Source-sink landscape spatial characteristics and effect on non-point source pollution in a small catchment of the Three Gorge Reservoir Region

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Abstract: The source and sink landscape patterns refer to landscape types or units that can either promote positive evolvement of non-point source (NPS) pollution process, or can prevent/defer the ecological process, respectively. Therefore, the role of a catchment landscape pattern in nutrient losses can be identified based on the spatial arrangement of source and sink landscapes. To reveal the relations between landscape spatial characteristics and NPS pollution in small catchment, a case study was carried out in a Wangjiagou small catchment of the Three Gorges Reservoir Region (TGRR), China. Google earth imagery for 2015 were processed and used to differentiate source and sink landscape types, and six subcatchments were selected as sample regions for monitoring nitrogen and phosphorus nutrients. Relative elevation, slope gradient and relative flow length was used to construct the Lorenz curves of different source and sink landscape types in the catchment, in order to assess the source and sink landscape spatial characteristics. By calculating the location-weighted landscape indices of each subcatchment and total catchment, the landscape spatial load characteristics affecting the NPS pollution was identified, with a further Pearson correlation analysis for location-weighted landscape indices and nitrogen-phosphorus monitoring indicators. The analysis of Lorenz curve has revealed that the obtained distribution trend of Lorenz curve and curve area quantified well the spatial characteristics of source and sink landscape pattern related to the relative elevation, slope gradient and relative flow length in small catchment. Results of Pearson correction analysis indicated that location-weighted landscape index (LWLI) combining of terrain and landscape type factor did better in reflecting the status of nitrogen and phosphorus loss than the indices related to relative elevation, slope gradient and relative flow length.

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Introduction

Surface environmental features consisting of large population, lack of arable land, high rate of land reclamation and rainfall concentration are prone to result in migration and transition of non-point source pollutants along with rainfall-runoff processes. Therefore, non-point source (NPS) pollution is one of the primarily ecological issues affecting Three Gorges Reservoir Region (TGRR) (Tian et al. 2010; Zhu et al. 2012; Xu et al. 2013), which leads to water quality deterioration, and affect residents' life and socioeconomic development. Especially, small catchment of the first grade small tributary of the Yangtze River in TGRR has critical effect on the water quality of the Yangtze River (Shi et al. 2004; Shan et al. 2014).

The contribution of landscape types and landscape spatial pattern in multiple scales to NPS pollution has been proved by a lot of researches (Basnyat et al. 1999; Gergel 2005; Ouyang et al. 2014), in which the study was carried out on the coupling relationships between the concentration and migration distribution of NPS pollutants with landscape spatial configuration and structure (Johnes 1996; Ierodiaconou et al. 2005; Wang et al. 2013; Randhir and Tsvetkova 2014). However, the basic methods used in these studies are reduced to the model simulation and mathematical statistics (Yeo et al. 2004; Xiao and Ji 2007; Shen et al. 2013), but provide no guidance on how to apply the source-sink approach to linking the landscape pattern characteristics with the NPS pollution parameters using these methods.

The source-sink landscape theory has been introduced as one of the most effective ways to couple the static landscape pattern with the dynamic ecological process. Within framework of this theory (Chen et al. 2008, 2009), land use units are classified into source and sink landscape, in accordance with source and sink functions of landscape. Then, a location-weighted landscape index (LWLI), which takes the landscape types, area, spatial location, and terrain feature into account, is constructed to assess the impact of source and sink landscape patterns on the NPS pollution process. This theory and LWLI have been applied into the problems involving water pollution (Jiang et al. 2013, 2014; Wang et al. 2016), soil erosion (Zhou and Li 2015; Wu et al. 2016), urban heat island (Chen et al. 2016a), etc. The study area of the source-sink landscape theory-based applications is mainly related to large and medium-sized watersheds (generally exceeding 1 km^2), with much less to small catchments (little than 1 km^2). However, a small catchment, as a relatively independent unit, is always a source of the NPS pollution process, which expands to the larger watershed and even the total region by the cumulative effect (Pärn et al. 2012). Therefore, there are some open issues that to be resolved, such as spatial distribution in a small catchment of source and sink landscape-related elements, including relative elevation, relative flow length and slope gradient, the ability of the LWLI to control the status of NPS pollution in a small catchment, etc.

In this study, Google earth's high-resolution imagery in 2015 was used to differentiate source and sink landscape types for the Wangjiagou catchment in the TGRR. Then, the method of Lorenz curve was used to analyze the spatial characteristics of source and sink landscape pattern related to relative elevation, slope gradient and relative flow length with regard to the outlet. By calculating LWLIs for the total catchment and its six subcatchments, this paper assessed the impact of landscape spatial load characteristics on the agricultural non-point source (ANPS) pollution. Finally, the Pearson Correlation Analysis between LWLI and nitrogen-phosphorus monitoring indicators were performed to reflect the applicability of the source-sink landscape pattern indices to small catchment of the TGRR.

