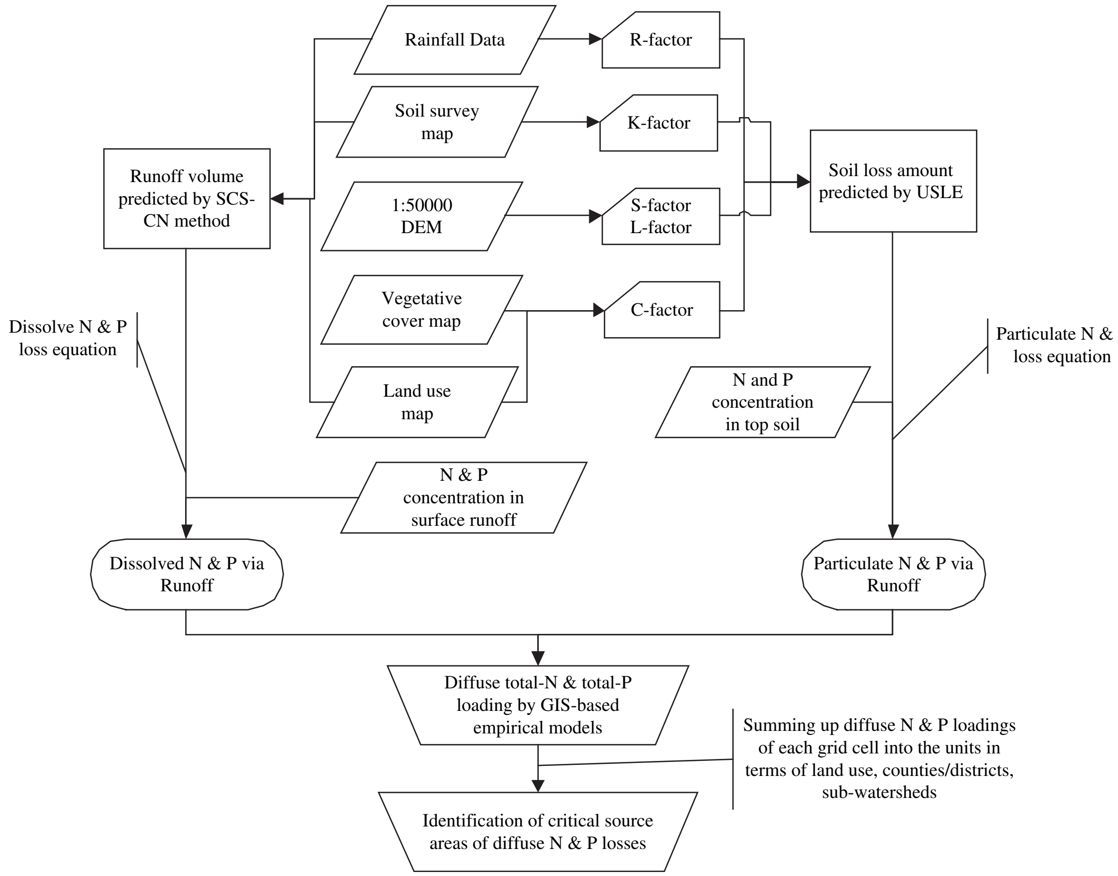

Fig. 2. Methodology schema of GIS-based empirical model.

source pollution, namely soil losses, excessive fertilizer use, rural sanitary waste and livestock breeding, was analyzed. It should be mentioned that the source and contribution of diffuse TN and TP from excess fertilizer, soil losses and rural domestic wastewater was estimated based on the pollutant loadings in terms of land-use type. Source and contribution of diffuse TN and TP from livestock breeding was calculated by rural yearbook and in-situ survey coupled with empirical discharge coefficient. The calculated nitrogen emission by the GIS-based empirical model is presented in Table 2 and Fig. 4.

