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Effects of ecological factors and human activities on nonpoint source pollution in the upper reach of the Yangtze River and its management strategies

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Abstract

The effects of ecological and human activities on nonpoint source (NPS) pollution are key issues for sustainable water resources management. In this study, the Improved Export Coefficient Model and the Revised Universal Soil Loss Equation were adopted to estimate the annual loads of NPS pollutants during the period from 1960 through 2003 in the upper reach of the Yangtze River (URYR). Ecological factors and human activities affecting NPS pollution were distinguished and their respective effects were assessed. Variations of the dominant cause (between ecological factors and human activities) were presented. Furthermore, the combined effect of them on NPS pollution were successfully revealed. The results showed that the annual loads raised from ecological factors of dissolved nitrogen (DN) and dissolved phosphorus (DP) were relatively steady from 1960 to 2003. But those of sediment, absorbed nitrogen (AN) and absorbed phosphorus (AP) decreased during that period. In terms of the annual loads caused by human activities, those of dissolved pollutants increased from 1960 to 2000 and then fell. Those of sediment as well as absorbed pollutants peaked in 1980 and then decreased. Simultaneously, the dominant cause of DN loads shifted from ecological factors to human activities after 1980 while DP loads were mainly contributed by human activities. However, sediment, dissolved pollutants were primarily exported by ecological factors. Finally, strategies for managing anthropogenic activities were proposed and their effects on NPS pollution reduction were also depicted quantitatively.

1 Introduction

Nowadays, nonpoint source (NPS) pollution becomes the major cause of the impairment of surface water in many countries, such as the UK (Whitehead et al., 2007), the USA (Emili and Greene, 2013), and China (Ding et al., 2010). The affecting factors include ecological factors and human activities, which influence NPS pollution together (Shen et al., 2013). Ecological factors are primary ones considering that precipitation

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is the main driving force of NPS pollution occurrence (FitzHugh and Mackay, 2000), that terrain plays an important role in NPS pollutant transport (Wang et al., 2012), and that ecological land is a considerable source of nutrient and sediment loss (Shi et al., 2012). Human activities are also important ones, which include land development, fertilizer and pesticide applications, solid waste disposal, wastewater drainage from animal feedlots and air pollution (Ribaudo et al., 2001; Ding et al., 2010). Especially in the past decades, Human activities have affected the sources, loads and distributions of NPS pollution deeply due to economic growth, social development and pollution explosion (Duda, 1993; Bernhard and Field, 2000; Shen et al., 2013). Analyzing affecting factors and their contributors to NPS pollution has a great importance of revealing the impacts of different causes on water pollution quantificationally. Moreover, management strategies proposed based on it is also significant for water quality protection and sustainable water resources management.

Therefore, researches on affecting factors of NPS pollution have been carried out. The results indicate that ecological factors (Halpern et al., 2007) and human activities (Dumont et al., 2005) have influenced NPS pollution universally and profoundly (Seitzinger et al., 2005; Halpern et al., 2007; Abdelzaher et al., 2010; Betrie et al., 2011). Ecological factors contain meteorological and hydrologic conditions (Halpern et al., 2007), ecological background values (Braskerud, 2002), as well as environment and ecosystem for pollutant transport (Halpern et al., 2007). Human activities include nutrient input (Seitzinger et al., 2005), land development (Azzellino et al., 2006), and fertilizer utilization (Dumont et al., 2005).

The Upper Reach of the Yangtze River (URYR) is a national biodiversity conservation zone in China (Zhu and Chang, 2008) and NPS pollution in this area has revealed a significant increase during the last several decades under the influence of the monsoon on the Tibetan plateau (Li et al., 2011; Wu et al., 2012) as well as increasing population and human activities (Ma et al., 2011; Hao et al., 2011; Zhang and Lou, 2011). The casual factors of NPS pollution in the URYR has been involved in the studies developed in the Three Gorges Reservoir region and the whole upper reach (Zhang et al., 2011; Shen et al., 2013). Massive use of fertilizers (Li et al., 2009; Shen et al., 2013) and the construction of Three-Gorges Reservoir (Zhang et al., 2011) have profoundly affected NPS pollution in the URYR. Shen et al. (2013) also concluded that the dissolved pollutants were mainly contributed by the anthropogenic factors, while the absorbed pollutants were primarily exported by the natural factors.

However, most of these studies focus on monitoring, simulation, impact analysis or control measures, in which causal factors of NPS pollution are not distinguished. Few studies discuss the respective contributions of ecological factors and human activities over long term periods. So the spatial-temporal heterogeneity of the dominant causes for different NPS pollutants in such important region is still unknown. The overall goal of this study is to reveal the effects of ecological factors and human activities on NPS pollution in the URYR, which will facilitate NPS pollution control and water environment improving of the URYR and some other watersheds of large scales. Firstly, macro-scales models for dissolved pollutants and absorbed ones were developed based on the Improved Export Coefficient Model (IECM) (Johnes, 1996; Ding et al., 2010) and the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997; Shen et al., 2013), and methods for obtaining their parameters were also proposed. Then, for various NPS pollutants, the annual loads caused by different ecological factors and human activities from 1960 to 2003 were simulated and analyzed. Finally, the respectively effects of ecological factors and human activities as well as the combined ones on NPS pollution were determined based on the variation analysis of the affecting factors of NPS pollution in the URYR.

2 Materials and methods

2.1 Models

In this study, dissolved nitrogen (DN), dissolved phosphorus (DP), sediment, absorbed nitrogen (AN) and absorbed phosphorus (AP) are selected as NPS pollutants, which

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are typical ones in the URYR (Shi et al., 2004; Wang et al., 2011; Shen et al., 2013). The IECM (Ding et al., 2010) and the RUSLE (Renard et al., 1997) are adopted to simulate the dissolved pollutants and absorbed pollutants (including sediment), respectively.

2.1.1 The IECM

The IECM model is based on the Export Coefficient Model (ECM) (Johnes, 1996), which is support by the theory that the nutrient load exported from a watershed equals the sum of the losses from individual sources. The individual sources consist of rural life, livestock breeding, land use and atmospheric deposition. It is outlined as:

$$L = \sum_{i=1}^{n} E_i[A_i(I_i)] + p \quad (1)$$

where L is loss of nutrients (kg), E_i is export coefficient for nutrient source i ($\mathrm{kg\,ca^{-1}\,yr^{-1}}$ or $\mathrm{kg\,km^{-2}\,yr^{-1}}$), A_i is area of the catchment occupied by land use type i ($\mathrm{km^2}$), or number of livestock type i, or that of rural people, I_i is the input of nutrients to source i (kg), and p is the input of nutrients from atmospheric deposition (kg).

