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A study of ecological red-line area partitioning in the Chishui River Basin in Guizhou

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Abstract. Maintaining ecosystem balance and realizing the strategic goal of sustainable development are key objectives in the field of environmental sciences. Accordingly, drawing ecological red lines in sensitive and vulnerable environmental areas and important ecological function areas, determining the distribution range of ecological red-line areas, providing scientific guidance for developmental activities, and effectively managing the ecological environment are significant work tasks supported by policy guidance from the State Council and from knowledge gained in educational circles. Taking the Chishui River Basin in Guizhou as the study object, this research selected water and soil loss sensitivity, as well as assessments of karst rocky desertification sensitivity as background assessments of the eco-environment. Furthermore, the functions of soil conservation, water conservation, and biodiversity protection were integrated with exploitation-prohibited areas, and an organic combination of ecological needs and social service functions was created. Spatial comprehensive overlay analysis and processing revealed that the combination marked nine major ecological red-line areas in a total area of 5,030.58 km^2, which occupied 44.16% of the total basin area. By combining the current eco-environmental situation of the Chishui River Basin with the marked out red-line areas, this research proposed corresponding ecological red-line area management suggestions. These suggestions are expected to provide a scientific foundation for eco-environmental protection and subsequent scientific research in Chishui River Basin.

1. Introduction

The Opinion on Reinforcing Key Work of Environmental Protection No.35 (2011) issued by the Chinese State Council recommended drawing ecological red lines in areas such as major ecological function areas, sensitive and vulnerable land, and marine ecological environment areas and formulated corresponding environmental standards and policies for all main functional areas [1]. It was in this published opinion that the concept of ecological red lines was first proposed. Ecological red line is a term used to represent the ecological bottom line required by a sustainable development strategy and ecological civilization. This ecological bottom line encompasses the implications of ecological and social development scopes. It is an organic combination of the two scopes, both of which provide mutual benefits and win-win results under the requirements of determining special geographical environmental conditions and objective human activities.

Studies and partition works of ecological red lines have been carried out successively in educational circles, although only in a small number as they are still in the exploratory stage. Na Fu, *et al.* pointed out that ecological red-line areas refer to areas with vulnerable ecosystems or important ecological functions or those that require comprehensive protection [2]. Taking Guigang City in Guangxi as an example, Zhili Zuo provided an effective approach to realizing the sustainable utilization of soil resources by dividing ecological red-line areas [3]. With Hulunbuir grassland as the study object, Yu Feng marked out red-line areas and proposed corresponding red-line management measures [4]. Yan Xu, *et al.,* on the basis of their analysis of eco-environmental features of the Bohai Sea, studied and determined a technical method suitable for ecological red-line partitioning in the area.

The current study conducted an investigation and partitioning work of ecological red-line areas of the Chishui River Basin in Guizhou, China. From the basin scale, the eco-environmental restoration task for the Chishui River Basin, in terms of the upstream water source conservation area, is significant. The development of the midstream wine industry has a high degree of dependence on the natural environment, and is accompanied by the rapid development of Maotai Town and the surrounding industries, cities, and towns. Consequently, the pressure borne by the eco-environment in the basin areas is increasing. The brewing environment for brand-name and high-quality wines, such as “Guizhou Moutai Liquor,” as well as the local economic and social development are also greatly influenced. The lower reaches are mostly distribution zones of national-level nature reserve areas and forest parks with significant ecological service functions as scientific research and investigation values. In recent years, as the population has continuously expanded, the influence of human activities in this area has intensified and the eco-environment has been seriously affected. Hence, conducting research on ecological red-line area partitioning and management methods in the Chishui River Basin in Guizhou is imperative and will be of significant guidance to protecting a continually deteriorating eco-environment.

2. Data and methods

2.1. Research area profile

The Chishui River Basin is located at E105°13′19″-106°58′34″ and N27°13′16-28°45′58″ in the northern part of Guizhou Province, which is located in the southwest region of China. Its landscape mainly consists of karst, and the ecological environmental is sensitive and vulnerable. The overall length of the main stream within Guizhou territory is 268.40 km. It occupies 61.5% of the total length of the Chishui River main stream and the basin area is 11,392.44 km^2 in Guizhou territory, which occupies 55.74% of the total basin area of the Chishui River. The basin belongs to a mid-subtropical monsoon climate, which is warm and humid. The variations of annual temperatures are minor; it is warm in winter and cool in summer, so the climate is pleasant. Vegetation types are mainly artificial *Pinus yunnanensis*, Masson pine, and subtropical secondary evergreen broad-leaf forests. Soil types are complicated and various, mainly yellow earth, lime earth, and purple soil. Danxia landform within the basin features a complete geomorphic development, where biological diversity is abundant and various old and endemic plants abound.