As Table 2 and Fig. 4 show, as a whole, for total N, sources from excessive fertilizer use, livestock breeding, rural domestic wastewater and soil losses occupied 53.4%, 21.0%, 13.3, and 12.4%, respectively. For total P, sources from excessive fertilizer use, livestock breeding, soil losses and rural domestic wastewater contributed 40.8%, 31.4%, 14.7% and 13.1%, respectively. Obviously, excessive fertilizer use and livestock breeding are the major contributors for total N and total P.

From such a method, it can be found that there are different sources and contributors for N and P loadings for major counties/districts in Jiulong River watershed. In other words, the GIS-based empirical model made it possible to obtain sound results of source apportionment of NPS for the administrative units in Jiulong River watershed. The total N and total P in Xinluo district is mainly from livestock breeding and soil losses, contributing 40.6% and 24.2% of total N, and 51.1% and 24.0% of total P, respectively. The total N in Zhangping is mainly from excessive fertilizer use and soil losses, adding 38.8% and 29.4%, respectively. The total P in Zhangping is mainly from soil losses and excessive fertilizer use, adding 34.1% and 27.8%, respectively. The total N in Zhangzhou district is mainly from excessive fertilizer use and livestock breeding, contributing 48.0% and 46.9%, respectively, the total P in Zhangzhou district is

Table 1
Input data formats of major parameters for AnnAGNPS and GIS-based empirical model.

Data	Data format	Data source
DEM	Grid (cell size 100 × 100 m)	46 DEMs with a scale of 1:50,000
Soil map	Vector map (polygon)	soil surveys at 1:200,000 scale
Land use map	Vector map (polygon)	Landsat-TM data by unsupervised classification
Soil parameter database	Table (text file)	Soil surveys in Fujian
Crop database	Table (text file)	AnnAGNPS document
Database of agricultural management operation	Table (text file)	AnnAGNPS document
Daily precipitation	Table (text file)	Climate station
Maximum and minimum daily air temperature, relative humidity, percentage of sky cover, wind speed[a]	Table of daily values	Climate station

[a] Used for AnnAGNPS.

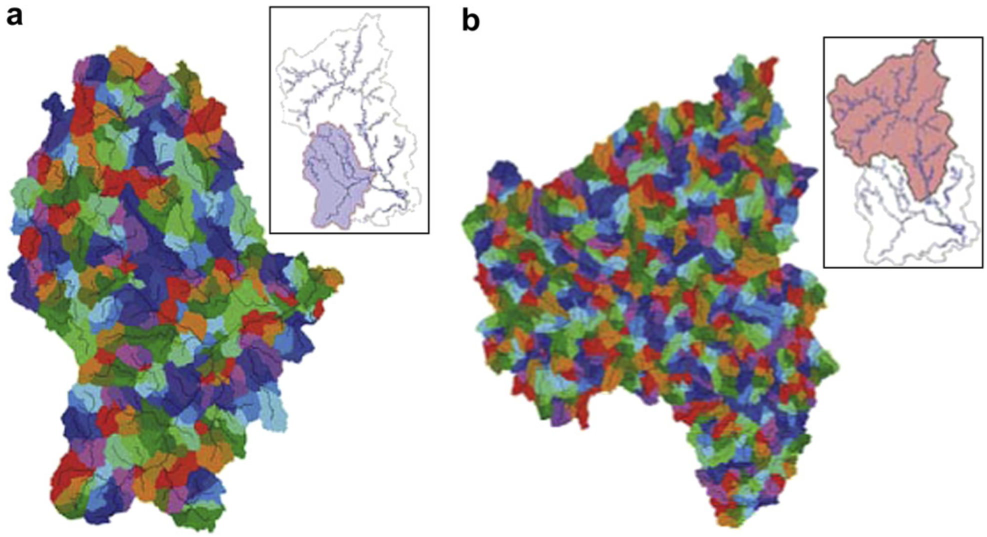

Fig. 3. Cell divisions for West river and North river by AnnAGNPS–ArcView interface. (a)-North river watershed; (b) West river watershed. Note: source from Hong et al. (2005).

mainly from livestock breeding and excessive fertilizer use, adding 61.6% and 34.8%, respectively. Excessive fertilizer use plays an important role in total N in Longhai, Changtai, Hua'an, Nanjing and Pinghe counties, all adding over 50% of total N.