The application of the ECM model to the URYR shows an observable error in the sub-watershed of which precipitation or slope is much different from the average value of the whole URYR (Ding et al., 2010). It also indicates that precipitation and terrain are the primary factors affecting NPS pollution and should be taken into account. Therefore, the Improved Export Coefficient Model (IECM) which can characterize the impact of heterogeneity of rainfall and topography on NPS pollution is developed (Ding et al., 2010) and expressed as:

$$L = \sum_{i=1}^{n} \alpha\beta E_i[A_i(I_i)] + p \quad (2)$$

where α is the precipitation impact factor, and β is the terrain impact factor.

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The precipitation impact factor α is determined by the temporal unevenness impact factor α_t and the spatial one α_s. Moreover, α_t is identified as:

$$\alpha_t = \frac{L}{\overline{L}} = \frac{f(r)}{f(\overline{r})} \tag{3}$$

where L is the annual loss of NPS pollutants that drain into a river with runoff (kg), $\overline{L}$ is the multi-annual mean loss of NPS pollutants (kg), r is the annual precipitation in the entire study watershed for a given year (mm), and $\overline{r}$ is the multi-annual mean precipitation in the entire study watershed (mm). In addition, α_s is defined as:

$$\alpha_s = \frac{R_j}{\overline{R}} \tag{4}$$

where R_j is the annual precipitation in grid cell j (mm) and $\overline{R}$ is the mean precipitation of the entire study watershed for a given year (mm). Therefore, α can be expressed as:

$$\alpha = \alpha_t \cdot \alpha_s = \frac{f(r)}{f(\overline{r})} \cdot \frac{R_j}{\overline{R}}. \tag{5}$$

Considering its temporal invariance in a relative long period, the terrain impact factor β is defined as

$$\beta = \frac{L(\theta_j)}{L(\overline{\theta})} = \frac{c\theta_j^d}{c\overline{\theta}^d} = \frac{\theta_j^d}{\overline{\theta}^d} \tag{6}$$

where L is the pollution load (kg), θ_j is the slope for grid cell j (°), $\overline{\theta}$ is the average slope of the entire study watershed (°), and c as well as d are constants.

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2.1.2 The RUSLE model

Absorbed pollutants can be estimated by the following formula (Shen et al., 2013):

$$L_A = D_r \cdot A \cdot Q \cdot \eta \tag{7}$$

where L_A is the sediment or absorbed pollutant loss into the river ($t\,km^{-2}$), Q is the background value of absorbed pollutants in soil ($kg\,kg^{-1}$), η is the enrichment ratio of the pollutants in soil, D_r is the sediment delivery ratio, and A is the soil loss per unit area ($t\,km^{-2}$), which can be calculated by the ULSE model. The formula of the USLE model is described as (Renard et al., 1997):

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \tag{8}$$

where R is the rainfall and runoff factor, K is the soil erodibility factor, L is the slope-length factor, S is the slope-steepness factor, C is the cover and management factor, P is the support practice factor, and L, S, C, and P are defined by the ratios of the soil loss from the actual areas to that of the standard plots. Considering the temporal-spatial heterogeneity of precipitation and its importance for NPS pollution in the URYR, a revised ULSE is set up based on the hypothesis that the soil loss A is strongly linear correlated with the rainfall and runoff factor R when the other factors did not change (Wischmeier and Smith, 1978; Ding et al., 2010; Shen et al., 2013). In the URYR, the RUSLE for can be expressed as:

$$A_j = \frac{R_{\mathrm{USLE}.j}}{R_{\mathrm{ULSE.avg}}} \times A_{\mathrm{USLE.avg}} \tag{9}$$

where A_j is the soil loss in year j (kg); $R_{\mathrm{USLE}.j}$ is the rainfall and runoff factor in year j, $R_{\mathrm{USLE.avg}}$ is multi-annual mean rainfall and runoff factor, and $A_{\mathrm{USLE.avg}}$ is the multi-annual mean soil loss (kg).

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2.2 Watershed description

The URYR, which has an annual mean stream flow of $4.35 \times 10^{11}\,m^3$ and a drainage basin area of $1.05 \times 10^6\,km^2$, accounts for approximately 58 % of the entire Yangtze Basin and 11 % of the total area of China, respectively. It rises in the Kunlun Mountains at an elevation of 4,800 m and extends 4500 km to Yichang city with steep channel slopes (1×10^{-4}–4×10^{-4}). In addition to the mainstream, there are four large anabranches, namely the Jinshajiang River, Min-Tuojiang River, Jialingjiang River and Wujiang River (Fig. 1). The Three Gorges Dam, the largest Dam in the world, is located at the outlet section the URYR. Under the influence of the monsoon on the Tibetan plateau, the annual rainfall is 1000–1400 mm and soil erosion (accompanied by nutrient loss) is liable to occur (Li et al., 2011; Wu et al., 2012; Lu et al., 2003). Furthermore, it is also an important industrial and agricultural region with huge population. Extensive cultivation and livestock breeding as well as long-term improper land use have led to severe NPS pollution in the URYT.

2.3 Data collection and preparation

The data available for this study include: (i) a digital elevation model (DEM) constructed from the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences (IGSNRR, CAS) that provides a consistent coverage of topography at a resolution of 1 km; (ii) land use maps (1960–2003) with a scale of 1 : 100 000 that was constructed from digitalizing and interpreting remote sensing images provided by IGSNRR, CAS; (iii) a landform map with a scale of 1 : 1 000 000 that was constructed by the National Geomatics Center of China to form the basin boundary; (iv) meteorological data (1950–2003) collected at over 173 stations in the study area obtained from the China Meteorological Administration. The station-based rainfall data can be interpolated into each subdivided area by Linear Interpolation Method; (v) hydrological data and water quality data (1960–2003) obtained from relevant monitoring stations throughout the study area; (vi) social economic data (1960–2003) acquired

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from different levels of statistical departments in the URYR; (vii) the layer of stream network built up using the geographic information system under the assumption that an upstream catchment greater than 1 km^2 defined a channel; (vii) the background values of absorbed pollutants in the soil and soil erodibility data attained from the China Soil Scientific Database; (viii) the layers of sediment delivery ratio and the enrichment ratios derived according to literatures (Yu, 2003; Shen et al., 2013); (ix) the layer of export coefficients that is related to each spatial unit (grid cell, 1 km × 1 km) determined through calibration using the Genetic Algorithm. The data available for this study are presented in Table 1.

