RESEARCH ARTICLE

Framework of multi-level regionalization schemes based on non-point source pollution to advance the environmental management of small watersheds

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Abstract
Regionalization exerts an important guiding role for sound environmental management, regional development, and schemes toward regionalizing ecological function, involving multiple levels. This paper formulated a framework for a detailed regionalization approach using the Ashi River watershed, China, as case study. Human activities, especially agriculture non-point source pollution (ANPS) and social factors, were identified as main factors. The results indicated that (1) the export coefficient model (ECM) can be used to determine ANPS loads in the watershed as well as total nitrogen and total phosphorus loads. (2) The minimum cumulative resistance model (MCR) showed that the middle and lower reaches had high risk for ANPS occurrence. (3) Based on the identified key factors, the watershed was divided into level IV and combined with existing level III using cluster analysis. Corresponding management countermeasures were proposed. This provides a scientific basis for pollution control planning and for management measures.

Keywords Regionalization scheme · Non-point source pollution · Export coefficient model · Minimum cumulative resistance model · The Ashi River watershed

Introduction

Ecological regionalization has been developed based on natural zoning, where natural partitioning is defined as functional zones (Gao et al. 2016; Wright et al. 1998). The growth of ecological regions began in the 19th century when Merriam (1898) departed from studying the division of life belts and crops to the development of the concept of ecological zones. Herbertson (1905) divided and introduced the major natural regional units and emphasized the need for the division of global ecological regions. Bailey (1983, 2004, 2009b) developed an ecological regionalization hierarchy, which involves the concept, principles, and methods of ecological regionalization, as well as the determinants of ecological boundaries.

Considering the ecological regions of America as example, Bailey suggested regionalization as a process that combined natural units according to their spatial relationships, and finally defined four levels. Research on ecological regions begins to gain interest and mainly focused on the following three aspects: (1) principles and methods of ecological regionalization guided by management, with specific focus on the theoretical analysis, particularly in Europe and the USA (Bailey 2009a; Boesch et al. 2001; Clarke et al. 1991; Klijn et al. 1995; Smith and Carpenter 1996); (2) construction of an ecological regional framework involves a classification scheme of ecological regionalization and practical application cases (McMahon et al. 2001; Omernik and Griffith 2014; Perera et al. 1996; Soltanifard and Jafari 2018); (3) both ecological function regionalization and ecological function services with characteristics of soil information or land use patterns and land types (Ehrlich et al. 2002; Gao et al. 2012; Rowe 1996; Saad et al. 2011; Yin et al. 2017).

The scale of ecological function division differs among nations and also based on the environmental settings of countries. Many scholars have analyzed ecological function regionalization in different parts of the world and have consequently formulated new concepts for ecological

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regionalization schemes. Omernik and Griffith (2014) analyzed level IV ecological regionalization using 967 units within the boundary of the USA and explained the logic behind the specific method that was used for this division. Klijn et al. (1995) introduced two related ecological regionalizations (eco-regions and eco-districts) as well as the nomenclature for ecosystem classification at the spatial scale, in the context of the national boundary of the Netherlands. Saad et al. (2011) studied the effect of land use on the soil ecological function framework, based on the Canadian ecological layered foundation, using 15 terrestrial eco-zones and 193 eco-region divisions (according to the ecological factors of ecology characteristics). Furthermore, Smith and Carpenter (1996) evaluated the national hierarchy of the concept of ecological units as adopted by the United Stated Department of Agriculture Forest Service and applied it at a sub-regional level within the states of New England to New York. Wright et al. (1998) examined the eco-regions of Idaho, Oregon, and Washington and the boundary for the used eco-zonal classification, which matched the vegetation cover boundary. Based on the characteristics of China's ecological environment, Fu et al. (1999, 2001) formulated China's ecological regionalization plan, which involves its purposes, tasks, and characteristics, especially by combining the impact of anthropogenic activities on the ecological environment. Through both a summary and analysis of previous research results, ecological regionalization concepts have been found to have the following aspects in common: (1) The boundaries of sub-regional work are dominated by either national or province boundaries, which have a large scale (Klijn et al. 1995; Omernik and Griffith 2014). (2) Administrative units are considered sub area management planning units (Wright et al. 1998). (3) Less consideration is given to the environmental indicators, and the degree of environmental quantification is low (Gao et al. 2012; Saad et al. 2011). (4) The framework and basic methods of ecological regionalization have been determined and achievements have been made at a finer level (Bailey 2004; Perera et al. 1996). In summary, focusing on ecological regionalization on a smaller scale and using a quantifiable factor as leading indicator helps to develop the refinement levels, which is significant for environmental management. Therefore, this paper develops a refined concept of an ecological regionalization scheme, which is based on an operational division method that combines natural and small-scale administrative boundaries.

In China, many years of investigations and discussions have been conducted on multi-level zoning. In recent years, research results focused on levels I–III using ecosystem function as unit (2003, 2008, 2015). However, due to the rapid rate of population growth coupled with the increase of urbanization, as well as the intensive agriculture and industrialization of China, these three levels of ecological function are not yielding the expected results and the problem of ecosystem deterioration still continues. Therefore, creating the concept of an ecological function regionalization scheme that focuses on the sub-regional level (level IV) is necessary to advance the environmental management in China. In addition, China is a large agricultural country, with intensive agricultural production in many small watersheds. However, excessive fertilization and irrigation with wastewater under the influence of human activities pollute the ecological environment of these small watersheds. Many studies identified agriculture non-point source pollution (ANPS) as the main environmental problem in small watersheds (Csatho et al. 2007; Ongley et al. 2010; Sun et al. 2012). ANPS is the dominant factor of the water quality deterioration in small watersheds as well as the decision factor for the restriction of regional economic development and the ecological function demand balance relationship.

Therefore, this study used the ANPS and social factors as the main factors affecting the environment and export coefficient model (ECM) to calculate the pollution load. Key risk areas of ANPS are identified in combination with the minimum cumulative resistance model (MCR). A "bottom-up" partition method is adopted to accomplish level IV scheme of ecological regionalization, where administrative boundaries and watershed boundaries exist simultaneously. This will be a more effective guidance of the science of land use and will be in accord with the balanced development of local economy and ecology. Thus, it provides a new research idea for fine-scale ecological regionalization.

Materials and methods

Theoretical framework

The combination of administrative boundary and natural boundary (i.e., watershed boundary) was used to formulate a new concept for an ecological regionalization scheme. This new way to refine ecological regionalization is based on the original ecological regionalization method and the hierarchical structure of the regionalization is referred to as "top-down" and "bottom-up" (Smith and Carpenter 1996). The logical hierarchy of the new concept of regionalization involves the creation of administrative units based on administrative boundaries. These are identified as regionalization object clusters via systematic clustering, and ecological regional units, where main factor attributes were merged and summarized from "bottom to top." This method focuses on quantitative partitioning, which distinguishes it from the existing ecological regionalization schemes. The divisions of which (from level I to level III) are based on logical hierarchical relationships among ecological regional elements identified by the "top to down" method, which is mainly based on qualitative analysis (Ongley et al. 2010). However, in this research, a

combination of quantitative zoning and qualitative analysis was established to develop level IV ecological regionalization scheme via the "bottom-top" approach, and the sub-objectives for the development of the framework were definite. The specific process is shown in Fig. 1.