The GIS-based empirical model was intentionally applied as not calibrated in this study to mimic the general situation of the watersheds without gauged station or sparse monitoring data regarding stream flow and water quality in China. This situation of model application has previously been reported in Korea (Jang et al., 2007), which is considered as normal at the planning level (Novotny, 2003).

3.2. Emissions of AnnAGNPS method

Four typical sub-watersheds were primarily chosen to calibrate the AnnAGNPS model by data collected from storm events during the period of April to September, 2003. The calibration results show that, with deviation errors (*Dv*) of less than ±9%, runoff volume for most of observed and simulated storm events show a high level agreement for all four sub-watersheds. This is similar to the results of former studies that report AnnAGNPS as good in predicting runoff volume (Shamshad et al., 2008). All four watersheds calculated satisfactorily total N and dissolved N yield, with deviation errors (*Dv*) of less than ±5%, respectively.

The model was further validated in the two biggest branches of Jiulong River watershed, i.e. West river and North river, by the data regarding climate and land-use conditions in 2002–2003 (Fig. 3). As shown in Fig. 3, for West river and North river the percentage of deviation error in surface runoff is within ±20% and correlation coefficient R^2 is 0.99 and 0.95, respectively. But the simulated sediment yield does not compare well with measured value for West river and North river, in particular North river. Prediction of nitrogen and phosphorus exports was acceptable, with average errors of ±30% (see Fig. 5).

After calibration and validation, the simulation results by AnnAGNPS showed that annual total nitrogen loadings were

Table 2
Sources and contributions of diffuse Total-N and Total-P loadings for main counties/districts in Jiulong River watershed. Unit: t yr^{-1}.

Counties/districts in Jiulong River watershed	TN loadings	Source from soil losses	Source from excess fertilizer use	Source from rural domestic wastewater	Source from livestock breeding
Pinghe (PH)	1434.2	182	859.2	181.1	211.9
Nanjing (NJ)	1696.8	200.9	1013.7	287.9	194.3
Longhai (LH)	2220.8	24.7	1509.2	316.4	370.5
Zhangzhou District (ZZ)	1138.7	0.3	546.6	57.6	534.2
Changtai (CT)	1400.1	31.2	1131	87.6	150.3
Hua'an (HA)	1071.0	182.5	583.5	168.3	136.7
Zhangping (ZP)	1415.9	415.6	549.7	280.7	169.9
Xinluo District (XL)	2083.4	505.0	456.4	276.2	845.8
Total	12460.9	1542.2	6649.3	1655.8	2613.6
Counties/districts in Jiulong River watershed	**TP loadings**	**Source from soil losses**	**Source from excess fertilizer use**	**Source from rural sanitary waste**	**Source from livestock breeding**
Pinghe (PH)	161.1	25.2	79.1	20.7	36.1
Nanjing (NJ)	187.3	27.5	92.8	34.0	33.0
Longhai (LH)	219.3	3.4	121.5	31.5	62.9
Zhangzhou District(ZZ)	149.0	0	51.9	6.0	91.1
Changtai (CT)	139.0	4.3	99.1	9.9	25.7
Hua'an (HA)	117.5	24.7	49.8	19.8	23.2
Zhangping (ZP)	162.7	55.5	45.3	32.6	29.3
Xinluo District (XL)	281.0	67.5	38.5	31.5	143.5
Total	1416.9	208.1	578.0	186.0	444.8