2.3.1 Precipitation impact factor

The relationship between the precipitation and discharge of the dissolved pollutants (DN and DP) in the URYR has been established by previous studies (Ding et al., 2010). According to Eq. (5), the precipitation impact factor α for DN and DP can be calculated as:

$$\alpha_{\mathrm{DN}} = \alpha_{\mathrm{tDN}} \cdot \alpha_{\mathrm{sDN}} = \frac{15.8907r^2 - 24712.1655r + 9851784.2910}{289579.19} \cdot \frac{R_j}{\overline{R}} \tag{10}$$

$$\alpha_{\mathrm{DP}} = \alpha_{\mathrm{tDP}} \cdot \alpha_{\mathrm{sDP}} = \frac{0.0273r^2 - 26.5101r + 11215.8465}{8226.91} \cdot \frac{R_j}{\overline{R}}. \tag{11}$$

2.3.2 Terrain impact factor

The terrain impact factor β is used to describe the effect of terrain heterogeneity on NPS pollutant loads. Many studies have demonstrated that slope gradient plays a more important role than any other parameter of terrain in NPS pollution (Gburek and Pionke, 1995; Sims et al., 1998; Ding et al., 2010; Shen et al., 2013). Therefore, based on Geographical Information System (GIS) and the DEM in the URYR, the terrain impact factor β is defined as (Ding et al., 2010):

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$$\beta_{\text{DN, DP}} = 0.2027\theta^{0.6104}. \tag{12}$$

2.3.3 Export coefficient

The NPS of the study watershed is categorized into four types, i.e. rural life, livestock breeding, land use and atmospheric deposition. According to the interpreted land use maps, the URYR was classified into paddy field, dry land, grassland, orchard, forest (except for orchard) (forest), urban land and unused land. The land uses were classified into seven types; dry land, paddy field, orchard, urban land, other forest, grassland and unused land. Considering their temporal-spatial homogeneity, the export coefficients of rural life and livestock breeding are determined based on literature review (Johnes, 1996; Zhuang, 2002). Additionally, the export coefficients of land uses are calculated using the method for obtaining parameters of export coefficient model using hydrology and water quality data (Ding et al., 2006, 2010; Shen et al., 2013). Atmospheric deposition is also an important source of NPS pollutants, but unfortunately, related data to calculate atmospheric deposition in the study area are not available. So the export coefficients of it are simplified and assigned as 33 % for DN and 6 % for DP of the total according to the researches in the URYR (Kuntz, 1980; Lovett and Lindberg, 1986; Winter, 1998; Shen et al., 2013). The export coefficients of each source in the study region are listed in Table 2.

2.3.4 Rainfall and runoff factor

Rainfall and runoff factor R is computed by the Wischmeier equation (Wischmeier and Smith, 1978; Shen et al., 2013):

$$R = \sum_{i=1}^{12} \left[1.735 \exp \left(1.5 \log \frac{p_i^2}{p} - 0.8188 \right) \right] \tag{13}$$

where p_i is the precipitation in month i (mm), and p is the annual precipitation (mm).

3 Results and discussion

The result of model validation shows that the relative errors for the whole study watershed are in the range of 5 to 10 % for the dissolved pollutants and those are between 3 and 23.3 % for sediment and the absorbed ones throughout the years from 1960 to 2003. It suggests that the IECM model and the RUSLE model are capable of NPS pollution predictions in the URYR.

In this study, the sources of dissolved pollutants include rural life, livestock breeding, land use and atmospheric deposition, while those of absorbed pollutions only involve land use. Moreover, the land use consists of paddy field, dry land, grassland, orchard, forest, urban land and unused land. From the immediate cause, different sources can be included in two categories: ecological factors and human activities. For rural life and livestock breeding, they are incorporated into human activities considering they are actions of human beings. As far as various land uses are concerned, grassland, forest, and unused land belong to ecological land owing to their natural states, while paddy field, dry land, orchard and urban land are included in anthropogenic land use considering that they are developed by human beings. Atmospheric deposition is caused by not only ecological factors but also human activities, so it is divided into two parts, i.e. atmospheric deposition raised from ecological factors (ADEF) and atmospheric deposition caused by human activities (ADHA). Therefore, ecological factors include ecological land and ADEF. Human activities contain rural life, livestock breeding, anthropogenic land use and ADHA. All of the ecological factors and human activities affecting NPS pollution in the URYR are given in Table 3. Based on the classification, effects of ecological factors and human activities on NPS pollution in the URYR from 1960 to 2003 are analyzed as following.

3.1 Effect of ecological factors on NPS pollution in the URYR

Using the IECM model and the RUSLE model, NPS pollution loads raised from different ecological factors during the period of 1960 to 2003 are calculated based on

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the constructed database (Fig. 2). In addition, the contributions of various ecological factors to annual NPS loads raised from ecological factors are also obtained (Fig. 2).

In terms of DN, the annual loads raised from ecological factors, in the range of 35.42×10^4 to 44.64×10^4 t, were relatively steady from 1960 to 2003. Among the annual loads raised from different kinds of ecological factors, those in forest, annual loads in grassland, and those due to ADEF were roughly equivalent. The multi-year mean loads in forest as well as grassland, and those due to ADEF were 12.17×10^4 t, 12.49×10^4 t and 13.27×10^4 t, respectively. Consequently contributions of the three sources to annual NPS loads raised from ecological factors, the multi-year mean values of which were 30.48, 31.37 and 33.24 %, were approximately the same. The loads and contributions of unused land, however, maintained relatively low levels from 1960 to 2003. Its multi-year mean load was 2.01×10^4 t, and its multi-year mean contribution to the DN loads raised from ecological factors equaled 4.91 %.

As for DP, the annual loads raised from ecological factors which were in the range of 0.51×10^4 to 0.64×104 t, were also generally constant during those decades. The ecological sources of DP ranked differently from those of DN: with grassland first (multi-year mean contribution equaling 48.23 %), followed by forest (37.28 %), ADEF (8.31 %), and unused land (6.19 %). The multi-year mean loads in grassland, forest and unused land were 0.27×10^4 t, 0.21×10^4 t and 0.04×10^4 t, respectively, and that raised from ADEF was 0.05×10^4 t.

As far as sediment is concerned, the annual loads raised from ecological factors, between 2.49×10^8 and 3.91×10^4 t, decreased slightly from 1960 to 2003. Among the different ecological lands, forest is identified as the dominant contributor. The multi-year mean load and its contribution to the sediment load raised from ecological factors were 2.40×10^8 t and 69.50 %, respectively. In addition, grassland had a less effect on natural sediment loss, which can be proved by the fact that the multi-year mean load and the contribution were 0.99×10^8 t and 29.32 % during the long period. However, unused land, the multi-year mean load and contribution of which were 0.04×10^8 t and

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1.18 % respectively, played only a small part in natural sediment loss due to its small area in the URYR.

With respect to AN, the annual load raised from ecological factors decreased from 46.69×10^4 to 25.24×10^4 t during 1960 to 2003. The ecological sources of AN ranked as the following: forest (with a multi-year mean load of 28.36×10^4 t and a multi-year mean contribution equaling 69.49 %), grassland (12.06×10^4 t and 29.76 %), and unused land (0.31×10^4 t and 0.75 %). Such characteristic are consistent with those of sediment raised from ecological factors, which can be explained that water and soil loss is an important driving force for AN loss.

Similarly, for AP, the annual load raised from ecological factors also decreased from 21.48×10^4 t to 11.37×10^4 t during 1960 to 2003. The contributors of AP load raised from ecological factors exhibited the same pattern as sediment and AN. The multi-year mean load of forest, grassland and unused land were 13.49×10^4 t, 5.02×10^4 t and 0.12×10^4 t, respectively. Meanwhile, the multi-year mean contribution of them equalled 72.25, 27.13 and 0.62 %. It can be seen that soil erosion is accompanied by absorbed NPS pollutants loss, the contributions of various ecological lands to which are determined by not only the characteristics of lost soil but also those of absorbed pollutants.