1 Materials and Methods

1.1 Catchment description

Wangjiagou small catchment (107°30'-107°31'E, 29°54'-29°55'N), which is located in the center of TGRR, includes the town of Zhenxi, Fuling district, and belongs to small first-order tributary of Yangtze River (Figure 1a and 1b), is selected as the study area. With more people and less land, this catchment is one agricultural landscape region, which mainly deals with crop production, area of which is 0.8234 km^2. The climate type belongs to subtropical monsoon climate, the annual mean temperature is 22.1°C, and the multi-year average precipitation is approximately 1011 mm. Low mountains and hills, having typical topography with mountainous and hilly gully, dominate the terrain of this catchment. Land use in this small catchment includes mainly dryland, paddy field, mulberry field, woodland and rural residence. In the whole catchment, annual application amount of nitrogen fertilizer, phosphate fertilizer and compound fertilizer is approximately 9.87 t, 2.56 t and 68.35 t, respectively, in which the active ingredient TN is 12.83 t, and TP is 3.33 t (Chen et al. 2016b). pH in soil is between 5.6 and 8.5, the content of organic matter and available nutrients are all medium, except for higher content of potassium, but low content of microelement. The major soil type in the catchment is purple soil and paddy soil, which belong to the partial acid environment. For population, 46 households live in this small catchment with 106 permanent residents and disperse rustic house, living garbage and sewage cannot be treated. As for socioeconomic status, local farmer's income mainly depends on planting pickle and mulberry, and migrant work, this catchment has no industrial pollution. Because of high multiple crop index, frequent farming activities and high crop alternate husbandry index, slope farmland is easy to cause soil erosion in this catchment.

1.2 Acquisition of remotely sensed image and interpretation of land use types

The main data for analyzing landscape pattern is remotely sensed imagery, this paper selected Google Earth's high-resolution imagery in August in 2015 covering the whole catchment. The reason of choosing Google Earth's high-resolution imagery is that Google Earth's high-resolution data are useful as a platform for validating datasets used previously with land cover (Defourny et al. 2009), and has the potential for wider use in scientific literature, particularly in land use/cover change (LUCC) analyses (Potere 2008). Spatial precision of this imagery was about 1.2 m per pixel, which can satisfy the research needs of small catchment. This imagery was carried on geometric precision

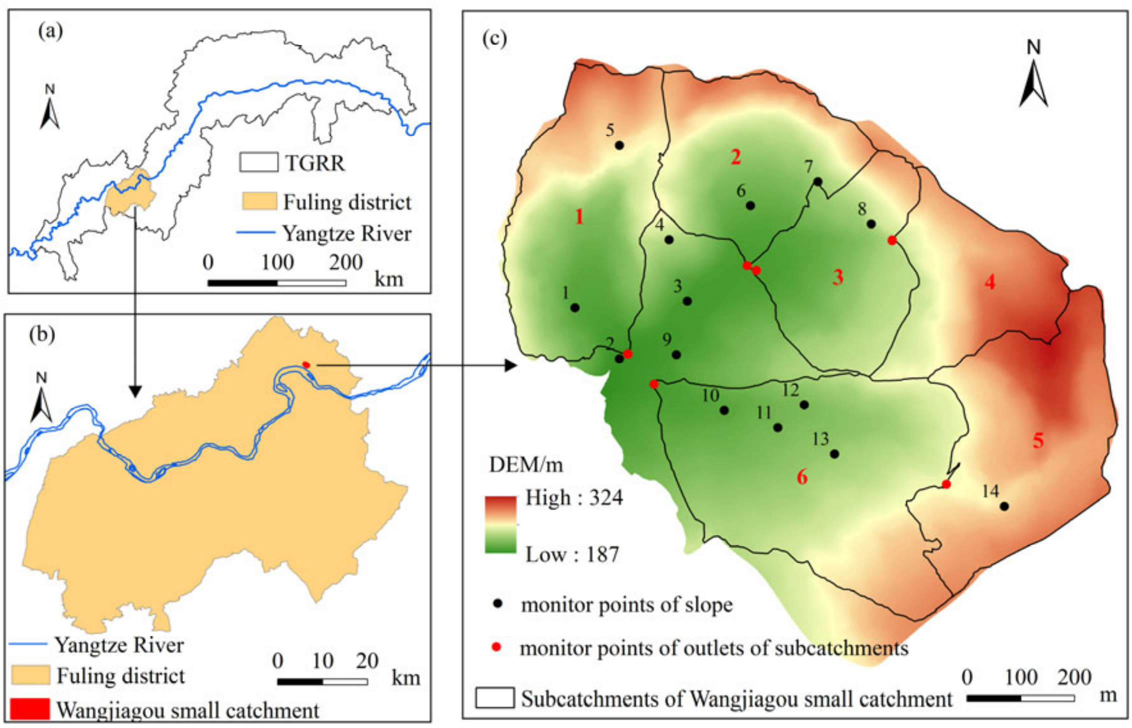

Figure 1 Location of Wangjiagou catchment in the Three Gorges Reservoir Region (TGRR) (a) and Fuling district (b), and its distribution of elevation, monitoring points and subcatchments (c).

correction and image registration by field survey and 1:1000 topographic map of this catchment, and then 3-degree-wide zones of Gauss-Kruger projection and WGS-84 (World Geodetic System-1984) coordinate system were applied. With the help of ArcGIS platform, the distribution of land use types were got through visual interpretation method, and land use maps containing 8 land use classifications including rural residential land, rural road, sloping dryland, dryland terrace, paddy terrace, forest land, mulberry field and water conservation.

1.3 Identification of source and sink landscape types

According to the source-sink landscape theory, source landscape is denoted as the landscape type or unit that can promote positive evolvement of NPS pollution process, sink landscape is denoted as the landscape type or unit that can prevent or defer ecological process (Chen et al. 2008). the main current methods of identifying source and sink landscape in the current research include expert's knowledge about the ordinary ecological functions of land use types in the NPS pollution and the sample analysis of surface runoff monitoring (Chen et al. 2009; Zhu et al. 2012; Jiang et al. 2013, 2014; Wang et al. 2016). Therefore, in this paper, the differentiation of source and sink landscape is based on expert knowledge and experience concerning the ecological functions of various land use types in NPS process, and N and P monitoring in different land use types in the watershed. The exact deal process was applied:

First, monitoring points of surface runoff were selected to lay on the gulley of different slope surfaces in which collecting area boundary are easy to distinguish, each slope surface has the same cropping pattern with uniform distribution. The land use type on each monitoring slope include sloping dryland (including monitoring point 3, 5 and 12), dryland terrace (including monitoring 6, 9 and 13), paddy field (including monitoring point 11 and 14), forest land (including monitoring point 1), mulberry field (including simulator point 4, 7 and 8) and water conservation (including monitoring point 2 and 10), which can be seen in Figure 1c.