Case study

This study investigated the Ashi River watershed, located in Harbin city in northeast China (126° 40′ 20″ E–127° 43′ 33″ E, 45° 5′ 30″ N–45° 50′ 28″ N), with a total area of 3540.74 km², which has 27 administrative towns (Fig. 2). These towns form the units of the ecological regionalization scheme. The Ashi River watershed was chosen as case study because of its high representativeness. The major land coverage in the study area consists of natural secondary forests and the forest

coverage is 60%. The second cultivated land coverage is 30% and uses agriculture as the main economic pillar. This area is mainly for the industrial development of the economy, and the development plan forms a priority for the promotion of the adjustment of the industrial structure and adheres to the concept of modern agriculture development. It has prominent agricultural features, which also identify this as an important commodity grain base of Harbin; moreover, it is a typical agricultural watershed. However, the weak awareness of the need for environmental protection by farmers leads to over-fertilization. The application of nitrogen and phosphorus fertilizers reached 122.26 kg/hm² and 36.07 kg/hm² in 2015, respectively. Harbin's wastewater discharge was 41.57 million tons, ammonia nitrogen was 17688.6 tons, and chemical oxygen demand was 280440.3 tons, which were point source pollution in 2015 (Zhao et al. 2016). Precipitation in summer
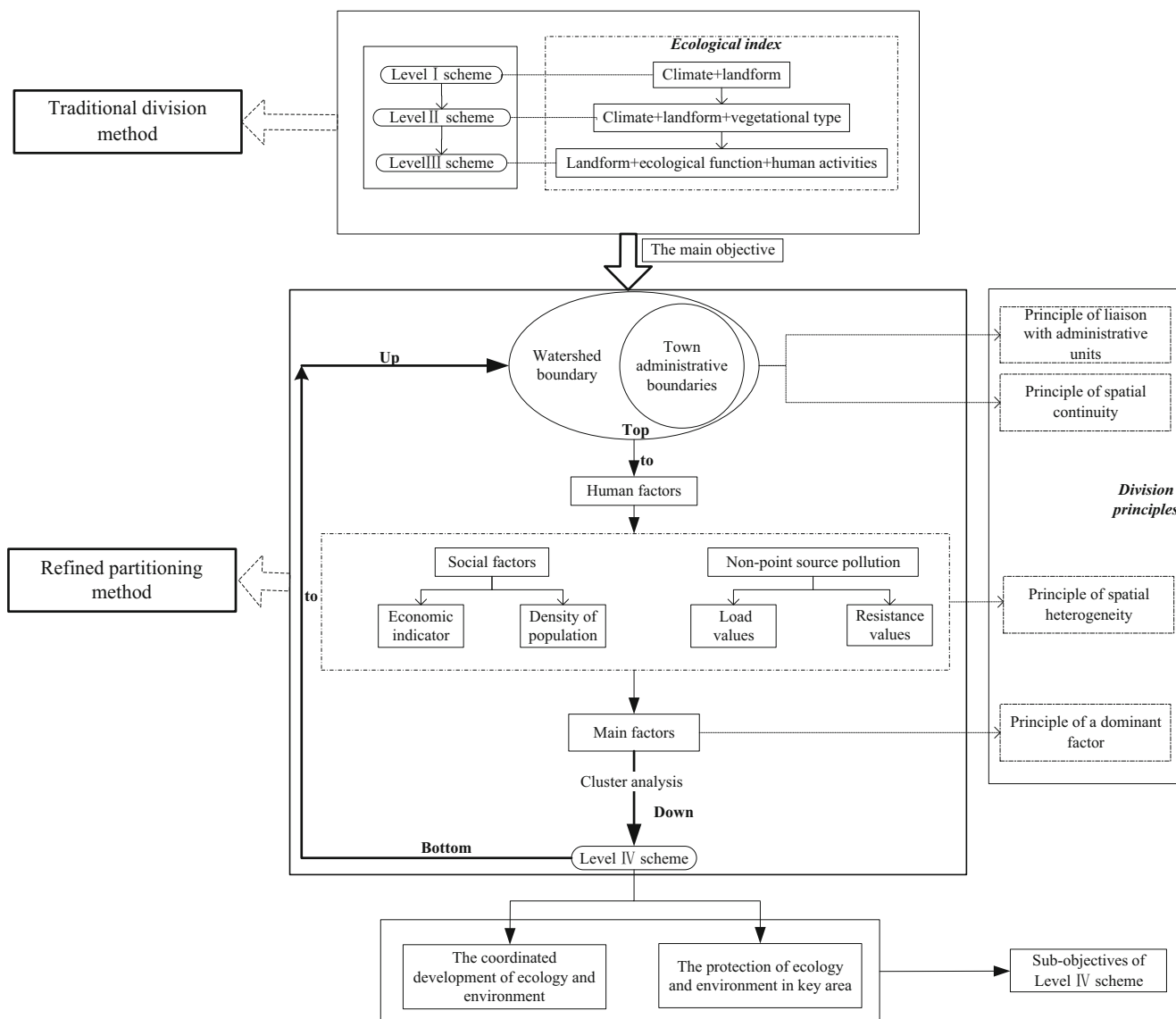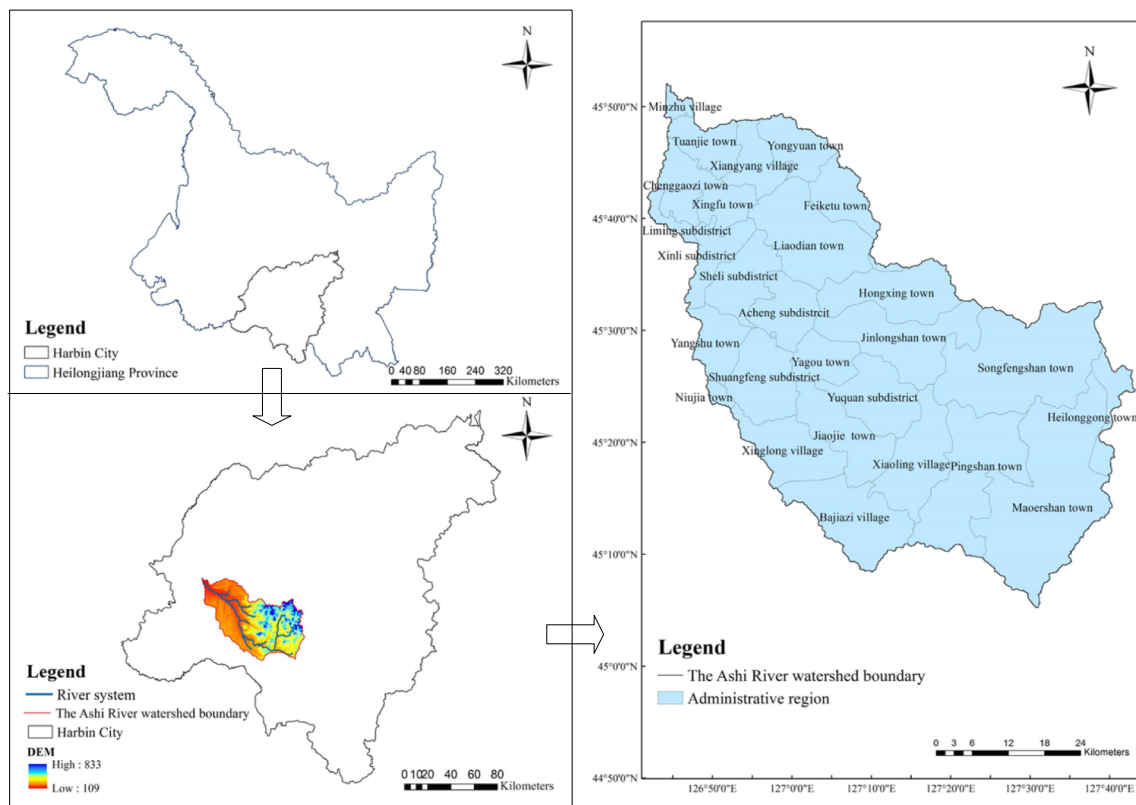