3.2 Effect of human activities on NPS pollution in the URYR

NPS pollution loads caused by different anthropogenic sources from 1960 to 2003 are simulated, and the contributions of various human activities to annual NPS loads cause by human activities are also evaluated (Fig. 3).

In terms of DN, the annual load caused by human activities increased significantly from 23.52×10^4 to 194.77×10^4 t during 1960 to 2000 but decreased after 2000, with an annual load of 170.46×10^4 t in 2003. Anthropogenic land use, the annual load and contribution to the anthropogenic DN load of which increased from 0.24×10^4 to 79.52×10^4 t and from 1.0 to 41.0 %, had displaced rural life, the annual load and contribution to the anthropogenic DN load of which varied from 8.70×10^4 to 17.04×10^4 t and from 37.0

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to 10.0 %, as the most important contributor during 1960 to 2003. It can be explained by that the growths of nitrogen fertilizer utilization in farmland (dry land, paddy field, and orchard) and nitrogen pollutants loss during the urbanization process were much more significant than those of the nitrogen exports of rural life, livestock breeding and ADHA. Unreasonable land development and overuse of nitrogen fertilizer have increasingly affected the loss of DN in the URYR.

As for DP, the annual load caused by human activities increased from 2.26×10^4 t in 1960 to 11.50×10^4 t in 2000, and fell to 9.19×10^4 t in 2003, which exhibited a similar trend of DN. Anthropogenic land use, with a rising annual load from 0.58×10^4 to 5.00×10^4 t and a growing contribution to the anthropogenic DP load from 25.6 to 54.4 %, had replaced rural life, with a increasing annual load from 1.10×10^4 to 1.89×10^4 t but a decreasing contribution to the anthropogenic DP load from 48.8 to 20.6 %, and become the dominant exporter. The reasons are consistent with those for DN.

As far as sediment is concerned, the annual load caused by human activities rose from 1.06×10^8 t to 2.13×10^8 t before 1980 but dipped to 0.64×10^8 t in 2003. Among the various kinds of anthropogenic land use, the major source was dry land, which accounted for 65.67 % (multi-year mean value) of the total sediment load caused by human activities, followed by paddy field (31.58 %), orchard (1.45 %) and urban land (1.30 %). Among those four land use types, that the multi-year mean load of dry land, equaling 0.96×10^4 t, is the largest.

With respect to AN, the annual load caused by human activities rose then decreased, with a peak at 2.13×10^8 t in 1980. The sort of the contributions of the various anthropogenic sources is the same with that for sediment. The multi-year mean loads were in the range of 0.10×10^4 t (urban land) to 6.78×10^4 t (dry land), while the multi-year mean contributions to anthropogenic AN load were between 1.09 (urban land) and 67.48 % (dry land). It can be found that a strong association exists between AN load and the area of land use.

For AP, the annual load caused by human activities showed an upward trend, peaked in 1980 and then decreased. Specifically, it rose from 2.95×10^4 to 6.53×10^4 t before

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1980, while it decreased to 3.37×10^4 t in 2003. The multi-year mean loads of different anthropogenic land uses (from 0.06×10^4 to 3.34×10^4 t) and their multi-year mean contributions (from 1.19 to 67.04 %) present the same characteristics as those for sediment and AN, which demonstrates that sediment erosion and absorbed pollutant loss are consistent in the URYR to some extent.

3.3 Combined effect of ecological factors and human activities on NPS pollution

In this study, the dominant cause between ecological factors and human activities of NPS pollution in the URYR were also analyzed (Fig. 4). Based on it and the analysis of Sects. 3.1 and 3.2, the combined effect of ecological factors and human activities on NPS pollution in the URYR during the period from 1960 through 2003 was revealed.

As for DN, ecological factors rather than human activities were the dominant cause before 1980. It can be approved by the fact that the annual loads raised from ecological factors accounted for 60.60 and 51.80 % of the total DN loads in 1960 and 1970 respectively. But then it converted to human activities, whose annual contributions were in the range of 69.9 to 82.80 % and revealed an increasing tendency after 1980. It can be concluded that rapid population growth, extensive livestock breeding, and excessive fertilizer use had played more and more important roles in DN pollution in the URYR.

Different from that for DN, human activities had always been the most important factor affected DP export even though its dominant source changed from rural life to anthropogenic land use. The annual load of DP cause by human activities accounted for 80.30 to 95.50 % of the total DP loads in the decades. It can be found that human activities including rapid population growth, extensive livestock breeding, excessive fertilizer use and land development, constantly played leading roles in DP export in the URYR during that period.

With respect to sediment and absorbed pollutants (AN and AP), it can be seen that their dominant cause exhibited a significant difference comparing with that of dissolved

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pollutants. Not human activities but ecological factors had always been the dominant cause. The annual loads of sediment, AN and AP raised from ecological factors made up from 63.2 to 79.60 %, 77.3 to 89.10 % and 76.70 to 87.90 % of its respective total loads in the decades. This can be explained by that sediment and absorbed pollutants export was determined by and coterminous with land use rather than rural life, livestock breeding and fertilizer use. Furthermore, ecological land, consisting of grassland and forest mainly, occupied most of the area even though agricultural and urban land expanded a lot during the period of 1960 to 2003.

3.4 Control measures and management strategies on NPS pollution in the URYR

It can be seen that NPS pollution in the URYR was deeply affected by rainfall, cultivation method, land use, nutrient management and livestock breeding simultaneously. Based on the previous simulation and analysis, control measures and management strategies on NPS pollution are put forward as following.

1. *Improving soil and water conservation and carrying out sink control*: from the previous assessment, it can be discovered that rainfall plays a significant role as a powerful driving force. Considering that rainfall is mainly caused and influenced by ecological factors rather than human activities, pollution reduction can only be conducted from "sink control" instead of "source control". The suggested means include cutting down fertilizer utilization, improving nutrient management, advancing soil and water conservation measures and implementing nutrient reduction engineering measures for farmland runoff in high-flow periods (years). According to the multi-year meteorological data, the centers of heavy rainfall are located in the DaZhou City, the Yaan City, the Panzhihua City and the Ganzi Tibetan Autonomous Prefecture of Sichuan Province, so countermeasures in those areas will promote water environmental protection and NPS pollution control for the URYR efficiently.

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2. *Advancing cultivation methods and turning downslope tillage into contour tillage*: downslope tillage is widely adopted in the URYR, and 55 % of the cultivated land is on slopes. After the great flood in 1998, a key project of soil and water conservation, including turning downslope tillage into contour tillage as an important engineering measure, has been put into effect in the URYR. This is also one of the reasons why absorbed pollutants reached their lowest levels in 2003. By scenarios simulation, it can be predicted that NPS pollution will be reduced by 9.17 % through the change from downslope tillage to contour tillage. Therefore, contour tillage should be further enforced as an effective management strategy in the URYR.