Figure 1. Location of Guizhou province in China.

2.2. *Data sources and preprocessing*

2.2.1. Data sources. Fundamental thematic data involved in this study included landform, soil type, geological background, and vegetation type from the Guizhou basic geological database. Land-cover data, a 30 m-resolution Landsat^{TM} remote-sensing image, and NPP data of 2010 were provided by the Ecology 10 Year Project group; 30 m-resolution DEM data were derived from the International Scientific Data Service Platform; and hydro-meteorological data information (1981–2010) was obtained from the China Meteorological Data Sharing Service Network platform. NDVI and bedrock bareness rate data were attained from remote-sensing image inversion. All data were uniformly placed under an equivalent secant conic (Albers) projection.

2.2.2. Data preprocessing. Supervised classification interpretation in ERDAS was utilized to determine the land-use type, which includes 10 types, namely, forest, spinney, grass, open woodland, water, paddy field, dry farm, building, rock, and bare soil. Vegetation coverage was calculated from the NDVI via dimidiate pixel model, which has been proven simple and effective in the case study region. NPP was provided by the Ecology 10-Year Project group using 10-day NPP data calculated from the 2010 annual NPP. The rate of exposed bedrock was calculated based on the rate of vegetation coverage and bare soil according to its relation. Rainfall data were used to calculate the precipitation erosion force according to the formula, and then spatial interpolation was applied to obtain the raster data of precipitation erosion force.

2.3. Study method

An analysis of the scientific value and connotation of ecological red lines provided in the Introduction section of this paper indicated that, at present, educational circles mainly adopt a certain degree of ecological sensitivity and vulnerability to define an unbridgeable bottom line in ecology. Based on the special ecological environment and eco-environmental background in the Chishui River Basin, this study took the Chishui River Basin as the study object and selected water and soil loss sensitivity, as well as assessments of karst rocky desertification sensitivity as background assessments of the eco-environment. By integrating the functions of soil conservation, water conservation, and biodiversity protection with the exploitation-prohibited area, an organic combination of ecological needs and social service functions was created. This combination completely marked out ecological red-line areas in the Chishui River Basin in Guizhou Province.

2.3.1. Assessment content and standard of ecological red lines in the Chishui River Basin

- Evaluation of water and soil loss sensitivity

Water and soil loss sensitivity in the karst region was shown to have a significant correlation with soil formation rate in addition to precipitation, soil, landform, and vegetation factors, which is closely related to acid-insoluble substance content in carbonatite [6–7]. This study selected five indexes, namely, precipitation erosion force, soil erodibility, topographic relief degree, aboveground vegetation coverage, and soil loss tolerance, to conduct an analysis and evaluation of water and soil loss sensitivity in the Chishui River Basin. A comprehensive overlapping calculation of water and soil loss was also conducted using Formula (1) [8–10].

$$SS_j = \sqrt[n]{\prod_{i=1}^{n} S_i} \tag{1}$$

In the formula, SS_i denotes the water and soil loss sensitivity index of space unit j, S_i is the sensitivity grade of factor i, and n is the number of factors. The natural parting method was used to compare the evaluation results. This method used demarcation points obtained by statistical Jenks optimization to make the sum of internal variance of grades reach the minimum value. The concrete grading standard (Table 1) refers to the Temporary Regulations on Ecological Function Areas Partitioning issued by the Ministry of Environmental Protection [11], the National Ecological Protection Red Lines—Technical Guide of Ecological Function Red-Line Partitioning (Trial) [12], and other relevant studies [13–14].

Table 1. Evaluation index grading standard of water and soil loss sensitivity.