Fig. 1 Framework of the regionalization scheme

Fig. 2 Geographic location, administrative regions, and digital evaluation model of the Ashi River watershed

and snowmelt in early spring cause ANPS pollution, which further degrades the quality of the water environment in the watershed. Therefore, the key environmental problem is ANPS pollution, which requires prompt solution.

Methodology

Export coefficient model

The ECM is a widely used model for the calculation of pollution load (Jing et al. 2017; Johnes 1996). Johnes (1990, 1996) improved the model by setting the influence of land use types, population, livestock, and poultry as the total ANPS of a basin equal to the sum of the pollutant loads of all sources, which can be summarized as:

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

where L represents the total load of pollutants in the study area (t); E_i represents the export coefficient of the pollution source i (t ca^{-1} year^{-1} or t km^{-2} year^{-1}); A_i represents the area of land use type i (km^2), or the number of livestock and poultry stock i or of the rural population. I_i forms the input of contaminants from source i (t), and p represents the input of pollutants from rainfall (t). Considering that the nutrient content in rainfall is relatively low, the precipitation intensity of each part of the study area

shows little difference after the occurrence of rain, and this basin lacks monitoring data of the pollutant content of the precipitation. In summary, the risk induced by precipitation to non-point source pollution in the study area has not been considered (Jing et al. 2017; Ma et al. 2011b). Export coefficients can be identified by conducting field tests or via monitoring; however, typically, the data are obtained from the existing literature (Wang et al. 2015a). This study adopted such a literature retrieval method to identify the output coefficient. However, there is no literature on the output coefficient model of the Ashi River watershed. Therefore, to obtain more reference data and to ensure sufficient accuracy of the output coefficient, the literature search was also extended to include the Songhua River watershed and the watersheds of Northeast China (including the Ashi River watershed). The empirical coefficients were mainly identified in reference to relevant literature (Chen et al. 2017; Geng et al. 2013; Long et al. 2016; Ma et al. 2011a; Sun et al. 2015; Wang et al. 2015a; Wu et al. 2015) (Table 1).

Minimum cumulative resistance model

The minimum cumulative resistance model (MCR) is mainly used to calculate the process from a particular "source" to the target, the cost through a landscape unit with different resistances, or the sum of the power overcoming the resistance. Theory based on a "source and sink" is applied to atmospheric

Table 1 Export coefficients of non-point source pollution

Nutrient sources	Types	Total nitrogen export coefficients	Total phosphorus export coefficients
Rural population living (kg·ind^{-1}·a^{-1})	\	2.14	0.214
Livestock (kg·ca^{-1}·a^{-1})	Pig	0.74	0.14
	Sheep	0.4	0.005
	Poultry	0.04	0.005
	Big livestock	10.21	0.22
Land use (kg·hm^{-2}·a^{-1})	Cultivated land	20.04	2.65
	Forest	2.38	0.15
	Grassland	10	0.2
	Urban	11	0.2
	Water	0.011	0.149

pollution, ecological corridor recognition, and the recognition of the area of ANPS (Li et al. 2015; Zhu et al. 2020). The principle and method follow Zhu et al. (2020) and Li et al. (2015).

The fundamental formula of the MCR model is presented in the following:

$$MCR = f \min \left(\sum_{j=n}^{i=m} D_{ij} \times R_i \right) \quad (2)$$

where MCR represents the minimum cumulative resistance value, f represents the correlation between the ecological process and the minimum cumulative resistance, D_{ij} represents the spatial distance from the ecological source patch j to the landscape unit i, and R_i represents the resistance coefficient of the landscape unit i to the species movement (He et al. 2020). This study determined and classified resistance factors, calculated the weight of each factor, and assigned grades by using expert scoring method and analytic hierarchy process (Peng et al. 2019; Prieto-Amparán et al. 2019; Zhu et al. 2020). Through preliminary investigation and identification of the factors affecting ANPS pollution load in the Ashi River watershed, the resistance-base surface construction system was built, as shown in Table 2. According to the sources of ANPS pollution loads, the "sources" were identified as the cultivated land and the urban areas that engaged in the breeding of livestock and poultry (Zhu et al. 2020). The MCR model analyzes areas of ecological risk based on the sources of ANPS; in contrast, the ECM model quantitatively analyzes the ANPS load based on the source of ANPS. The relationship between these two models can be analyzed from a "source and sink" perspective, and they have a logical causal relationship. Furthermore, the combination of qualitative and quantitative analysis has research significance.

Data sources and processing

Social and economic data for 2015 were obtained from official statistics (Acheng Archives Bureau 2016; Zhao et al.

2016) (http://www.harbin.gov.cn/). The boundaries of administration data were based on resources and an environmental data cloud platform (http://www.resdc.cn/) and the borders of the towns in the study area were based on a map of Harbin city. Cluster analysis (CA) is widely used in the field of ecology and was applied during the analysis process to further extend the ecological regionalization scheme (Kumar et al. 2011; Zhang et al. 2004). CA was performed using SPSS 25.0 software, and the system clustering method was adopted.