3. *Conceding farmland to nature and reducing slope erosion*: according to Soil and Water Conservation Law of the PRC, cultivation on a slope of more than 25° is banned. Previous researches have also indicated that a slope of more than 25°, in which soil is liable to erosion, is not suitable for farming. After the great flood in 1998, China has carried out conceding farmland to nature project. Aiming at the farmlands on slopes of more than 25°, the scenarios simulation of NPS pollution reduction was developed. The result shows that final implementing of conceding farmland to nature project will lead to 4.79 to 10.72 % reduces. Therefore, it is also an effective strategy for NPS pollution control in the URYR. By geographical information system (GIS) and the constructed database, it can be deduced that the farmlands on slopes of more than 25° are mainly concentrate in mountains around the Sichuan Basin, the lower reach of the Jinsha River Baisin, as well as the Wujiang River Basin. Therefore, conceding farmland to nature should focus on those farmlands.

4. *Enhancing nutrient management and lessening fertilizer loss*: the previous load simulation shows that fertilizer utilization in anthropogenic land use is the main source of DN and DP. Tendency of dissolved pollution is forecasted on the condition that the fertilizer loss is still at current loss-utilization ratio (loss

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amount/utilization amount) and no nutrient management measure is taken. The predict result shows an 8.60 % increase in DN load and a 35.36 % increase in DP load by 2020 relative to the loads in 2003. By 2050, DN land DP loads will have growths of 28 and 163 % respectively relative to the values in 2003. Therefore, nutrient management, including nutrient preserving, increasing the utilization rate of fertilizer and lessening fertilizer loss, should be regarded as a key management strategy to be further taken. According to the results of load simulation, the Sichuan Basin, the Three Gorges Reservoir Area, the Wujiang River Basin, and the lower reach of the Jinshajiang River are areas with serious nutrient loss. Therefore, more attention should be paid to those regions when nutrient management measures are taken.

5. *Controlling discharge of livestock breeding and applying centralized management*: from the results of load simulation, it can be found that livestock breeding is also a key source of dissolved pollutants. Aiming at livestock breeding, scenario simulation of pollution variation is also developed on the condition that livestock breeding expands according to the 12th five-year plan while the proportion of dissolved pollutants output (dissolved pollutant output for specific livestock breeding scale) and livestock breeding scale are uncontrolled. Comparing with the loads in 2003, it will be a 2.95 % increase in DN load and a 7.73 % increase in DP load by 2020. And by 2050, the compare results for DN and DP loads show growths of 25 and 29 % respectively. As a result, the control of nutrition loss from animal feedlots is also an effective management strategy to curtail NPS pollution in the URYR. The results of load simulation also reflect that high dissolved pollutant loads caused by livestock breeding are distributed in the Sichuan Basin, the Guiyang City and the Tongren Area of Guizhou Province, and the Three Gorges Reservoir Area, where centralized breeding should be applied, as well as discharged nutrient should be treated or recycled through measures such as producing farmyard manure and methane.

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4 Conclusions

Nowadays, nonpoint source pollution (NPS) has become the major cause of the impairment of surface water in many countries. Analyzing affecting factors and their contributors to NPS pollution have a great importance of revealing the impacts of different causes on water pollution quantitatively. This study reveals the effects of ecological factors and human activities on NPS pollution in the upper reach of the Yangtze River which is a state biodiversity conservation zone in China with increasing NPS pollution during the last several decades.

In this research, macro-scale models for dissolved NPS pollutants and absorbed ones were developed based on the Export Coefficient Model and the Revised Universal Soil Loss Equation. In addition, methods for obtaining their parameters were proposed. The relative errors for the whole study watershed are in the range of 5 to 10 % for the dissolved pollutants and those are between 3 and 23.3 % for sediment and the absorbed ones in the research watershed throughout the years from 1960 to 2003, which indicates that the proposed models are capable of NPS pollution predictions in the research area. For different nonpoint sources in the upper reach of the Yangtze River, grassland, forest, unused land, and atmospheric deposition raised from ecological factors can be included in ecological factors. Human activities consist in rural life, livestock breeding, paddy field, dry land, orchard, urban land and atmospheric deposition caused by human activities. The effect of ecological factors and human activities on the nonpoint source pollution in the research area during the period from 1960 to 2003 was analyzed. The dominant cause of dissolved nitrogen converted from ecological factors to human activities in 1980. Rapid population growth, extensive livestock breeding and excessive fertilizer use had played more and more important roles in DN pollution. As for DP, human activities constantly played leading roles in its export. With respect to sediment and absorbed pollutants, ecological factors had always been the dominant cause because of the huge area of ecological land.

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Control measures and management strategies should be taken in the upper reach of the Yangtze River to control its growing NPS pollution. Soil and water conservation and sink control should be improved in the DaZhou City, the Yaan City, the Panzhihua City and the Ganzi Tibetan Autonomous Prefecture of Sichuan Province. Cultivation method should be advanced and downslope tillage should be turned into contour tillage. Conceding farmland to nature and reducing slope erosion should be carried out in mountains around the Sichuan Basin, the lower reach of the Jinsha River Baisin, as well as the Wujiang River Basin. Nutrient management should be enhanced and fertilizer loss should be lessened in the Sichuan Basin, the Three Gorges Reservoir Area, the Wujiang River Basin, and the lower reach of the Jinshajiang River. Discharge from animal feedlots should be controlled and centralized management should be applied in the Sichuan Basin, the Guiyang City and the Tongren Area of Guizhou Province, and the Three Gorges Reservoir Area.

This study mainly focused on the effects of different causes on nonpoint source pollution in the reach of the Yangtze River. In a future study, specific and quantitative management strategies for different areas in the watershed will be proposed based on the results of this research and economic benefits analysis.

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References

Abdelzaher, A. M., Wright, M. E., Ortega, C., Solo-Gabriele, H. M., Miller, G., Elmir, S., Newman, X., Shih, P., Bonilla, J. A., Bonilla, T. D., Palmer, C. J., Scott, T., Lukasik, J., Harwood, V. J., McQuaig, S., Sinigalliano, C., Gidley, M., Plano, L. R. W., Zhu, X. F., Wang, J. D., and Fleming, L. E.: Presence of pathogens and indicator microbes at a non-point source subtropical recreational marine beach, Appl. Environ. Microb., 76, 724–732, doi:10.1128/AEM.02127-09, 2009.

Azzellino, A., Salvetti, R., Vismara, R., and Bonomo, L.: Combined use of the EPA-QUAL2E simulation model and factor analysis to assess the source apportionment of point and non point loads of nutrients to surface waters, Sci. Total Environ., 371, 214–222, doi:10.1016/j.scitotenv.2006.03.022, 2006.