Second, the monitoring of surface water quality was conducted from May 2014 to January 2016, and water samples were collected at the gulley of each slope after rainfall every two days until the runoff termination. About four to six bottles (200 mL each) were collected in each sampling, and the samples were preserved at 4 °C, and the concentrations of TN, NH_4^+-N, NO_3^--N, and TP were subjected to the immediate laboratory analyses. TN was determined by the peroxide potassium sulfate-ultraviolet spectrophotometry (GB11894-89, water quality-determination of total nitrogen-alkaline potassium persulfate digestion-UV spectrophotometric method); TP was determined by the molybdenum blue method (GB11893-89, water quality-determination of total phosphorus-ammonium molybdate spectrophotometric method); NH_4^+-N and NO_3^--N were determined by ion chromatography (DX120).

Third, there were statistics for the average concentration of TN and TP of different land use types (sloping dryland, dryland terrace, paddy field, forest land, mulberry field and water conservation) in all rainfall events in order to identify source or sink landscape types. Additional, for rural residential land and rural road, no monitoring points were lay because of their dispersal spatial pattern and low area. Therefore, identification of source or sink landscape for rural residential land and rural road were based on expert knowledge and experience concerning their ecological functions.

1.4 Weight of source and sink landscape types to NPS pollution

As for setting the weights of landscape types, reference method is the main method in the current researches. The exact process includes selecting one landscape type as a reference type, then the other landscape types are assigned different weights according to their potential contribution on NPS pollution, the field measurements and expert's knowledge (Chen et al. 2009; Wang et al. 2012; Zhou and Li 2015). Chen et al. (2009) though that the weight of source landscape is determined by comparing its importance to the nutrient loss and the residential area is assigned 1 as a key pollution source, and the other land use types are assigned different weights according to their potential contribution on nutrient loss. Zhou and Li (2015) also though that the weight of source landscape is determined by comparing its importance to the soil erosion and the construction land is assigned 1 as a key pollution source, and the other land use types are assigned different weights according to their potential contribution on soil erosion. 'Sink landscapes are determined by comparing their role in nutrient retention or soil erosion according to the field measurements and expert's knowledge.

Therefore, in this paper, the human disturbance effect on the source landscape is significant, wherein the rural residential land, as the farmers' living place, has the biggest impact of human disturbance. Massive production of garbage, feces, and wastewater, with on effective intercept measurements, implies the highest risk of nutrient loss. Therefore, the rural residential land was assigned as a reference type, its weight was set as 1, while those of the slope cultivated land, dryland terrace, and rural road were assigned values of 0.8, 0.6, and 0.4, respectively. The forest land in sink landscape was assigned as reference type, its weight was set as 1, and then the weights of other landscape types were assigned according to the field measurements and expert's knowledge (Shi 2015; Chen et al. 2016b): 0.8 for paddy terrace, 0.6 for mulberry field, and 0.4 for water conservation.

1.5 Abstraction of subcatchments and monitor of nitrogen and phosphorus in outlets

The elevation data of study area were obtained from 1:1000 topographic map that was drafted by the field survey in 2008, from which a digital elevation model (DEM) of the terrain's surface was created from terrain elevation data and slope were abstracted. With the help of ArcGIS platform, the catchment boundary was abstracted using ArcHydro Tools, and six subcatchments were selected as sample regions of monitoring nitrogen and phosphorus nutrients (Figure 1c). In particular, the identification of boundaries between subcatchment 3 and 5, as well as between 5 and 6, considered the interception of rural road to runoff. Since all monitoring stations of subcatchments were far apart, monitoring data of each subcatchment was not affected by nesting. The monitoring of surface water quality (TN, NH_4^+-N, NO_3^--N, and TP) was conducted at the mouth of each subcatchment at the same time with the slope monitoring.

1.6 Construction of Lorenz curve of source and sink landscape

The Lorenz curve, which has been initially designed for economy-related analyses to show the distribution of assets and measure the social inequality, was recently reported to be very instrumental for the description of landscape pattern in a watershed, in order to define the configuration of source and sink landscapes (Leitão et al. 2006; Chen et al. 2009). In a watershed, if the outlet is used as the reference point, the spatial pattern of source and sink landscapes can be identified by comparing it to the landscape factors, such as distance, relative elevation, and slope gradient. In this study, the spatial distribution of source and sink landscape were compared with the outlet of catchment (monitor station) to calculate accumulated area percentage of different landscapes related to relative elevation, relative flow length and slope gradient, and the Lorenz curves for different source and sink landscape types were constructed and analyzed.

The following procedure was applied. First of all, raster value of these three landscape spatial elements of the total catchment were normalized to the range of [0, 1] by the method of min-max normalization, which can be reduced to engineering formula: *Normalized value* =(*value*-*min*)/(*max*-*min*), where *min* and *max* are the minimum and maximum values of the data array, and then reclassified into 20 equal zones and converted into vector map. Secondly, the reclassified vector map of each element and of source and sink landscape types were superimposed using spatial intersect tool in ArcGIS, with a further area calculation of each landscape type. Finally, the accumulated area percentages were calculated according to the area arrangement to construct the Lorenz curves of these landscape elements for each source and sink landscape type.