Results and discussion

Spatial distribution characteristics of ANPS pollution

ANPS pollution derived from land use types such as rural settlements and livestock showed that the total nitrogen load was 6001.69 t and total phosphorus load was 501.67 t (Fig. 3). The total nitrogen value was 11.96 times that of the total phosphorus value. Nitrogen is an element with widespread soluble forms in the watershed, which is highly mobile and not easily absorbed by soil; phosphorus is a sedimentary micro element, which exists mostly in the form of particles with low mobility, and is not easy to leach down (Antonpoulos 1993; Dossa et al. 2009; Sun et al. 2015). ANPS pollution in the Ashi River watershed mainly consisted of nitrogen and phosphorus, which caused eutrophication of water bodies. According to government data (Acheng Archives Bureau. 2016), in the Ashi River watershed, nitrogen fertilizer accounted for 53.50% of the total fertilization amount and phosphorus fertilizer accounted for 15.78%. This indicates that the high consumption of nitrogen fertilizer leads to large nitrogen load. In 2015, the total nitrogen load was sorted according to pollution sources as follows: land use types > livestock > rural population. The total nitrogen load of cultivated land was highest because nitrogen fertilizer was used in the

Table 2 Evaluation indexes of resistance-base surface for non-point source pollution, data sources, and methods in the Ashi River watershed

| Index	Data sources	Classification method	Assignment					Weight	Data processing method
			1	3	5	7	9		
Relative elevation (m)	Digital elevation model (DEM) data with a 90-m spatial resolution were download from Geospatial Data Cloud (http://www.gscloud.cn/)	Natural breakpoint method	109–211	211–300	300–400	400–530	530–833	0.19	By ArcGIS 9.3
Slope (°)	DEM	Natural breakpoint method and literatures	25–33.95	15–25	6–15	2–6	0–2	0.1	The slope tool is extracted in the special analyst module in ArcGIS 9.3
Vegetation coverage degree	It was download from Resource and Environment Science and Data Center (http://www.resdc.cn)	Natural breakpoint method	0.20–0.44	0.44–0.59	0.59–0.74	0.74–0.85	0.85–0.90	0.17	Choosing the normalized differential vegetation index (NDVI) and cutting the data
Rainfall erosivity (MJ·mm·hm^{-2}·h^{-1}·a^{-1})	Daily precipitation of different stations in and around the study area in 2015 were download from China Meteorological Data Network (http://data.cma.cn)	Natural breakpoint method	1277–1395	1192–1277	1101–1192	987–1101	827–987	0.12	Using the Kriging interpolation, the calculation method is referring toChen and Zha (2018)
Land use types	Landsat 8 OLI-TIRS with a 30-m spatial resolution were downloaded from Geospatial Data Cloud (http://www.gscloud.cn/)	Land attribute and literatures	Urban	Water	Cultivated land	Grass land	Forest	0.2	The land use data was based on an artificial interpretation by ENVI 5.3 and Google Earth
Distance to the urban place (m)	Basing on land use types	Natural breakpoint method	0–400	400–1158	1159–2538	2538–4720	4720–11354	0.12	Using the cost distance tool in ArcGIS 9.3
Distance to the water body (m)	Basing on land use types	Natural breakpoint method	0–2726	2726–7057	7057–13152	13152–21172	21172–40900	0.1	Using the cost distance tool in ArcGIS 9.3
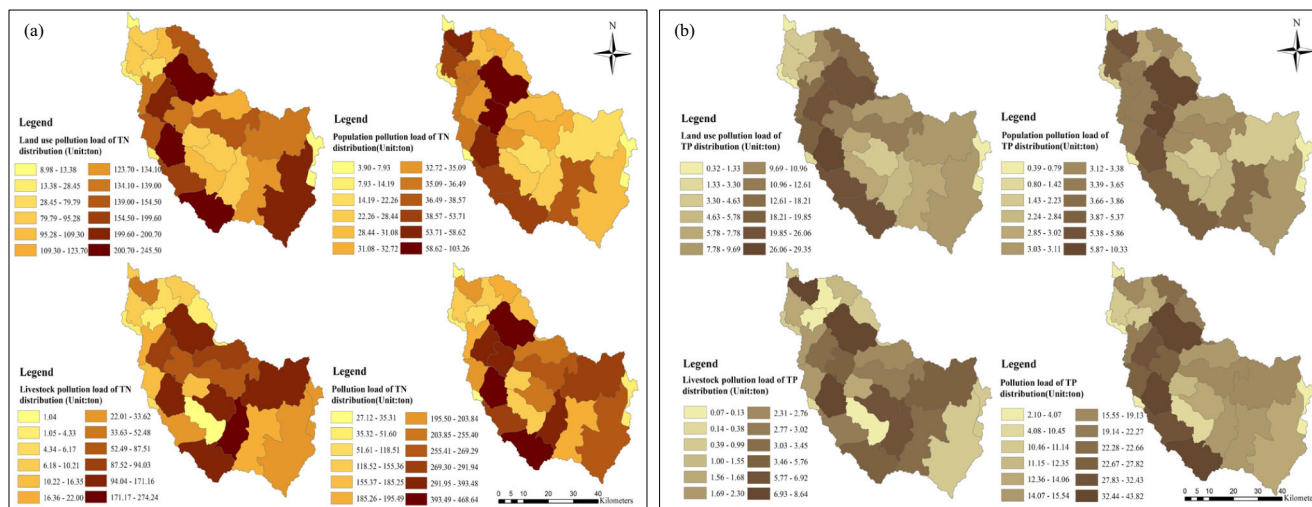
Fig. 3 Loads of total nitrogen (**a**), and total phosphorus (**b**) for the Ashi River watershed in 2015

watershed. Furthermore, the total phosphorus load was sorted from large to small as listed in the following: land use types, rural population living, and livestock. This is because rural residents commonly use a large volume of detergents, which increase the total phosphorus load in the watershed.

These results indicated that among the three sources of ANPS pollution, the land use resulted in the highest load, followed by the population and livestock breeding. This finding agrees with the findings of Sun et al. (2015). This is due to the enormous size of the cultivated land area, which is regularly fertilized with large amounts of chemical fertilizers. Therefore, there is a need to implement environmental management in the watershed toward controlling the spread of these specific nutrients. Non-point source pollution loads resulting from agricultural activities (e.g., nitrogen and phosphorus) are applied during agriculture processes in the form of fertilizers. These uses lead to the enrichment of soil with nitrogen and phosphorus. Eventually, excess nitrogen and phosphorus are transported to the water ecosystem, which results in a series of environmental problems in water bodies, such as eutrophication (Carpenter et al. 1998). Therefore, sound environmental management practices need to be established to control these pollution loads via effective ecological function regionalization.

Risk identification areas of ANPS

Via weighted superposition analysis, the comprehensive resistance of ANPS and the minimum cumulative resistance surfaces of different sources were identified as shown in Fig. 4. The comprehensive resistance values were particularly large in the upstream region of this watershed, while the middle and lower reaches had smaller resistance values. This indicated that the influence of ANPS was larger in the upstream region. The sources of ANPS in this watershed were cultivated land

(because of the use of fertilizers) and livestock breeding (because of the discharge sewage and excrement), which were used to determine the minimum resistance values of different towns according to both sources (Table 3). In the source of cultivated land, Yangshu town and Niujia town had the smallest minimum value, illustrating that ANPS easily happened in these areas. The minimum values of resistance in Yongyuan town, Sheli subdistrict, Xinglong village, and Xinli subdistrict (key areas of ANPS) remained below 2000. Under the source of urban Xingfu town, Liming subdistrict, Tuanjie town, and Minzhu village should receive further focus on ANPS in the areas. In general, the middle and lower reaches of the Ashi River watershed were areas with high incidence of ANPS, which is closely related to human activities (Ongley et al. 2010). In the middle and lower reaches, cultivated land is large and the urban distribution is scattered; therefore, the pollution generated easily enters the surrounding water bodies. Therefore, watershed management needs to focus on the middle and lower reaches.