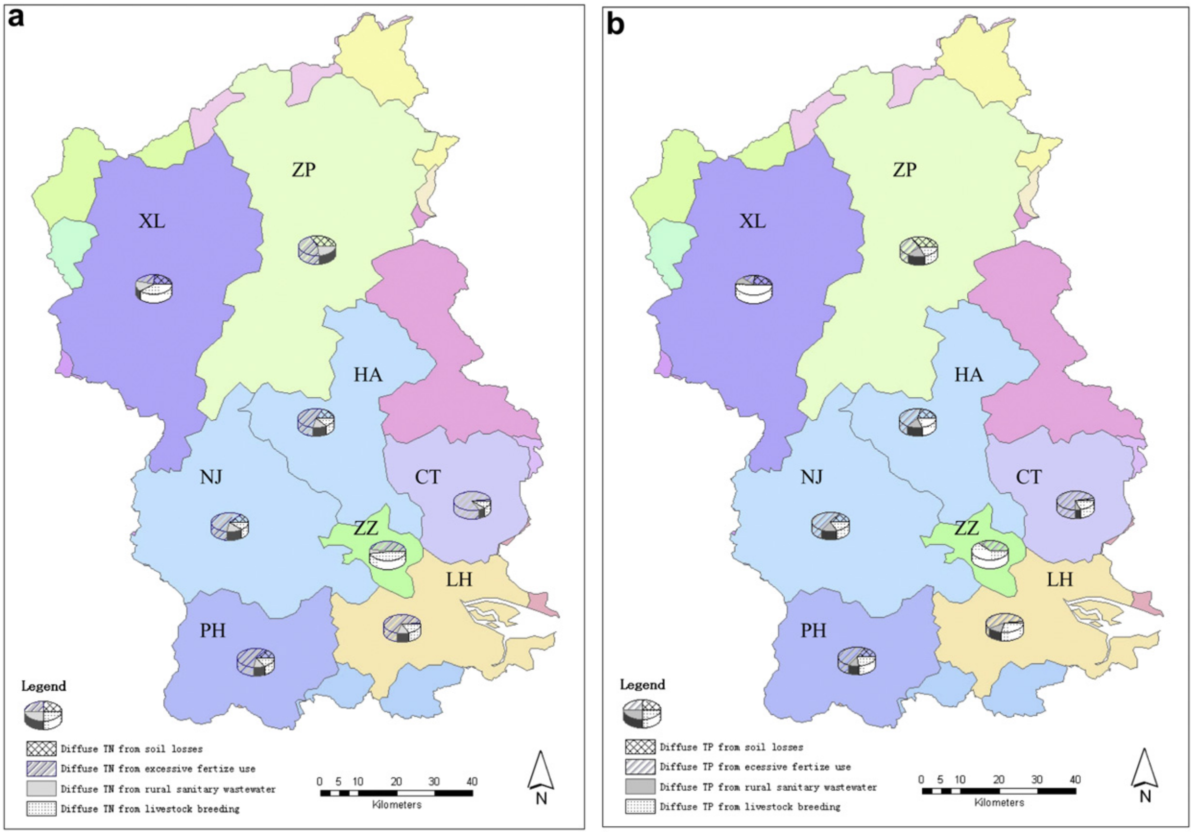

Fig. 4. Sources and contributor of N from NSP for major administrative units in Jiulong River watershed (a) TN; (b) TP. PH, Pinghe; NJ, Nanjing; LH, Longhai; ZZ, Zhangzhou; CT, Changtai; HA, Hua'an; ZP, Zhangping; XL, Xinluo.