1.7 The building of location-weighted landscape index (LWLI)

Based on the impact of landscape types on the ecological process, and the values of relative elevation, relative distance and slope gradient from landscape units to outlets, the location-weighted landscape index (LWLI) was constructed to measure spatial distribution of source and sink landscape (Chen et al. 2009). Based on LWLI, the landscape load characteristics of catchment were estimated as flows:

$$\mathrm{LWLI}' = \log\left[\sum_{i=1}^{m}(P_i \cdot W_i \cdot \int_{x=0}^{1} A_i \cdot d_x) / \sum_{j=1}^{n}(P_j \cdot W_j \cdot \int_{x=0}^{1} A_j \cdot d_x)\right] \quad (1)$$

$$\mathrm{LWLI} = \mathrm{LWLI}'_{\text{flow length}} \times \mathrm{LWLI}'_{\text{elevation}} / \mathrm{LWLI}'_{\text{slope}} \quad (2)$$

where LWLI′ denotes location-weighted landscape index with regard to landscape elements in a catchment (relative elevation, relative flow length and slope gradient), LWLI denotes synthetic location-weighted landscape index; A_i and A_j denote accumulated area percentage of source landscape i and sink landscape j; x denoted normalized value of different landscape factors, the range are from 0 to 1; $\int_{x=0}^{1} A_i \cdot d_x$ and $\int_{x=0}^{1} A_j \cdot d_x$ denote Lorenz curve area of source landscape i and sink landscape j; W_i and W_j denote the weight of source landscape i and sink landscape j; P_i and P_j denote area radio of source landscape i and sink landscape j in catchment; m and n denote the number of source landscape type and sink landscape type. The ecological significance of LWLI is reduced to the following:

(1) When LWLI>0, it shows that the contribution of source landscape to NPS pollution of the outlet is greater than sink landscape, there will be more pollutants exported from catchment with high risk of NPS pollution.

(2) When LWLI<0, it shows that the contribution of sink landscape to NPS pollution of the outlet is greater than source landscape, there will be little pollutants exported from catchment with low risk of NPS pollution.

(3) When LWLI=0, it shows that spatial distribution of source and sink landscapes is in a state of equilibrium, and their contribution to NPS pollution keep balance.

1.8 Correlation analysis of landscape indices and concentration of NPS nutrients

The analysis of correlation analysis between landscape indices and concentration of nutrients is aimed at validating the representation ability of source and sink landscape for the NPS pollution in a small catchment. The Pearson correlation analysis was conducted using the SPSS 17.0 statistical software package to assess the correlation between the landscape indices ($LWLI_{dem}$, $LWLI_{flow\ length}$, $LWLI_{slope}$ and LWLI) and the NPS nutrients in outlets (TN, NH_4^+-N, NO_3^--N, and TP).

2 Results

2.1 Source and sink landscape types

According to statistics of TN and TP from the monitoring of water samples (Table 1), it can be found that the average concentration of TN and TP in sloping dryland (26.7 mg/L and 0.27 mg/L, respectively) and dryland terrace (18.85 mg/L and 0.32 mg/L, respectively) were higher than that in other investigated land use types. Moreover, because of high multiple crop index, frequent farming activities and high crop alternate husbandry index, sloping dryland and dryland terrace are specified as source landscape in NPS pollution process.

Paddy field is designated as sink landscape type for N and P loss because of the lower average concentration of TN and TP (10.21 mg/L and 0.18 mg/L, respectively) in agricultural land. Moreover, as a kind of ecological system, paddy field located in the bottom of slope has general ecological function of reducing the original slope gradient of farmland mesa.

Forest land, where has the functions of conserving water, absorbing pollutants, keeping soil and maintaining biodiversity because of high

Table 1 The average concentration of total nitrogen (TN) and total phosphorus (TP) in surface runoff of different land use types (mg/L)

	Sloping dryland	Dryland terrace	Forest land	Mulberry field	Paddy field	Water conservation
TN	26.7	18.85	8.56	11.27	10.21	10.42
TP	0.27	0.32	0.12	0.21	0.18	0.15

vegetation coverage, and has the lowest average concentration of TN and TP (8.56 mg/L and 0.21 mg/L, respectively), is considered as the standard sink landscape type. The average concentration of TN and TP in mulberry field (11.27 mg/L and 0.18 mg/L, respectively) are also lower than that in dryland, and mulberry field with high planting density has similar functions of intercepting and absorbing water and nutrients. Therefore, mulberry field is identified as sink landscape type. Water conservation including pond, reservoir and main canal, which are generally regarded as buffers of pollutants, had a low average concentration of TN and TP (10.42 mg/L and 0.15 mg/L, respectively) and are considered as a sink landscape.

Additional, the identification of source or sink landscape for rural residential land referred to expert knowledge on the general ecological function of land use in NPS pollution. Rural residential land is treated as a standard source landscape type, because living pollution of rural residential land is the main source of NPS pollution, the nutrients of nitrogen and phosphorus are transported mainly due to availability of scattered farms, with no harmless disposal and indiscriminate discharge of wastewater and household garbage (Jiang et al. 2013; Zhang et al. 2014). Rural road is also identified as source landscape, because rural road has hardened cement and soil surface without little vegetation cover, is easy to produce surface runoff under the condition of rainfall, and is the sink of automobile exhaust, a small amount of garbage and sewage (Jiang et al. 2013; Zhang et al. 2014).

Finally, spatial distribution of source and sink landscape in Wangjiagou small catchment can be seen in Figure 2.