Bernhard, A. E. and Field, K. G.: Identification of nonpoint sources of fecal pollution in coastal waters by using host-specific 16s ribosomal DNA genetic markers from fecal anaerobes, Appl. Environ. Microb., 66, 1587–1594, doi:10.1128/AEM.66.4.1587-1594.2000, 2000.

Betrie, G. D., Mohamed, Y. A., van Griensven, A., and Srinivasan, R.: Sediment management modelling in the Blue Nile Basin using SWAT model, Hydrol. Earth Syst. Sci., 15, 807–818, doi:10.5194/hess-15-807-2011, 2011.

Braskerud, B. C.: Factors affecting phosphorus retention in small constructed wetlands treating agricultural non-point source pollution, Ecol. Eng., 19, 41–61, doi:10.1016/S0925-8574(02)00014-9, 2002.

Ding, X. W., Liu, R. M., and Shen, Z. Y.: Method for obtaining parameters of export coefficient model using hydrology and water quality data and its application, Journal of Beijing Normal University (Natural Science), 42, 534–538, 2006.

Ding, X. W., Shen, Z. Y., Hong, Q., Yang, Z., Wu, X., and Liu, R. M.: Development and test of the export coefficient model in the upper reach of the Yangtze River, J. Hydrol., 383, 233–244, doi:10.1016/j.jhydrol.2009.12.039, 2010.

Duda, A. M.: Addressing nonpoint sources of water pollution must become an international priority, Water Res., 28, 1–11, 1993.

Emili, L. A. and Greene, R. P.: Modeling agricultural nonpoint source pollution using a geographic information system approach, Environ. Manage., 51, 70–95, doi:10.1007/s00267-012-9940-4, 2013.

Fitzhugh, T. W. and Mackay, D. S.: Impacts of input parameter spatial aggregation on an agricultural nonpoint source pollution model, J. Hydrol., 236, 35–53, doi:10.1016/S0022-1694(00)00276-6, 2000.

Gburek, W. J. and Pionke, H. B.: Management strategies for land-based disposal of animal wastes: hydrologic implications, Lewis, Boca Raton, USA, 1995.

Halpern, B. S., Selkoe, K. A., Micheli, F., and Kappel, C. V.: Evaluating and ranking the vulnerability of global marine ecosystems to anthropogenic threats, Conserv. Biol., 21, 1301–1315, doi:10.1111/j.1523-1739.2007.00752.x, 2007.

Johnes, P. J.: 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, 323–349, doi:10.1016/0022-1694(95)02951-6, 1996.

Kuntz, K. W.: Atmospheric bulk precipitation in the Great Lakes Basin, Inland Waters Directorate, Water Quality Branch, Burlingtong, Ontario, Canada, 1980.

Li, Q., Yu, M., Lu, G., Cai, T., Bai, X., and Xia, Z.: Impacts of the Gezhouba and Three Gorges reservoirs on the sediment regime in the Yangtze River, China, J. Hydrol., 403, 224–233, doi:10.1016/j.jhydrol.2011.03.043, 2011.

Li, S., Gu, S., Tan, X., and Zhang, Q.: Water quality in the upper Han River basin, China: the impacts of land use/land cover in riparian buffer zone, J. Hazard. Mater., 165, 317–324, doi:10.1016/j.jhazmat.2008.09.123, 2009.

Lovett, G. M. and Lindberg, S. E., Dry deposition of nitrate to a deciduous forest, Biogeochemistry, 2, 137–148, doi:10.1007/BF02180191, 1986.

Lu, X., Ashmore, P., and Wang, J.: Sediment yield mapping in a large river basin: the Upper Yangtze, China, Environ. Modell. Softw., 18, 339–353, doi:10.1016/S1364-8152(02)00107-X, 2003.

Ma, X., Li, Y., Zhang, M., Zheng, F., and Du, S.: Assessment and analysis of non-point source nitrogen and phosphorus loads in the Three Gorges Reservoir Area of Hubei Province, China, Sci. Total Environ., 412–413, 154–161, doi:10.1016/j.scitotenv.2011.09.034, 2011.

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., and Yoder, D. C.: Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE), US Department of Agriculture, Washington, D.C., USA, 404 pp., 1997.

Ribaudo, M. O., Heimlich, R., Claassen, R., and Peters, M.: Least-cost management of nonpoint source pollution: source reduction versus interception strategies for controlling nitrogen loss in the Mississippi Basin, Ecol. Econ., 37, 183–197, doi:10.1016/S0921-8009(00)00273-1, 2001.

Seitzinger, S. P., Harrison, J. A., Dumont, E., Beusen, A. H. W., and Bouwman, A. F.: Sources and delivery of carbon, nitrogen, and phosphorus to the coastal zone: an overview of Global Nutrient Export from Watersheds (NEWS) models and their application, Global Biogeochem. Cy., 19, GB4S01, doi:10.1029/2005GB002606, 2005.

Shen, Z. Y., Chen, L., Ding, X. W., Hong, Q., and Liu, R.: Long-term variation (1960–2003) and causal factors of non-point source nitrogen and phosphorus in the upper reach of the Yangtze River, J. Hazard. Mater., 252–253, 45–56, doi:10.1016/j.jhazmat.2013.02.039, 2013.

Shen, Z. Y., Chen, L., and Chen, T.: Analysis of parameter uncertainty in hydrological and sediment modeling using GLUE method: a case study of SWAT model applied to Three Gorges Reservoir Region, China, Hydrol. Earth Syst. Sci., 16, 121–132, doi:10.5194/hess-16-121-2012, 2012.

Shi, Z. H., Cai, C., Ding, S., Wang, T., and Chow, T.: Soil conservation planning at the small watershed level using RUSLE with GIS: a GIS study in the Three Gorge Area of China, Catena, 55, 33–48, doi:10.1016/S0341-8162(03)00088-2, 2004.

Shi, Z. H., Ai, L., Fang, N. F., and Zhu, H. D.: Modeling the impacts of integrated small watershed management on soil erosion and sediment delivery: a case study in the Three Gorges Area, China, J. Hydrol., 438–439, 156–167, doi:10.1016/j.jhydrol.2012.03.016, 2012.

Sims, J. T., Simard, R. R., and Joern, B. C.: Phosphorus losses in agricultural drainage: Historical perspective and current research, J. Environ. Qual., 27, 277–293, doi:10.2134/jeq1998.00472425002700020006x, 1998.

Wang, H. X., Shi, Y., Ma, J., Lu, C. Y., and Chen, X.: Characteristics of non-point source N export via surface runoff from sloping croplands in Northeast China, J. Renew. Sustain. Ener., 347–353, 2302–2307, doi:10.4028/www.scientific.net/AMR.347-353.2302, 2011.

Wang, X., Hao, F., Cheng, H., Yang, S., Zhang, X., and Bu, Q.: Estimating non-point source pollutant loads for the large-scale basin of the Yangtze River in China, Environ. Earth Sci., 63, 1079–1092, doi:10.1007/s12665-010-0783-0, 2011.