Cluster analysis results

The administrative units of the watershed were used as sample units. Then, ANPS pollution loads (i.e., total nitrogen and total phosphorus), the minimum resistance values of different sources in ANPS pollution, and social factors (i.e., economic indicator and population density) were selected as cluster factors. Finally, the 27 administrative units in the watershed were divided into six parts (Fig. 5). Cluster analysis is an effective approach in the process of ecological regionalization. Sun et al. (2019) used both spatial analysis and classification clustering methods to divide an urban city into four functional types. Kupfer et al. (2012) used a regionalization algorithm with dynamically constrained agglomerative clustering and identified hierarchical regions based on measures of forest extent in the
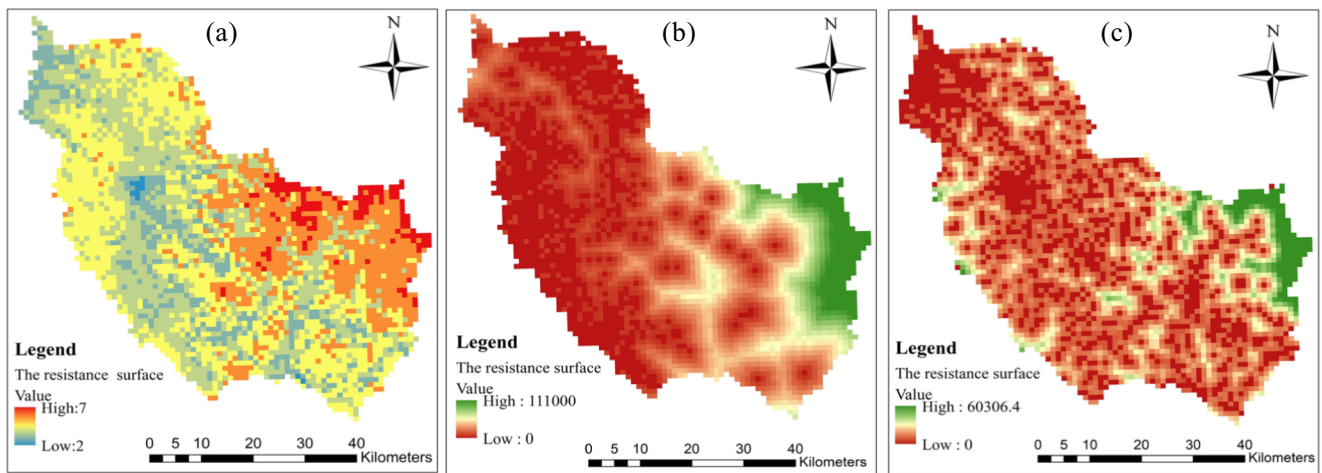
Fig. 4 Calculation results of resistance values. Comprehensive resistance surface (**a**), minimum accumulative surface of sources that are identified as cultivated land (**b**), and minimum accumulative surface of urban sources (**c**)

Table 3 Details of the main factors of level IV scheme

Units	Social factors		Non-point source pollution			
	Economic indicator (100 million yuan)	Population in per square kilometer	Total TN loads (ton)	Total TP loads (ton)	Minimum resistance value of urban source landscape	Minimum resistance value of cultivated land source landscape
Acheng town	117.61	2301.17	329.79	27.29	2918.35	2375.67
Sheli subdistrict	12.50	224.87	326.67	31.88	3313.72	1880.04
Xinli subdistrict	9.14	232.90	195.47	22.27	5023.52	1212.26
Shuangfeng subdistrict	14.53	208.60	468.32	43.82	4234.48	2740.95
Yuquan subdistrict	14.18	204.16	255.40	13.17	6452.32	14194.12
Xiaoling subdistrict	11.28	141.28	393.48	15.54	6110.78	20797.47
Pingshan town	12.03	88.36	193.19	14.87	4265.72	17661.51
Yagou subdistrict	9.13	235.03	140.05	12.35	2874.42	4201.42
Jiaojie subdistrict	9.14	132.51	138.42	10.45	4990.85	8772.46
Songfengshan town	6.18	31.91	291.92	17.18	16963.48	45188.21
Feiketu town	7.79	170.88	185.26	21.96	5251.60	5138.63
Yangshu town	9.03	218.76	203.80	25.69	6811.16	409.97
Liaodian town	22.39	199.86	468.62	41.66	3147.75	4296.99
Hongxing town	7.76	92.55	248.77	15.45	6040.94	16172.22
Jinlongshan town	8.11	76.85	269.31	18.86	6717.66	15271.35
Tuanjie town	12.16	372.35	195.40	18.51	1768.72	3516.69
Minzhu village	1.64	234.89	26.62	2.05	1427.31	11004.64
Yongyuan town	8.50	242.07	190.93	22.67	4846.28	1357.06
Xiangyang town	12.76	211.43	144.10	14.06	3147.60	4293.99
Xingfu town	55.75	854.31	155.36	11.13	933.03	4675.37
Liming subdistrict	10.81	566.16	46.54	3.48	949.39	2843.87
Chenggaozi town	19.53	423.87	118.51	10.89	3059.92	3117.80
Niujia town	1.31	240.56	35.31	4.07	13290.85	10.00
Xinglong village	10.09	194.81	282.23	32.43	5233.36	1598.92
Bajiazi village	10.45	130.38	286.61	27.82	5155.44	6241.66
Heilonggong town	0.93	41.20	27.62	1.67	36253.23	87712.63
Maoershan town	8.45	46.02	265.41	13.60	13235.39	47050.86