Index	Precipitation Erosion Force	Soil Erodibility	Topographic Relief Degree	Vegetation coverage	Soil Loss Tolerance	Grading Valuation	Grading Standard
No	<25	＜0.20	0–20	≥0.8		1	1.0–2.0

Sensitivity							
Mild Sensitivity	25–100	0.20–0.25	20–50	0.6–0.8		3	2.1–4.0
Medium Sensitivity	100–400	0.25–0.30	51–100	0.4–0.6	Inter-bedding Area of Carbonatite	5	4.1–6.0
High Sensitivity	400–600	0.30–0.40	101–300	0.2–0.4	Interlayer Area of Carbonatite	7	6.1–8.0
Extreme Sensitivity	>600	＞0.40	>300	≤0.2	Continuity Carbonatite Area	9	＞8.0

- Evaluation of karst rocky desertification sensitivity

Karst rocky desertification, which results from the irresponsible social and economic activities of humans acting on a vulnerable eco-geological environmental background, is one of the most prominent eco-environmental problems in Guizhou Province [15]. This study chose four factors, namely, bedrock bareness rate, topographic slope, vegetation coverage, and lithology, as evaluation factors of karst rocky desertification sensitivity. Furthermore, an evaluation of the single factors of karst rocky desertification sensitivity in the Chishui River Basin was conducted with grading standards determined in table 2 [16–17]. Next, according to formula (1), a comprehensive overlapping calculation was conducted and a grade map of karst rocky desertification sensitivity was developed.

Table 2. Grading standard table of karst rocky desertification sensitivity evaluation indexes.

Index	Bedrock Bareness Rate	Topographic Slope	Vegetation Coverage	Lithology	Grading Valuation	Grading Standard
No Sensitivity	≤0.3	≤5°	≥0.8	Non Carbonatite	1	1.0–2.0
Mild Sensitivity	0.3–0.5	5°–8°	0.6–0.8	Secondary Impure Limestone	3	2.1–4.0
Medium Sensitivity	0.5–0.6	8°–15°	0.4–0.6	Limestone and Clasolite	5	4.1–6.0
High Sensitivity	0.6–0.7	15°–25°	0.2–0.4	Limestone and Dolomite	7	6.1–8.0
Extreme Sensitivity	≥0.7	≥25°	≤0.2	Continuity Limestone	9	＞8.0

- Evaluation of soil conservation function significance

According to suggestions put forward in Temporary Regulations on Ecological Functional Areas Partitioning, the evaluation of soil conservation significance should be based on soil erosion sensitivity, as well as on the analysis of the endangered degree and scope it may cause to the downstream bed and water source [11]. The universal soil loss equation contains the following five factors that can be used to conduct a quantitative calculation of soil conservation function: precipitation erosion force (R), soil erodibility factor (K), slope factors (S), slope length factor (L), and vegetation coverage factor (C). This study used a rectified universal soil loss equation to conduct a quantitative calculation of soil conservation while only taking the soil conservation amount in its natural state into consideration. The model structure was arranged as follows [20–22]:

(2)

$$A_P = R \cdot K \cdot LS \tag{3}$$

In the above equation, *Ac* denotes the soil conservation amount, *Ap* is the potential soil erosion amount, and *Ar* is the actual soil erosion amount. A spatial overlapping calculation of grid maps of the above factors was conducted, and then fractile quantile sorting method was adopted to divide overlapping calculation results into five grades, namely, generally significant, relatively significant, moderately significant, highly significant, and extremely significant. Then, a grading distribution graph of soil conservation significance of the study area was obtained.

- Evaluation of water source conservation function significance

Water source conservation is an important service function of an eco-system. Different eco-systems have different water source conservation capacities. Specifically, the water storage effects of eco-systems are used to measure their functions of intercepting precipitation and conserving moisture. This study adopted a precipitation storage method to conduct a quantitative evaluation of water source conservation [23, 24]. The formula is shown below:

$$Q = A \times J \times R \tag{4}$$

$$J = J_0 \times K \tag{5}$$

$$R = R_0 - R_g \tag{6}$$

In the above formula, *Q* denotes an increment of the precipitation and moisture intercepted and conserved by eco-systems compared to bare land (unit is m^3); *A* is the area of eco-system types in the calculation region; *J* is the average runoff-producing precipitation over the years in the calculation region (P>20 mm); J_0 is the average total precipitation over the years in the calculation region (mm); and *K* is the proportion of runoff-producing precipitation in total precipitation of the calculation region. According to relevant study results, 0.6 was selected for the *K* value, and *R* was the efficiency coefficient of precipitation interception and runoff reduction of eco-systems when compared to bare land (or clear-cutting slash) [25, 26]. According to measured data and relevant study results, as well as a combination of the distribution, vegetation coverage, soil, topographic features, and relevant features of the corresponding bare land of eco-system types, this study determined the *R* values of vegetation types of eco-systems [27-31]. R_0 is the precipitation/runoff ratio of bare land under runoff-producing precipitation conditions, and R_g is the precipitation/runoff ratio of eco-systems under runoff-producing precipitation conditions.