Whitehead, P. G., Heathwaite, A. L., Flynn, N. J., Wade, A. J., and Quinn, P. F.: Evaluating the risk of non-point source pollution from biosolids: integrated modelling of nutrient losses at field and catchment scales, Hydrol. Earth Syst. Sci., 11, 601–613, doi:10.5194/hess-11-601-2007, 2007.

Winter, J. G.: Export coefficient modeling and bioassessent in two tributaries of the Grand River, Soutkew Ontario, Canada, University of Waterloo, Ontario, 1998.

Wischmeier, W. H. and Smith, D. D.: Predicting rainfall erosion losses: a guide to conservation planning, US Department of Agriculture, Washington, D.C., USA, 62 pp., 1978.

Wu, L., Long, L., Liu, X., and Mmereki, D.: Simulation of soil loss processes based on rainfall runoff and the time factor of governance in the Jialing River Watershed, China, Environ. Monit. Assess., 184, 3731–3748, doi:10.1007/s10661-011-2220-6, 2012.

Yu, X.: A Study of Sustainable Development in Yangtze River Watershed, Science Press, Beijing, 2003.

Zhang, Q. and Lou, Z.: The environmental changes and mitigation actions in the Three Gorges Reservoir region, China, Environ. Sci. Policy, 14, 1132–1138, doi:10.1016/j.envsci.2011.07.008, 2011.

Zhu, D. and Chang, J.: Annual variations of biotic integrity in the upper Yangtze River using an adapted index of biotic integrity (IBI), Ecol. Indic., 8, 564–572, doi:10.1016/j.ecolind.2007.07.004, 2008.

Zhuang, Y.: Non-point source TN load research in Weihe Basin above Lintong section, Xi'an University of Technology, Xi'an, 2002.

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Table 1. Data available for constructing NPS database of the upper reach of the Yangtze River.

Data type	Scale	Data description	Source
DEM	1 : 250 000	Elevation, overland and channel slopesand lengths	Institute of Geographical and Natural Resources Research, Chinese Academy of Sciences; National Geomatics Center of China
Landform map	1 : 1 000 000	the basin boundary	The National Geomatics Center of China
LULC	1 : 100 000	Land use classifications	Institute of Geographical and Natural Resources Research, Chinese Academy of Sciences
Soil map	1 : 1 000 000	Soil physical and chemical properties	Institute of Soil Science, Chinese Academy of Sciences
Weather	173 stations	Weather data (1950–2003) regarding rainfall data, temperature, relative humidity and solar radiation	China Meteorological Administration
Social, economic	Data of each province	Data regarding population, cattle, pigs, sheep, poultry, planting, harvest, and tillage operations (1960–2003)	China Agriculture Yearbook; China Statistic Yearbook
Water quality and sediment data	11 stations	Sediment (1960–2003); nitrogen and phosphorus (1991–2000)	China Environment Yearbook (1989–2000); the Bulletin of Yangtze River Sediment (1960–2003)

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Table 2. Export coefficients of various nonpoint sources in the upper reach of the Yangtze River.

Nonpoint source			Export coefficients of dissolved nitrogen load	Export coefficients of dissolved phosphorus load
Rural life ($t\,ca^{-1}\,yr^{-1}$)			1.872	0.214
Livestock breeding ($t\,ca^{-1}\,yr^{-1}$)		Cattle	7.320	0.310
		Pig	1.390	0.142
		Goat	1.400	0.045
		Poultry	0.060	0.005
Land use ($t\,km^{-2}\,yr^{-1}$)	Anthropogenic land use	Paddy field	0.150	0.032
		Dry land	0.230	0.068
		Orchard	0.080	0.030
		Urban land	1.100	0.050
	Ecological land	Grassland	0.300	0.006
		Forest	0.200	0.003
		Unused land	0.500	0.008
Atmospheric deposition			33 % of the total	6 % of the total

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Table 3. Ecological factors and human activities affecting NPS pollution in the upper reach of the Yangtze River.

Cause	Factor	Land use/land cover
Ecological factors	Ecological land	Grassland Forest Unused land
	Atmospheric deposition raised from ecological factors	
Human activities	Rural life	
	Livestock breeding	
	Anthropogenic land use	Paddy field Dry land Orchard Urban land
	Atmospheric deposition caused by human activities	

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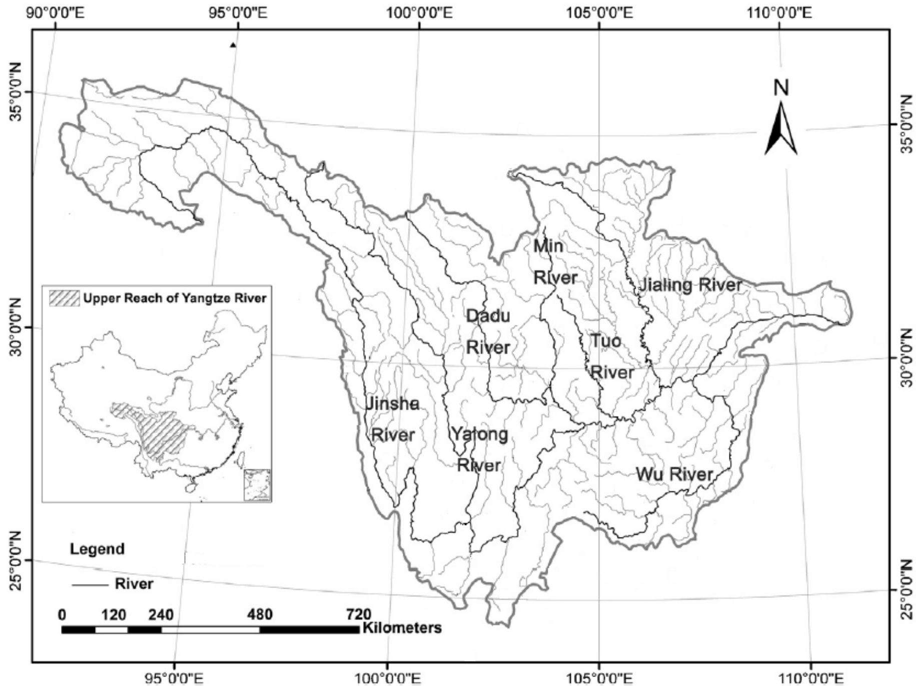

Fig. 1. Location of the upper reach of the Yangtze River and its sub-watersheds.