2.2 Spatial distribution of source and sink landscape related to landscape elements

2.2.1 Distribution characteristics of source and sink landscape related to relative elevation

The Lorenz curve constructed for relative elevation can reflect the distribution degree of source and sink landscape in the vertical direction (Figure 3a). The curve distribution of dryland terrace in the source landscape and paddy terrace in the sink landscape are of a convex type, their Lorentz curves are hump-shaped, while their curve areas (normalized, and thus, dimensionless) are also largest, namely 73.64 and 74.03 (Tables 2 and 3), which implies a lower elevation distribution of these two landscapes. The concentrated curve distributions were mainly observed in the forest land and water conservation in sink landscape, and rural residential land and rural road in source landscape in Figure 3a, their curve area varied from 55 to 65, according to Tables 2 and 3. These four landscape types were all distributed in each zone of elevation.

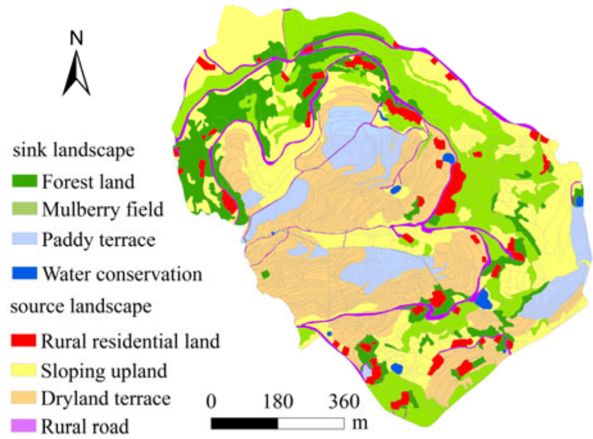

Figure 2 Spatial distribution of source and sink landscape type in Wangjiagou small catchment.

The highest significance was manifested by the sloping upland, whose Lorenz curve of relative elevation was close to balance line in Figure 3a, and the respective curve area was equal to 47.53, as is shown in Table 2. Therefore, the sloping upland was evenly distributed in each zone of elevation, thus, the potential impact of slope cultivated land on the NPS pollution was distributed along the total catchment. As is seen in Table 3, the curve area of mulberry field (43.76) was lower than that of the balance line (47.5), which implied that elevation of mulberry field was larger, which is confirmed by Figure 2, wherein mulberry field is centrally distributed on a higher ring of mountains.

2.2.2 Distribution characteristics of source and sink landscape related to relative flow length

The Lorenz curve related to relative flow length reflects the distribution degree of source and sink landscape in the flow direction (Figure 3b). As is seen in Tables 2 and 3, the respective distributions of source and sink landscapes related to relative flow length are mostly concentrated, and their curve areas vary from 54.02 (for sloping upland) to 68.13 (for dryland terrace). Therefore, the value of relative flow length of source and sink landscapes mainly fall into the middle zones of relative flow length. Similar to the distribution of relative elevation, the curve of dryland terrace is shifted to the upper left of the balance line, which indicates that flow length of dryland terrace is the shortest, so that the pollutants from dryland terrace can relatively easily reach the outlets of catchment. It also follows from Figure 2 that dryland terrace is located near the outlet. To a certain extent, dryland terrace controlled nitrogen and phosphorus pollution loads of outlet of this catchment.

2.2.3 Distribution characteristics of source and sink landscape related to slope gradient

In contrast to the Lorenz curves of relative elevation, relative flow length depicted in Figure 3a and 3b, respectively, all curves of slope gradient curve for all source and sink landscape are convex (Figure 3c). The areas of slope gradient curve for all source landscape types tabulated in Table 2 exceed 70, while that of dryland terrace is the largest (83.27). According to the sink landscape data in Table 3, the slope gradient curve areas for the forest land and mulberry field are the lowest (62.97 and 64.85, respectively), while those of paddy terrace and water conservation are the largest (87.8 and 85.65, respectively). Therefore, the slope gradient of paddy terrace in this catchment was the least, which can effectively reduce the loss pollutants and preserve nutrients. Meanwhile, the slope gradient of water conservation was also low, because ponds, main canal, etc. are mainly distributed in the low-lying places, which have the advantage of collecting precipitation and runoff. The slope gradients of forest land and mulberry

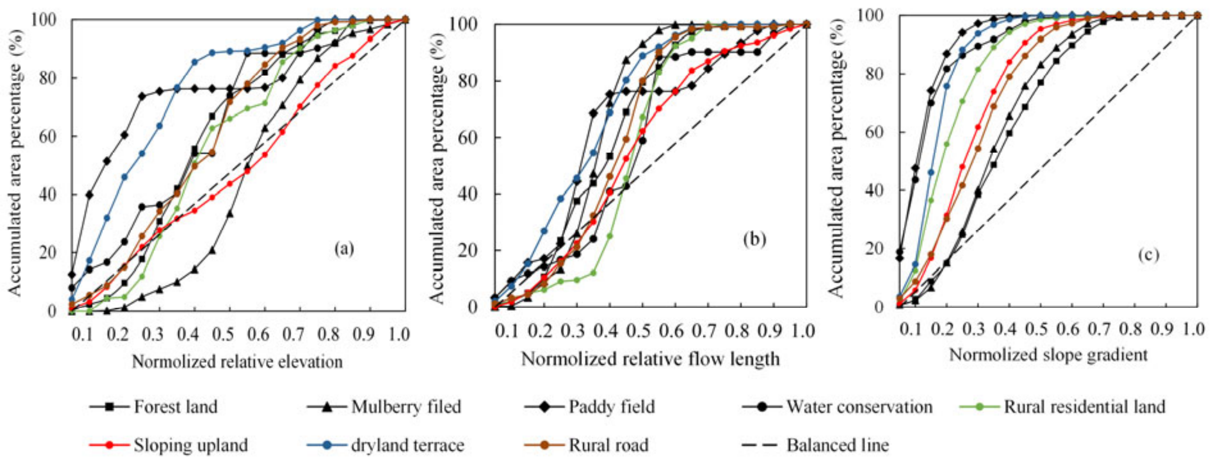

Figure 3 Lorenz curves of source and sink landscapes related to landscape elements: relative elevation (a), relative flow length (b), and normalized slope gradient (c).