- Biodiversity protection function evaluation

Biodiversity refers to a great variety of living organisms within a specific spatial scale; it is an embodiment of the complicated relationship between organisms and between them and the environment, as well as a sign of rich and colorful biological resources [32]. According to the National Ecological Protection Red Lines—Technical Guidance of Ecological Function Red-Line Partitioning (Trial), the present study adopted the method based on biodiversity to conduct a biodiversity protection significance evaluation. The model is shown below:

$$S_{bio} = NPP_{\text{mean}} \times F_{pre} \times F_{tem} \times (1 - F_{alt}) \quad (7)$$

In the equation, S_{bio} is the biodiversity protection significance, NPP_{mean} is the net primary productivity, NPP_{mean} is the precipitation, F_{tem} is the temperature parameter, and F_{alt} is the altitude parameter.

- Exploitation-prohibited area

Exploitation-prohibited areas in the Chishui River Basin include nature reserve area/scenic spots, exploitation-prohibited areas of wine production, and special water source protection areas for national wine. Nature reserve area and scenic spot distribution diagrams are from the directories of national-level and province-level nature reserve areas and scenic spots, as well as their distribution diagrams in Guizhou Province. After researching relevant data [33], the exploitation-prohibited areas for wine production were determined to be located mainly on the upper reaches of the wine production base and surrounding regions of the Chishui River in Renhuai City. According to the Upstream Ecological Function Protection Area Partitioning in the Chishui River (within Guizhou territory) [34], special water source protection areas for national wines refer to basin areas within the Guizhou territory, from the Jiucang River at the right bank of the Chishui River to the original water intake of Yuwo Moutai brewery.

2.3.2. Ecological red-line partitioning method in chishui river of guizhou province. Using GIS spatial analysis technology, and on the basis of the evaluation of eco-environmental sensitivity and ecological service function significance, extremely sensitive eco-environmental areas and extremely significant ecological service function areas were extracted to conduct broken patch processing. Low-grade patches were contained inside patches with extremely sensitive grade and extremely significant grade. All patch scopes with a lower grade were incorporated into patches with a higher grade. Based on this and comparing the results with land coverage data in 2010, the main construction lands were separated from the red-line areas. The determination of red-line borders should take full consideration of information, such as mountain ranges, rivers, geomorphic units, and vegetation to maintain the integrity of the eco-system and the connectivity of landscapes as best as possible. Furthermore, it should give priority to marking out areas with little artificial interference and easy mastery and form a spatial distribution diagram containing all ecological red lines.

3. Analysis of ecological red-line area partitioning results in the Chishui River Basin in Guizhou Province

3.1. Ecological red-line area types in the Chishui River Basin in Guizhou Province

According to the above partitioning method, ecological red-line areas in the Chishui River Basin were divided into nine major types as expounded in the basic definition of national ecological red lines including water and soil loss, karst rocky desertification, soil conservation, water source conservation, biodiversity, and nature reserve area/scenic locations. For the local typical ecological industry, namely, the wine making industry, this study also marked out exploitation-prohibited red-line areas of wine production and special water source protection red-line areas for national wines. Given the particularity of the geo-ecological environment in the Chishui River Basin, the same unit of some regions within the basin involved multiple red-line areas. Overlapped areas in red-line areas were uniformly called comprehensive ecological red-line protection areas. The situation of ecological red-line areas partitioning in the Chishui River Basin is shown below (table 3, figure 2).

Table 3. Scheme of ecological red-line area partitioning in Chishui River Basin.