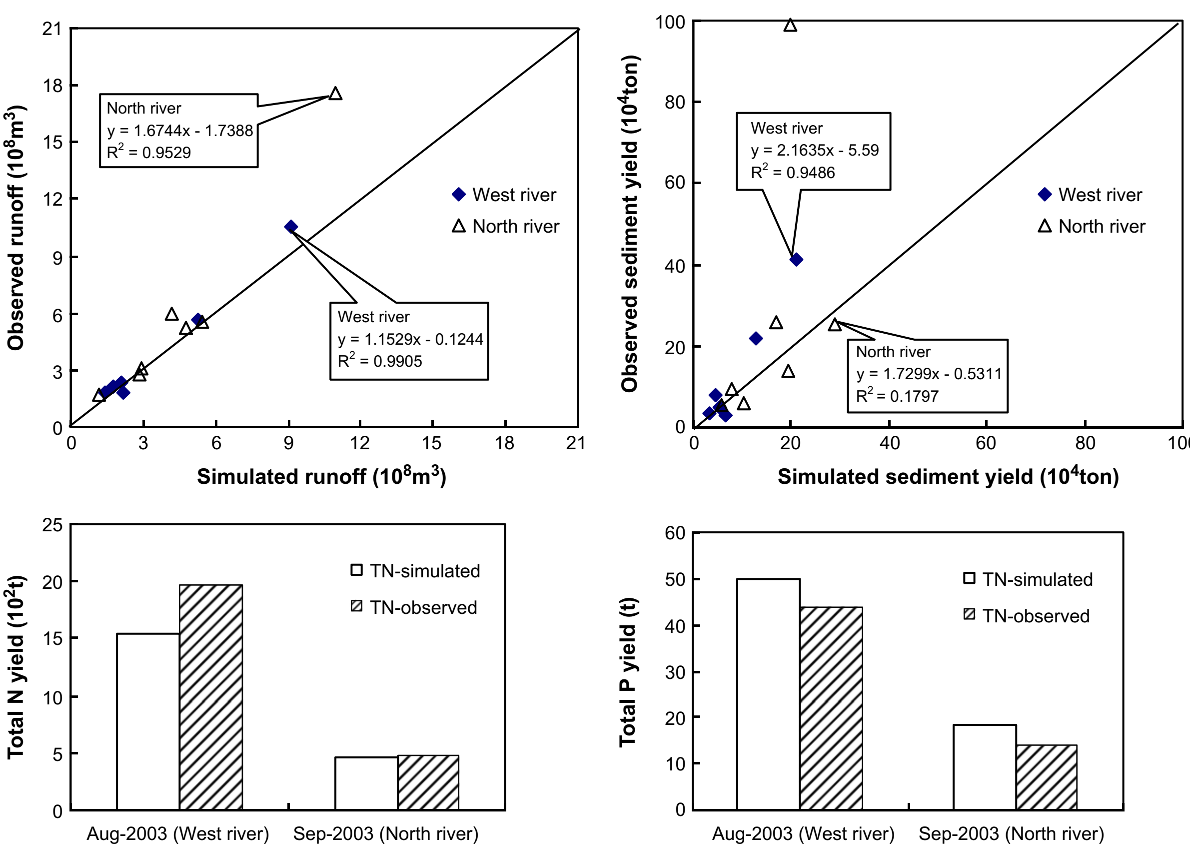

Fig. 5. Comparison of simulated and observed runoff and sediment yield, TN, TP for model validation for West river and North river watersheds. Note: source from Hong et al. (2005).

Table 3
Comparisons of N and P loadings by two models and other studies in Jiulong River watershed. Unit: kg hm^{-2} yr^{-1}.

Component	GIS-based empirical model[a]	AnnAGNP[b]	Chen et al. (1985)[c]	Cao et al. (2005)[d]	Wang et al. (2006)[e]	Sun (1997)[e]
TN	11.07	12.72	3.88			
TP	1.35	0.41	0.04–0.07			
DIN				6.33		
NH_4-N					1.38	1.70

[a] TN and TP loadings estimated by GIS-based empirical model are 16,270 t and 1980 t, respectively. TN and TP loadings are calculated via dividing TN and TP flux by area of study watershed (14,700 km^2), and then multiplying by 10.
[b] TN and TP loadings estimated by AnnAGNPS model is 17,480 t and 5700 t, respectively. TN and TP loadings are calculated via dividing sum value of annual average TN, TP fluxes from West river and North river by the sum value of area of West river and North river watershed (13,744.14 km^2), and then multiplying by 10.
[c] TN and TP flux estimated by Chen et al. (1985) is 5700 t and 57–109 t, respectively. TN and TP loadings are calculated via dividing TN and TP flux by area of study watershed (14,700 km^2), and then multiplying by 10.
[d] DIN flux estimated by Cao et al. (2005) is 9300 t. DIN loading is calculated via dividing DIN flux by area of study watershed (14,700 km^2), and then multiplying by 10.
[e] NH_4-N flux estimated by Wang et al. (2006) and Sun, 1997 is 2500 t and 3500 t, respectively. NH_4-N loading is calculated via dividing NH_4-N by area of study watershed (14,700 km^2), and then multiplying by 10.