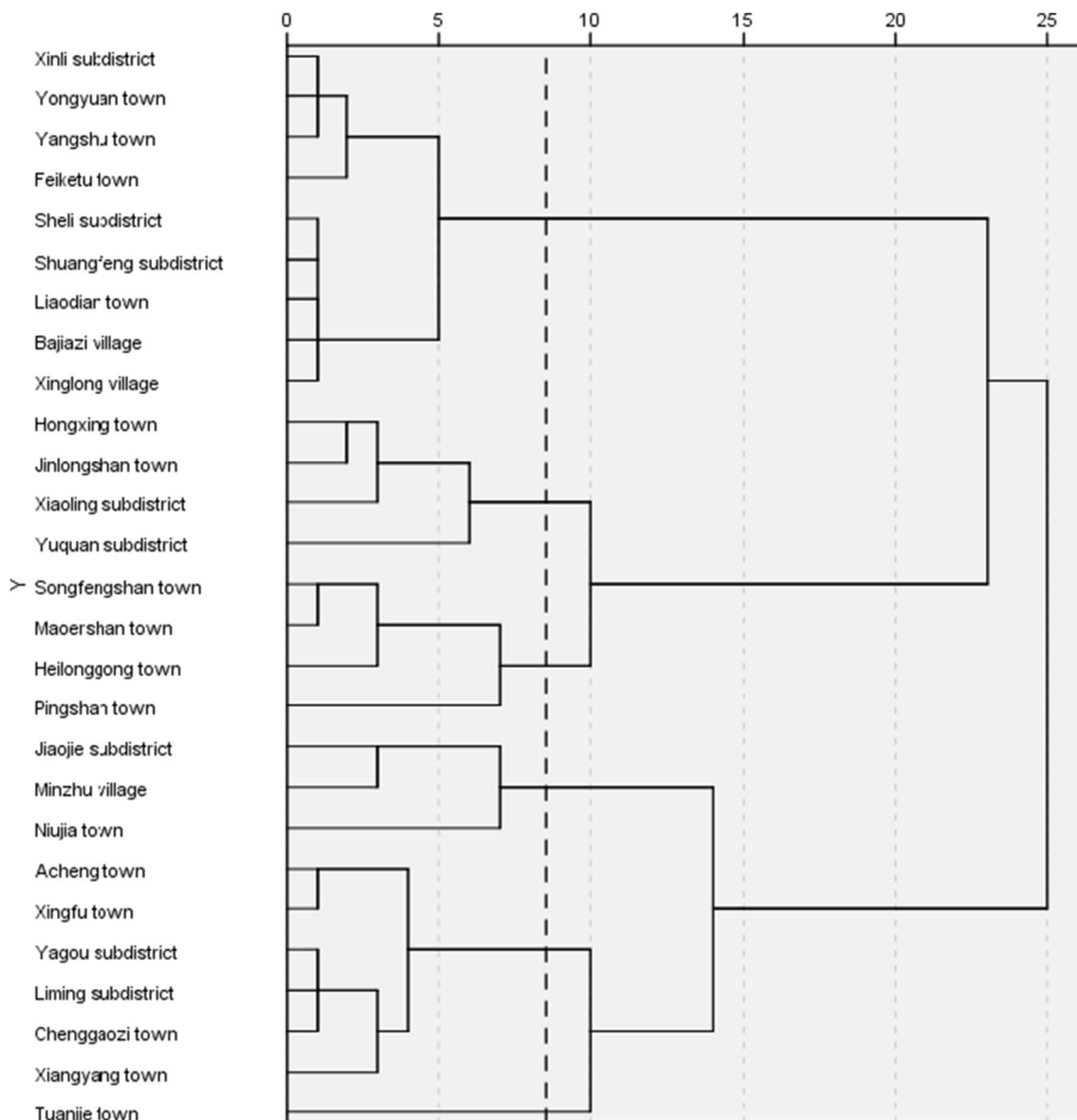Economic indicator is gross regional domestic product

Fig. 5 Result of cluster analysis

continental USA. Cervantes-Jimenez et al. (2017) used PCA and the k-method clustering algorithm to identify regions with similar characteristics and to regionalize the urban sub-basins of Mexico. Furthermore, in the process of zoning, the partitioning methods range from "bottom to up" to "top to down" (Smith and Carpenter 1996). These methods can clarify the hierarchical relationship of ecological zoning. In this study, in contrast to the simple "bottom-up" and "top-down" processes, the importance of "bottom-up" is emphasized. The "bottom-up" method is therefore the main method, while the "top-down" method is the auxiliary method. Both paths are combined to form the final zoning scheme. In the level I to level III schemes (Fig. 6), the ecosystem was first divided via systematisms by "top-down"

bottom method, and then, based on the ecological zoning, the ecological function was divided into four zones, according to the importance of attributes with the same ecological function. The unit was then inductively clustered and classified into second-level ecological functions, which were further classified into first-level ecological functions according to the principle of dominance (Fu et al. 2001; Wu et al. 2018). This study used these two approaches to clarify the hierarchical structure and to have internal coherence at level IV. In this study, the "bottom-up" method was considered to conduct a detailed regionalization scheme, using small-scale partitioning, and using the basic ecological unit clustering partition that can be implemented. This concept was demonstrated in this study by considering
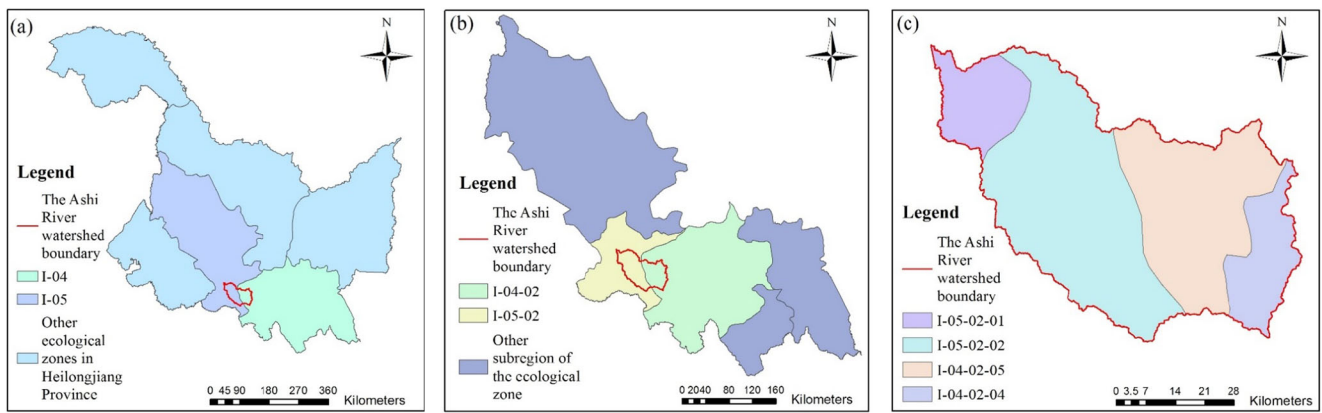
Fig. 6 Ecological function regionalization of level I–level III in the study area. Please note: the data originate from the Chinese ecosystem assessment and ecological security pattern database (http://www.ecosystem. csdb.cn), and the area of ecological function scheme was extracted and confirmed from the Ashi River watershed

the geographical location of towns. The result is shown in Fig. 7. This study therefore provides a new idea for the in-depth division of small-scale research areas.

Level IV scheme

To ensure that the partition of level IV and levels I–III management is aligned, the principle of naming level I–III scheme was adopted. Using the Ashi River watershed as example, ecological region (I) was partitioned based on climatic region; ecological zones (I-0X) represent level I and geographical space; sub-region (I–0X-0X) represent level II and imply more detailed location; function region (I–0X-0X-0X) represent level III and the most

Fig. 7 The results of level IV scheme

detailed geographical location and ecological function. I–0X-0X-0X-0X (level IV) is referred to as a function unit, the zones of which are more complex and divided based on the main factors of ANPS pollution and social factors. To decrease redundancies in the name, the characteristics of the partition index were highlighted and combined with the degree of pollution. Therefore, level IV zones were named as the key control areas of ANPS pollution and the general control area of ANPS pollution. Different zones are distinguished by various names and numbers that are assigned according to the latitude of the regions. According to these division principles, the results of cluster analysis and the orders of hierarchical structure showed that each level III zone could be divided into one to four zones as level IV. The details are presented in Table 4, and according to the pollution load degree and the risk zones, these two aspects were used to determine key prevention and control units.