Table 2 The Lorenz curve normalized area of source landscape related to landscape elements (dimensionless)

Landscape spatial elements	Source landscape			
	Rural residential land	Sloping upland	Dryland terrace	Rural road
Relative elevation	55.84	47.53	73.64	59.96
Relative flow length	55.12	54.02	68.13	60.04
Slope gradient	79.24	72.62	83.27	71.13
Equilibrium distribution	47.5			

Table 3 The Lorenz curve normalized area of sink landscape related to landscape elements (dimensionless)

Landscape spatial elements	Sink landscape			
	Forest land	Mulberry field	Paddy terrace	Water conservation
Relative elevation	59.05	43.76	74.03	62.01
Relative flow length	62.26	64.99	62.64	55.73
Slope gradient	62.97	64.85	87.80	85.65
Equilibrium distribution	47.5			

field are larger, and they are distributed in the locations with middle- or steep- slope gradients or steep slope, which is also seen in Figure 2. Therefore, these sink landscape types can intercept N and P pollutants coming from steep slopes.

2.3 Characteristics of landscape spatial load and their correlations with water quality

2.3.1 Characteristics of landscape spatial load

Figure 4 depicted the characteristics of landscape spatial load related to relative elevation, relative flow length and slope gradient of the total catchment and its six subcatchments. The distribution of $LWLI_{dem}$ and $LWLI_{flow\ length}$ exhibit the same trend, because the values of these two indices in subcatchment 1, 2, 4, and 5 were smaller than zero, while those of subcatchments 3 and 6 had nonzero positive values. Therefore, positive or negative sign of LWLI was mainly controlled by the value of $LWLI_{slope}$, so $LWLI_{slope}$ of subcatchment 2 and 4 were smaller than zero, and LWLI of those catchments also were smaller than zero, which showed that slope played a decisive role in impacting on NPS pollution in this catchment.

A further analysis of Figure 4 reveals that all four indices in subcatchments 1, 3 and 5 fall into the range of [-0.1, 0.1], they are distributed near the equilibrium point of zero value, this is a strong indication that the spatial distribution of source and sink landscapes of these subcatchments is close to equilibrium state. Moreover, subcatchment 2 and 4, all four location-weighted landscape indices are only lower than -0.1, except for $LWLI_{slope}$ of subcatchment 4 (-0.07), and their area radio of source and sink landscape is close to unity (Figure 4). This implies that the landscape pattern of subcatchments 2 and 4 is that of "sink" landscape, especially due to the mulberry field "sink" contribution to NPS pollution, thus reducing its risk.

Meanwhile, all location-weighted landscape indices of subcatchment 6 exceed 0.4, and the area radio of source and sink landscape reached the value of 3.81, which exceeds that of the total catchment. Therefore, this result indicated that the contribution of source landscape in this catchment

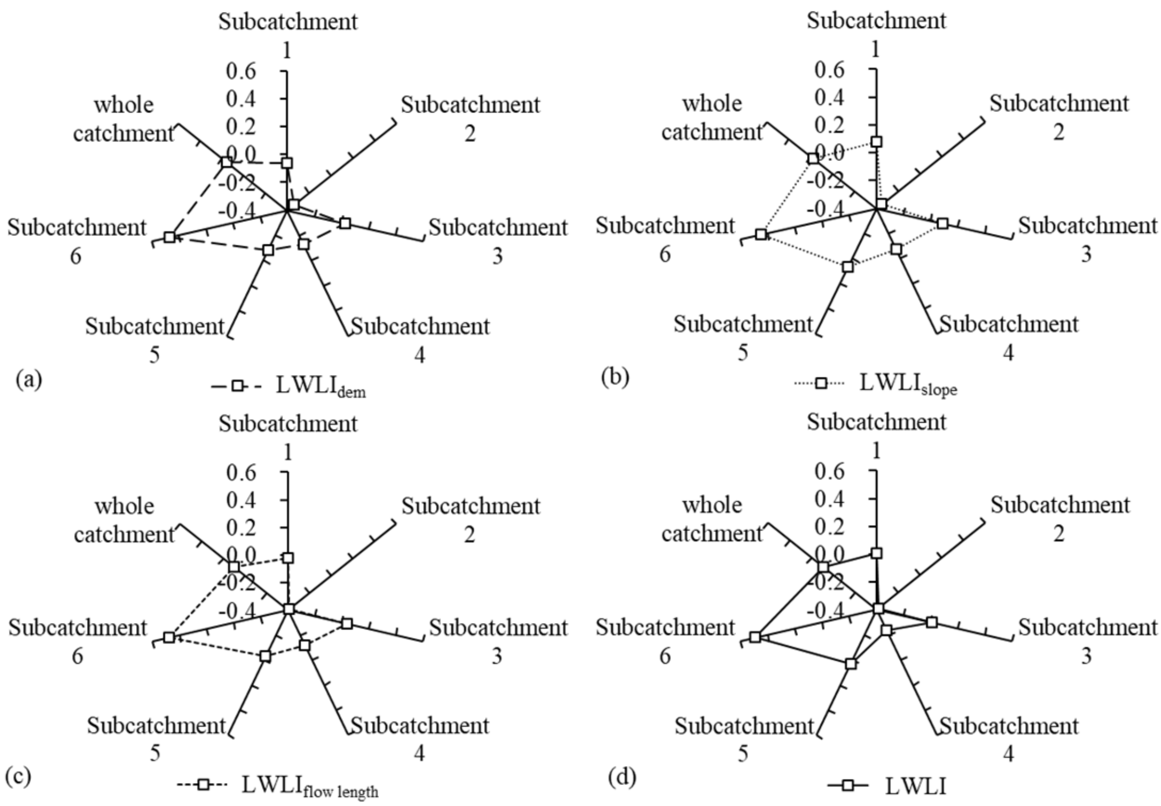

Figure 4 Location-weighted landscape indices of the total catchment and its six subcatchments.