24.76 kg hm^{-2} yr^{-1} and 10.28 kg hm^{-2} yr^{-1} in the West river and North river, respectively, and annual total phosphorus loadings were 0.67 kg hm^{-2} $yr^{-1}$and 0.4 kg hm^{-2} yr^{-1} in the West river and North river, respectively.

3.3. Comparison of the diffuse nitrogen and phosphorus loadings

Comparison of simulated TN and TP loadings by the two models is presented in Table 3. Regarding TN loading, there islittle difference between the two methods whereas for TP loading, there is a big difference. But it should be mentioned that the result by the GIS-based empirical model provided only the potential values of TN and TP loadings for the entire watershed, whereas the result by AnnAGNPS is the sum value of the TN and TP fluxes at the catchment outlet of the West river and North river, respectively. The first method did not conclude the processes of sediment and pollutants transport and retention, merely focusing on the spatial distribution of annual nitrogen and phosphorus loading in terms of sub-watersheds, administrative units and land-use units, which facilitated us to locate the critical source areas with the aid of the GIS method. TN and TP loadings of each grid cell were summed up into the unit of each land use, and four sources for TN and TP from NSP were further put forward and discussed (Huang, 2004), namely: soil losses, excessive fertilizer use, rural domestic wastewater and livestock breeding. The quantitative results regarding contributor or source of NSP in Jiulong River watershed was firstly mentioned and used as a reasonable explanation for NSP in Jiulong River watershed. This method showed the advantage of little data requirement and applicability by integrating Grid-based GIS with empirical models (Letcher et al., 2002; Kliment et al., 2008).

The AnnAGNPS model contains the nitrogen and phosphorus routing sub-model, which facilitated calculation of the TN and TP loadings at the catchment outlet. As shown in Table 3, N load simulated by AnnAGNPS is approximately close to the value of some studies in Jiulong River watershed (Table 3). Cao et al. (2005) estimated the DIN loading in Jiulong River watershed at 6.33 kg hm^{-2} yr^{-1}. The simulated TN loading of Chen et al. (1985) in Jiulong River watershed is 3.88 kg hm^{-2} yr^{-1}.

Additionally, as a distributed parameters model, AnnAGNPS can be used to simulate NSP processes and management alternatives. In such a study, several management alternatives were separately simulated in the typical sub-watersheds, West river and North river. In the specific cell with cell-ID 92 in Tianbao and Xiandu sub-watershed, after reforesting in a sloping field, the runoff surface, sediment yield, TN and TP loadings were reduced by 21.6%, 25.9%, 96% and 79.2%, respectively. In West river, after changing the cultivation plant from banana to rice, TN, dissolved nitrogen, TP and dissolved phosphorus were reduced by 23.83%, 25.44%, 9.08% and 19.84%, respectively. In North river, on removing all the hoggeries, the TN and dissolved nitrogen fell by 63.54% and 76.92%, respectively.

It can be assumed that AnnANGPS has its advantage in simulating the processes including surface flow, sediment, and nutrient transport and retention, and can provide detailed results for TN and TP from the outlet of the catchment. Management alternatives can also be further simulated aided by scenario analysis, which is helpful in the control of NSP in Jiulong River watershed. On the other hand, it should be mentioned that the AnnAGNPS model should be calibrated and validated by sufficient water including water quality data, stream flow, and rainfall measurement. In this study, due to the lack of long-term monitoring data, calibration and validation of the AnnAGNPS model should be further carried out in the future.