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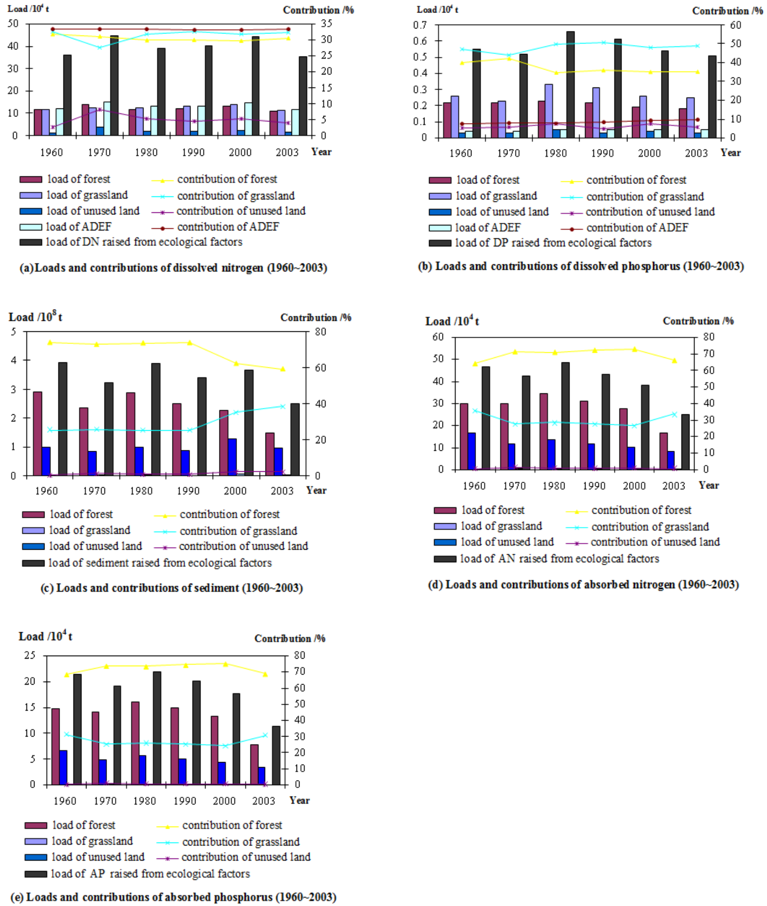

Fig. 2. Loads of ecological factors and their contributions to total natural loads (1960–2003) (DN: dissolved nitrogen; DP: dissolved phosphorus; AN: absorbed nitrogen; AP: absorbed phosphorus; ADEF: atmospheric deposition raised from ecological factors).

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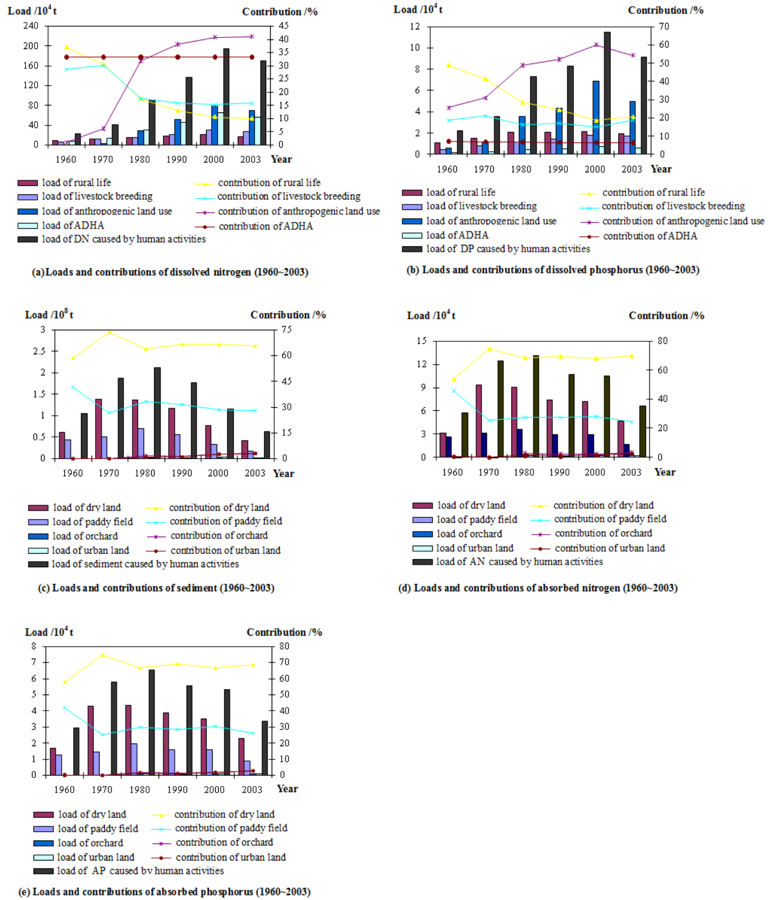

Fig. 3. Loads of human activities and their contributions to total anthropogenic loads (1960–2003) (DN: dissolved nitrogen; DP: dissolved phosphorus; AN: absorbed nitrogen; AP: absorbed phosphorus; ADHA: atmospheric deposition caused by human activities).

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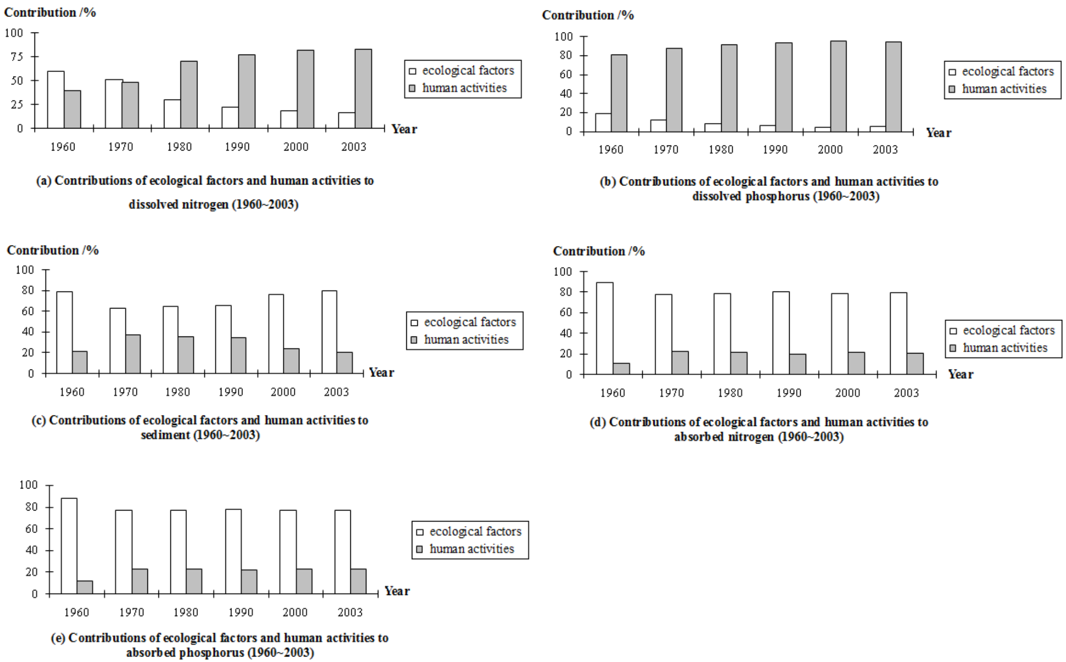

Fig. 4. Dominant cause of NPS pollution in the upper reach of the Yangtze River (1960–2003).

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