to NPS pollution is significantly higher than that of sink landscape, and more pollutants are exported, with a higher risk of NPS pollution.

2.3.2 Correlation analysis for landscape indices and concentration of NPS nutrients

By comparing the results depicted in Figures 4 and 5, one can see that the distribution trend of N and P is similar to that of location-weighted landscape indices. The main manifestations include: the average concentrations of TN, TP, NH_4^+-N and NO_3^--N in the outlet of subcatchment 2 and 4 are smaller than those in the other subcatchments, while the maximum value of average concentration of NPS nutrients is also observed in the outlet of subcatchment 6. This implies that differentiated source and sink landscape types and landscape indices have a certain correlation with NPS nutrients of outlets. Moreover, some local spatial difference can also be revealed in these distribution trends, using the derived correlations between landscape indices and concentrations of NPS nutrients, which are presented in Table 4.

As is seen from Table 4, The LWLI has the maximal correlation coefficient of 0.889 with TN corresponding to the only highly significant correlation (θ<0.01), and somewhat low ones with NH_4^+-N and TP, being 0.859 (θ<0.05) and 0.825 (θ<0.05), respectively. In contrast to LWLI, correlations of the remaining indices with concentration of NPS nutrients are much less close and, in the particular case of TP, is not significant. These implies that the LWLI index provides a more comprehensive accounts of the terrain and landscape type and can better reflect the NPS nutrients loss than single-factor analysis using other indices ($LWLI_{dem}$. $LWLI_{flow\ length}$, $LWLI_{slope}$).

Moreover, the analysis of data from Table 4 shows that TN and NO_3^--N nutrients exhibit more significant correction with $LWLI_{flow\ length}$ than with $LWLI_{dem}$ and, especially, with $LWLI_{slope}$ where a weak correction or even insignificant correction is observed. These findings strongly suggest that TN and NO_3^--N are prone to the impact of flow length, but are slightly affected by slope gradient. Meanwhile, despite the lack of significant correlation between located-weighted landscape indices and TP, it is relatively stronger correlated to $LWLI_{slope}$, as compared to $LWLI_{dem}$ and $LWLI_{slope}$ which may indicated that TP is more susceptible to the slope gradient impact.

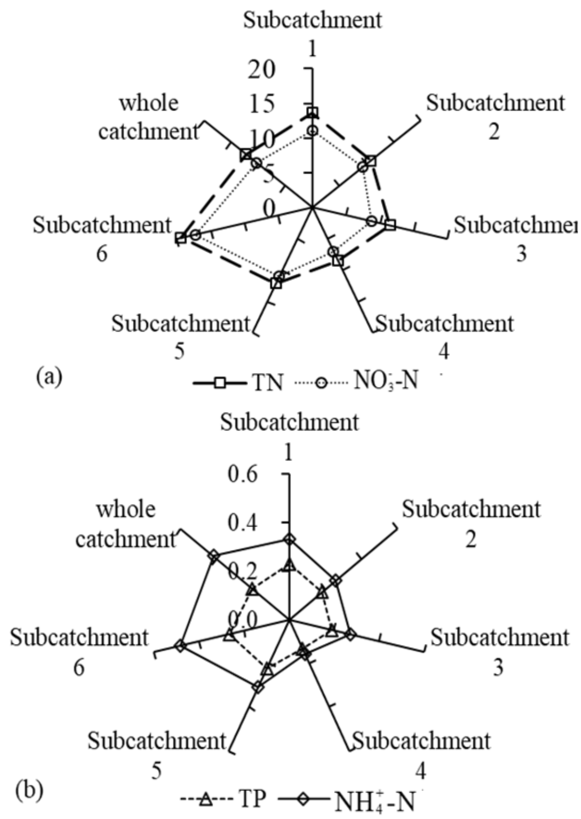

Figure 5 Average concentration of NPS nutrients in the total catchment and its 6 subcatchments (mg/L).

Table 4 The results of Pearson correlation analysis between concentration of nutrients and various source and sink landscape indices

Local-weighed landscape index	TN	TP	NH_4^+-N	NO_3^--N
$LWLI_{dem}$	0.819*	0.671	0.818*	0.784*
$LWLI_{flow\ length}$	0.824*	0.697	0.781*	0.787*
$LWLI_{slope}$	0.784*	0.710	0.779*	0.743
LWLI	0.889**	0.825*	0.859*	0.858*

Notes: *θ < 0.05, significance level Sig (θ) (significant correlation); **θ < 0.01, significance level Sig (θ) (highly significant correlation).

3 Discussion

3.1 Differentiation of source and sink landscape

The source-sink landscape concepts were proposed based on the ecological balance theory, by which the general landscape was endowed with process connotation, therefore all analyses of source-sink landscape pattern in current researches were based on the function of landscape playing as positive or negative to distinguish a landscape as source or sink (Chen et al. 2008, 2009). The results of these studies have shown that different landscape patterns exhibit significantly different source and sink strengths during the formation of NPS pollution. In this paper, source and sink landscape types in small watershed were also divided according to the general function of landscape in ANPS process and N and P monitoring for land use in the watershed.