4. Conclusions

The GIS-based empirical model and the physically-based AnnAGNPS model were evaluated for comparative purposes. The methodologies were applied for the Jiulong River watershed, covering 14,700 km^2, located in southeast China, with intensive agricultural activities. The calculated loadings by the AnnAGNPS model were checked by the measured values at the watershed outlet, whereas the calculated nitrogen and phosphorus emission by the GIS-based empirical model spatially provided the potential values in terms of sub-watersheds, districts/counties, and land-use type. Both models gave similar levels of diffuse total nitrogen emissions, which also fit well with previous estimates made in Jiulong River watershed. Comparatively, the GIS-based empirical model gave sound results for source apportionment of NPS from the available input data and critical source areas identification of diffuse nitrogen and phosphorus pollution. The AnnAGNPS model predicted reasonable nitrogen loadings at the watershed outlet and simulated well for NPS management alternatives under changing land-use conditions. The study indicated that the GIS-based empirical model has its advantage in extensive studies as a decision support tool for preliminary design since it is easily applied to large watersheds with fewer data requirements, while AnnAGNPS has its advantage in detailed emission assessment and scenario development.

Acknowledgments

The authors wish to acknowledge the government of Fujian province for providing financial assistance to conduct this study (No. 2002H009 and No. 2007F3093). The Monitoring station of EPB in Zhangzhou city is also acknowledged by the authors for providing zealous support in analyzing the samples collected during storms.

References

Arnold, J.G., Srinivasan, R., Muttiah, R.S., et al., 1998. Large area hydrologic modeling and assessment: part I: model development. Journal of American Water Resources Association 34, 73–89.

Baginska, B., Milne-Home, W., Cornish, P.S., 2003. Modelling nutrient transport in Currency Creek, NSW with AnnAGNPS and PEST. Environmental Modelling & Software 18, 801–808.

Beven, K.J., 2001. Rainfall-Runoff Modelling—The Primer. John Wiley and Sons, Chichester, UK. 360pp.

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., et al., 1996. Hydrological Simulation Program—Fortran, Version 12, User's Manual. AQUA TERRA Consultants, Mountain View, California, USA.

Bingner, R.L., Theurer, F.D., 2003. AnnAGNPS technical processes: documentation version 3. Available at http. www.ars.usda.gov/Research/docs.htm?docid=7000 2003 Accessed 11.10.2006.

Borah, D.K., Bera, M., 2003. Watershed-scale hydrologic and nonpoint-source pollution models: Review of mathematical bases. Transactions of the ASAE 46 (6), 1553–1566.

Cao, W., Hong, H., Yue, S., 2005. Modelling agricultural nitrogen contributions to the Jiulong River estuary and coastal water. Global and Planetary Change 47, 111–121.

Chen, S.T., Ruan, W.Q., et al., 1985. Chemical properties of nutrient elements and fluxes in Jiulong river estuary. Tropical Oceanology 4 (4), 16–24 (in Chinese).

Das, S., Rudra, R.P., Goel, R.K., et al., 2006. Evaluation of AnnAGNPS in cold and temperate regions. Water Science and Technology 53 (2), 263–270.

Francos, A., Bidoglio, G., Galbiati, L., et al., 2001. Hydrological and water quality modeling in a medium-size coastal zone. Physics and Chemistry of the Earth 26 (1), 47–52.

Guo, H.Y., Wang, X.R., Zhu, J.G., 2004. Quantification and index of non-point source pollution in Taihu Lake region with GIS. Environmental Geochemistry and Health 26, 147–156.

Grizzetti, B., Bouraoui, F., Marsily, G.D., 2005. Modelling nitrogen pressure in river basins: A comparison between a statistical approach and the physically-based SWAT model. Physics and Chemistry of the Earth 30, 508–517.

Heidtke, T.M., Auer, M.T., 1993. Application of GIS-based nonpoint source nutrient loading model for assessment of land development scenarios and water quality in Owasco Lake, New York. Water Science and Technology 28, 595–604.

Hong, H., Huang, J., Zhang, L., et al., 2005. Modelling pollutant loadings and management alternatives in Jiulong River watershed with AnnAGNPS. Chinese Journal of Environmental Science 26 (4), 63–69 (in Chinese).

Huang, J.L., 2004. Study on Agricultural Non-point Source Pollution of Jiulong River Watershed Based on GIS and Environmental Models. PhD thesis, Xiamen University. (in Chinese).