Level I to level III schemes differ from level IV schemes. Firstly, they have different management objectives, level I to level III focus on the integrated management of ecosystems while level IV emphasizes fragile ecosystem management. Secondly, level I to level III have different partition factors. However, level IV was divided based on the main factors. Finally, a comprehensive evaluation index is required to divide level I to level III, which requires the heterogeneity of the underlying environment. Level IV considers the homogeneity needs of dominant factor, which is targeted for environmental management, and is therefore more administrative and easier to operate and execute. Furthermore, ecological function zoning should be applied on this basis. The main sources and loads of non-point source pollution in each ecological function area were determined via the zoning of level IV. This serves as a guidance to monitor and evaluate non-point source pollutants to determine watershed management objectives in the future. Using the typical agricultural area of the Ashi River watershed as example, this report developed a level IV scheme for ecological function zone that uses ANPS pollution and social factors as the main factors. This can be used to guide the scientific use of land more effectively toward a sound environmental management.
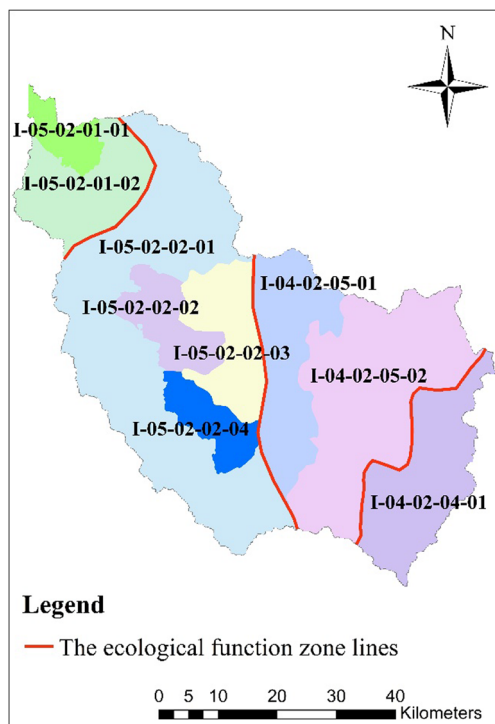
Table 4 Details of the applied level I to level IV regionalization

Ecological region	Ecological zone (level I)	Sub-region (level II)	Function region (level III)	Function unit (level IV)
I Eastern monsoon ecological region	I-04 Changbai Mountain–Qianshan Mountain coniferous and broad-leaved mixed forest ecological area	I-04-02 Zhang Guangcai Ling Mountain coniferous and broad-leaved mixed forest and agro-ecological sub-region	I-04-02-04 Water conservation and soil conservation ecological functional zone in the upper reaches of Mayan River	I-04-02-04-01 General control area of agricultural non-point source pollution
			I-04-02-05 Water conservation and soil conservation ecological function zone in the upper reaches of the Ashi River	I-04-02-05-01 Agricultural non-point source pollution key control area
				I-04-02-05-02 General control area of agricultural non-point source pollution
	I-05 Northeast agro-ecological zone	I-05-02 Harbin-Changchun City and agricultural ecology sub--region	I-05-02-01 Harbin urban and suburban agro-ecological functional zone	I-05-02-01-01 Agricultural non-point source pollution key control area
				I-05-02-01-02 General control area of agricultural non-point source pollution
			I-05-02-02 Lalin River–Ashi River watershed agriculture and soil conservation ecological functional area	I-05-02-02-01 Agricultural non-point source pollution key control area
				I-05-02-02-02 General control area of agricultural non-point source pollution
				I-05-02-02-03 Agricultural non-point source pollution key control area
				I-05-02-02-04 Agricultural non-point source pollution key control area

Levels I–III originate from the National ecological Function Zoning (Revised Edition), 2015

Analyzing the environmental management of the Ashi River watershed

Table 5 presents the objectives of environmental management from level I to level III. Practical applications of regionalization schemes are important and necessary for sound environmental management. However, Table 5 indicates that the application of level III scheme had both low vegetation coverage and water conservation capacity. This study showed that the scheme led to an overlap of the environmental situation and goals development. Other zones indicated that the management was analyzed at large scale. Therefore, level III scheme is too extensive and lacks focus on the zones that require environmental management to solve specific environmental issues. On the other hand, level III scheme reflected a weak integration with the management objectives of the local

Table 5 Details of level III scheme

Function region (level III)	Dominant ecological function	Environmental situation	General location	Goals of development
I-04-02-04	Water conservation	The terrain is complex; the forest quality declines; water conservation capacity decreases and soil erosion are severe.	Close to Shangzhi district	Strengthen the protection of natural forests, restore and protect vegetation, improve ecological agriculture, and prevent soil erosion
I-04-02-05	Water conservation	Forest coverage is low; ecological function is weakened, which easily causes soil erosion.	Southeast of Acheng district	Strengthen the protection of natural forests, increase afforestation, increase forest coverage, and develop ecological agriculture
I-05-02-01	Urban	The green land coverage rate and the natural reserve area rate are low, the future will be affected by desertification, and the land ecological environment is polluted to varying degrees.	Outskirts of Harbin City	Strengthen comprehensive control of the urban and regional environment, strictly control the exploitation of groundwater, improve the regional water environment, and strengthen ecological functions and ecological agriculture
I-05-02-02	Soil conservation	There are many sloping lands, severe soil and water loss, and severe damage to the landscape.	Northwest of Acheng district	Protect forest vegetation, increase ecological agriculture, and prevent soil erosion

The data originate from the Chinese ecosystem assessment and ecological security pattern database (http://www.ecosystem.csdb.cn)

administration. In light of these problems above, in level IV scheme, the management reference factor was assumed as the dominant factors in combination with the development goals of different towns. In-depth partition yields good management goals that match local management needs. The Ashi River watershed has a high urbanization level, with continually expanding scale of livestock and poultry breeding. Consequently, the water quality deteriorates from upstream to downstream. Environmental management measures have mostly adopted engineering remediation and management has also been continuously strengthened. The implementation of level IV scheme is more in line with the developmental goals of township administrative zones, and more targeted toward environmental management.

By using level IV classification, I-05-02-01, where the ecological function of land needs to be strengthened, can be narrowed (to I-05-02-01-02). This control unit mainly consists of the land use types of cultivated land and urban land. One of the reasons for the decline of environmental quality is the excessive use of fertilizers, which does not sufficiently emphasize the development of level III ecological agriculture. Hence, the awareness for the need of environmental protection needs to be strengthened among rural inhabitants. As a result of level IV, I-05-02-01-01 zone is the discharge outlet of the runoff of the entire watershed, the special geographical location of which determines the management style, which is not prominent in level III and does not consider small watershed boundaries. This unit has a large population and its main source of pollution is domestic sewage; therefore, it is necessary to set up an observation station as well as a sewage collection and treatment system to ensure that ANPS pollution generated throughout the watershed does not severely impact the water quality.