Nevertheless, current method of dividing source and sink landscape according to the function of landscape is just a kind of subjective experience without quantitative recognition, and which is the same for setting the weights of different landscapes, because the role of source or sink for a landscape is not only decided by the types of land use but also relate to spatial location, soil attributes, and mutual spatial relations with other landscape types (Wang et al. 2016). Especially, there is no clear standards to divide source or sink landscape and set the weights to determine the effects of these landscape on the formation of NPS pollution. Therefore, distinguishing a landscape as source or sink and setting its contribution weight in small watershed must be further studied.

3.2 Spatial characteristic analysis of source and sink landscape related to landscape spatial factors

The Lorenz Curve approach was used in this study to describe certain spatial features of source and sink landscape related to three landscape element, including relative elevation, relative flow length and slope gradient from landscape unit to the watershed outlet. This particular selection is attributed to the fact that the Wangjiagou small catchment terrain mainly consists to low hills with relative elevation not exceeding 200m (Figure 1), which affect spatial distribution of source and sink landscape in small catchment, and lastly affect $LWLI_{dem}$, $LWLI_{flow\ length}$, $LWLI_{slope}$ and LWLI.

Certainly, the factors impacting on spatial distribution of landscape in small catchment conclude not merely these three landscape spatial factors, and also have soil erobility, soil texture, rainfall intensity, slope length, and surface roughness, etc. The spatial differences of those factors control runoff intensity, and affect the transition and migration of N and P pollutants (Gergel et al. 2002; Pärn et al. 2012). Therefore, more landscape spatial factors will be used to identified the impact on spatial distribution of source and sink landscape.

3.3 Applicability of located-weighted landscape index in small catchment

The fact that correlations of all source-sink landscape indices with TP turned out to be less close than nitrogen nutrients (TN, NH_4^+-N and NO_3^--N) strongly suggests that nitrogen nutrients play a critical role in the NPS pollution of the Wangjiagou small catchment, and have to be more strictly controlled to prevent NPS pollution. Previous studies also have investigated the spatial and temporal variations in non-point source losses of N and P and found that N had more significant correlation with rainfall and land use structure than P in this catchment (Chen, et al. 2016b).

Correlation of $LWLI_{flow\ length}$ with TN and NO_3^--N is more significant than those of $LWLI_{dem}$ and $LWLI_{slope}$ with TN and NO_3^--N, but relatively weaker correlation of $LWLI_{slope}$ with TN and NO_3^--N. These findings suggest that TN and NO_3^--N are prone to the impact of flow length and runoff water. Similarly, Zhu, et al (2009) found that interflow is an important pathway for nitrogen loss especially NO_3^--N leaching which explains NO_3^--N is the dominant TN form in the runoff water. Therefore, NO_3^--N is the dominant portion of TN in the small catchment, and runoff is the main migration carrier of TN and NO_3^--N, so it should be expected that nitrogen loss is controlled by precipitation and runoff. Additional, it is needed to allocate source and sink landscape pattern to decrease pollutants load in the waters, especially seek better effect of sink landscape for NO_3^--N retaining, such as substantial nutrient filtering along hydrologic flow paths by the construction of riparian buffers and grassed swales (Baker et al. 2006; Dindaroğlu et al. 2015; Zhao et al. 2016).

Meanwhile, when location-weighted landscape indices are constructed, the hydrological and environmental factors, such as rainwater path and basin shape, also have to be considered for a small catchment, because LWLI is a relative value, which is applicable to the similar environmental background of basin (Chen et al. 2008, 2009; Yang et al. 2012). Moreover, additional environmental factors should be used to rectify and improve source-sink landscape indices, in order to provide a deeper insight into the impact of source and sink landscape pattern on ecological process in further studies.

4 Conclusions

The performed study mad it possible to draw the following basic conclusions.

(1) Based on the source-sink principle in NPS pollution process, source and sink landscape of Wangjiagou small catchment in the TGRR were differentiated according to their ecological function, the field measurement and expert's knowledge. Nevertheless, this small catchment belongs to typical agricultural zone along Yangtze River with high intensity of agricultural activities, the differentiate of source and sink landscape will also be need to consider human activities factors including fertilizer and pesticide input, diversion irrigation, and crop planting in the future study.

(2) The distribution trend and area of Lorenz curve constructed in this study successfully quantified the spatial distribution characteristics of source and sink landscape related to relative elevation, relative flow length and slope gradient in Wangjiagou small catchment in the TGRR. It is expedient to take into account additional landscape factors for more unbiased identification of source and sink landscape spatial characteristics in small catchments.

(3) The sign of LWLI index for the study area is found to be controlled by $LWLI_{slope}$, in contrast to $LWLI_{dem}$ and $LWLI_{flow\ length}$ indices, while all four applied location-weighted landscape indices demonstrated that the spatial pattern of source and sink landscape types significantly affected the status of NPS pollution in different subcatchments.

(4) The correlation analysis performed for each location-weighted landscape index against N and P nutrients has revealed that the LWLI index provides a more comprehensive accounts of the terrain and landscape type factors and can better reflect the NPS nutrients loss than single-factor analysis using other indices ($LWLI_{dem}$, $LWLI_{flow\ length}$, $LWLI_{slope}$). More environmental factors will be in further study to refine the source-sink landscape indices, and elucidate the impact of landscape pattern on ecological process in small catchments.

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