Jang, S., Cho, M., Yoon, J., et al., 2007. Using SWMM as a tool for hydrologic impact assessment. Desalination 212, 344–356.

Kliment, Z., Kadlec, J., Langhammer, J., 2008. Evaluation of suspended load changes using AnnAGNPS and SWAT semi-empirical erosion models. Catena 73, 286–299.

Knisel., 1980. CREAMS: A Field Scale Model for Chemical, Runoff, and Erosion from Agricultural Management Systems. USDA, Conservation Research Report 26.

Kovacs, A., 2006. Comparative study of two watershed scales to calculate diffuse phosphorus pollution. Water Science and Technology 53 (2), 281–288.

Kovacs, A., Honti, M., 2008. Estimation of diffuse phosphorus emissions at small catchment scale by GIS-based pollution potential analysis. Desalination 226, 72–80.

Letcher, R.A., Jakeman, A.J., Calfas, M., et al., 2002. A comparison of catchment water quality models and direct estimation techniques. Environmental Modelling & Software 17, 77–85.

Markel, D., Somma, F., Evans, B.M., 2006. Using a GIS transfer model to evaluate pollutant loads in the Lake Kinneret watershed, Israel. Water Science and Technology 53 (10), 75–82.

Novotny, V., 2003. Water Quality: Diffuse Pollution and Watershed Management, second ed. John Wiley & Sons Inc., New York, 864 pp.

Pullar, D., Springer, D., 2000. Toward integrating GIS and Catchments Models. Environment Modelling & Software 15, 451–459.

Renard, K.G., 1991. RUSLE: Revised Universal Soil Loss Equation. Journal of Soil and Water Conservation 46 (1), 30–33.

Shamshad, A., Leow, C.S., Ramlah, A., et al., 2008. Application of AnnAGNPS model for soil loss estimation and nutrient loading for Malaysian conditions. International Journal of Applied Earth Observation and Geoinformation 10 (3), 239–252.

SCS (Soil Conversation Service), 1985. Hydrology, section 4. In: SCS National Engineering Handbook. United States Department of Agriculture, Washington, DC.

Shi, P., Yuan, Y., Zhen, J., et al., 2007. The effect of land use/cover change on surface in Shenzhen region, China. Catena 69, 31–35.

Sivertun, A., Prange, L., 2003. Non-point source critical area analysis in the Gisselo Watershed using GIS. Environmental Modelling & Software 18, 887–898.

Sun, 1997. Calculation of contaminations fluxes from major streams to sea in Fujian province, China. Fujian Environment 14 (1), 17–18 (in Chinese).

Tim, U.S., Mostaghimi, S., Shanholtz, V.O., 1992. Identification of critical nonpoint source pollution source areas using geographic information systems and water quality modelling. Water Resource Bulletin 28 (5), 877–887.

Tripathi, M.P., Panda, R.K., Raghuwanshi, N.S., 2003. Identification and prioritization of sub-watersheds for soil conservation management using SWAT model. Biosystems Engineering 85 (3), 365–379.

USEPA, 2002. National Water Quality Inventory: Report to Congress. EPA 841-R-07–001. Office of Water, Washington, DC, 39 pp.

Wang, W., Hong, H., Zhang, Y., et al., 2006. Preliminary estimate for the contaminations fluxes from Jiulong river to the sea. Marine Environmental Science 25 (2), 45–57 (in Chinese).

Wong, K.M., Strecker, E.W., Stenstrom, M.K., 1997. GIS to estimate storm-water pollution mass loading. Journal of Environmental Engineering 123 (8), 737–745.

Young, R.A., Onstad, C.A., Bosch, D.D., et al., 1989. AGNPS: A nonpoint-source pollution model for evaluating agriculture watersheds. Soil and Water Conservation 44 (2), 168–173.

Yuan, Y.P., Binger, R.L., Rebich, R.A., 2003. Evaluation of AnnAGNPS nitrogen loading in an agricultural watershed. Journal of the American Water Resource Association 39 (2), 457–466.