The division of I-05-02-02 at level IV makes this zone simple to manage. This unit is further divided into four smaller units, each of which with consistent management objectives. I-05-02-02-01, I-05-02-02-03, and I-05-02-02-04 belong to key non-point source pollution prevention and control areas, where a large volume of fertilizers is applied during the planting process, thus intensifying the non-point source pollution load in this zone. According to the different load levels of these units, and the actual fertilizer usage, it is necessary to teach farmers to use fertilizers more rationally, and to utilize biological fertilizers. The proportion of fertilizers should be calculated to decrease the contribution of fertilizers to non-point source pollution based on different load levels.

ANPS of I-04-02-05-01 is mainly livestock and the management is very extensive. I-04-02-05-02 is forest, where the risk of ANPS is relatively small. As a result of this, the environmental management mode should adopt hierarchical management, focusing on the management of I-04-02-05-01. Firstly, a combination of crop production and livestock breeding should be considered, which implies an ecological agriculture model that can fully use the waste generated by livestock breeding. Secondly, the geographic location of the existing livestock breeding base should be adjusted according to local conditions, and sewage treatment technology and manure resource technology should be strengthened. Nitrogen and phosphorus recycling management measures should become a focus to reduce the load of non-point source pollution.

I-04-02-04-01 is located upstream, which has the function of water conservation. This is a tourist scenic area and an important water source for the Ashi River watershed. This unit should focus on protecting aquatic and forest resources. The protection plan is basically consistent with level III; thus, it should strengthen the protection of natural forests, restore and protect vegetation, strengthen the construction of ecological agriculture, and prevent soil erosion.

In terms of policies, appropriate laws and regulations need to be implemented to restrain misconduct, and to strengthen the environmental awareness of local farmers. These means can reach the objectives of a coordinated development of ecology and environment, and the protection of both the ecology and environment of key non-point source pollution control areas.

Prospects

An urgent research direction

Ecological regional refinement is an urgent research direction for social and environmental needs. With the increased requirements for environmental quality and refining zones of ecological regions, real-time controllable zoning development mode and zoning management are imperative. This study showed that the current main management model and division basis include three factors, which are based on hydrological units, aquatic ecological areas, and administrative areas (Du et al. 2007; Sun et al. 2019; Wang et al. 2015b; Xu et al. 2009). Most of the research on ecological regionalization is based on national or provincial administrative boundaries, where aquatic ecology or ecosystem is continually divided. The internal division uses natural boundaries and considers various ecological factors; the division scale is large. This type of large-scale ecological regionalization scheme is not conducive for the management and development of small-scale regions. This study discussed the feasibility method of fine ecological regionalization from a different perspective to provide a new idea for future small watershed ecological regionalization.

Updating of regionalization technology

The need for ecological regionalization technology should be continuously developed. With the continuous development of big data technology, basic unit identification and analysis technology have become possible. Therefore, it is more accurate to identify the leading factor by using the "bottom-up" method by using digital information technology. This means that ecological regionalization technology has improved recently. The process of ecological development is a long-term process, and three aspects need to be further studied: firstly, the study on the dynamic continuity of main factors by using

digital technology needs to be further developed and discussed; secondly, with regard to the application of a constantly improved ecological model, it is necessary to update the useful model in time to ensure the accuracy of main factors; thirdly, dominant factors should be selected according to the actual situation, and ecological sensitivity vulnerability indicators need to be considered in the future.

Integration of different boundaries

Integration of ecological boundary and administrative boundary involved in ecological regionalization requires further discussion. Ecological regionalization management involves two aspects. One is the traditional division method based on the administrative boundary, and the other is the functional partition method based on the ecosystem. Administrative boundaries (such as provinces) hardly reflect the dynamics of ecosystems. Bio-geographic unit boundaries are considered more appropriate since they provide important information on the integrity, management, and environmental analysis of natural resources (Saad et al. 2011). However, even if natural boundary functional regionalization offers the advantage of conforming to the rules of nature, administrative boundaries cannot be completely abandoned. Both should be considered simultaneously and combined with the suitability of the specific study area to enable a reasonable choice. However, a complete ecological functional unit often has a large area, where multiple administrative units overlap, and different areas have different land use patterns and regional development goals. Ecological function regionalization plays an important guiding role in the sustainable healthy development of regional economy and ecology. However, large-scale ecological regionalization (at the nation or province level) is not completely applicable to the actual situation of specific river watersheds. Therefore, the combination of administrative boundary and natural boundary provides an effective method to solve this problem. During the process of specific zoning, the integration of both needs to be defined according to the specific situation, which is also a direction for further research in the future.

Incorporating other environmental schemes

The convergence technology between ecological regional refinement and related schemes needs to be further improved. The process of ecological regionalization is a complete and considerable work; therefore, it is necessary to always refer to the existing zoning scheme when conducting the ecological region refinement. Taking China's ecological regionalization scheme as example (the latest updated version of which was 2015), the ecological function regionalization of China originates from both the national and provincial perspective, which forms the basis of ecological fine regionalization. To match

the time of the scheme and to facilitate follow-up research, this paper studied the year 2015. In addition, the formulation of China's plan is a step every 5 years. 2015 was an important year for making the plan, which can guide short-term planning measures to 2020 and mid to long-term planning vision of 2030. Therefore, this paper has research value and significance. Moreover, administrative divisions at village level within small watershed areas tend to have homogeneous land use patterns, which make it easier to match regional development plans and formulate sustainable environmental management policies. It is scientifically significant to conduct research in small nature units, as the requirements for watershed management becomes a global concern. Therefore, with greater heterogeneity than similarity in small watersheds, an undetailed ecological function zone cannot appropriately meet the needs of more refined regional management. Consequently, further zone planning is urgently needed. Therefore, as an in-depth scheme, level IV is seamlessly integrated with level I–III scheme, and large-scale comprehensive management practices can be implemented. Moreover, this scheme matches the "river chiefs' system" and other small regional responsibility management regimes and ensures the feasibility of the ecological regionalization scheme. In summary, the relevant documents and schemes of national policies should be considered when conducting ecological regionalization to serve environmental management.

Conclusions

This paper introduced a framework for ecological regionalization by combining administrative boundaries and natural watershed boundaries. This refined analysis is based on original rough ecological function regionalization schemes and utilizes the principles, frame, theoretical basis, and naming of these zones. ANPS loads were identified as main factors, simultaneously considering social factors, and the framework was applied to the Ashi River watershed. The results showed that the total nitrogen load was 6001.69 t and the total phosphorus load was 501.67 t in 2015. The watershed was divided into 9 units in level IV scheme based on the national level I–III scheme, thus defining the general control area of agricultural non-point source pollution and the key control area of ANPS pollution according to the loads of ANPS pollution sources. This scheme, which is extended to similar watersheds, is easier to match the development plan, to formulate sustainable environmental management policies, and to effectively guide environmental protection and the regional economic development.

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

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