Name of Red-Line Area	Area (km^2)
Karst Rocky Desertification Sensitivity Red-Line Area	1.42
Water and Soil Loss Sensitivity Red-Line Area	295.70
Soil Conservation Red-Line Area	156.09
Water Source Conservation Red-Line Area	61.06
Biodiversity Red-Line Area	787.86
Nature Reserve Area/Scenic Spot Red-Line Area	273.54
Exploitation-prohibited Red-Line Area for Wine Production	254.24
Special Water Source Protection Red-Line Area for National Wines	489.79
Comprehensive Ecological Protection Red-Line Area	2710.88
Total	5030.58

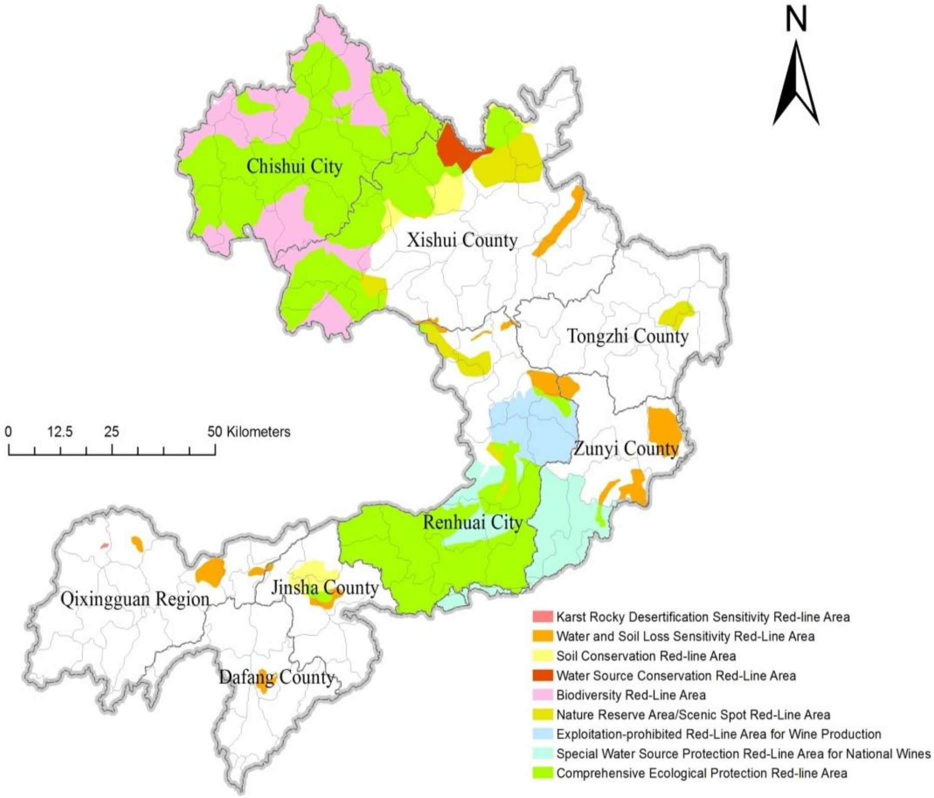

Figure 2. Distribution diagram of ecological red-line areas in the Chishui River Basin.

3.2. Distribution of ecological red-line areas in the Chishui River Basin in Guizhou Province

- Karst rocky desertification sensitivity red-line areas

One karst rocky desertification sensitivity red-line area (1.42 km2) is intensively distributed in Bijie. The lithological characters of these areas are mainly continuity limestone with geological conditions for karst rocky desertification, and the land-cover types are mainly barren grassland and dry cropland, upon which karst rocky desertification can easily happen under artificial interference. Although this red-line area is relatively small and presents random and crushing-state distribution, the influence of karst rocky desertification on the agriculture and the eco-environment cannot be underestimated. To protect this area, man-made land reclamation and soil vegetation damaging behaviors should be strictly restricted. In addition, the government should actively give guidance for the restoration and construction of vegetation and restrain further expansion of karst rocky desertification.

- Water and soil loss sensitivity red-line areas

There are 13 of this type of red-line area (295.70 km2) with a broad distribution range, including the Qixingguan region, Dafang County, Jinsha County, Zunyi County, and Renhuai City. Areas sensitive to water and soil loss usually have many sloping croplands with low vegetation coverage. These are major areas of water and soil conservation, as well as eco-environmental construction in the Chishui River Basin. Governance and protection projects centering on slope remediation should be carried out, a complete basic farmland water conservancy infrastructure constructed, and basic agricultural conditions improved. Furthermore, farmland should be actively returned to forests or grasslands, a planned development of economic forests conducted, forest and grass coverage increased, the base of soil conservation stabilized, and full advantage should be taken of the self-repairing capacity of nature to effectively control water and soil loss.

- Soil conservation red-line areas

Three soil conservation red-line areas (156.09 km2) are mainly distributed in the middle of Jinsha County and a small part of northwestern areas of Xishui County. In terms of geological lithology, these are areas where limestone mixed with clasolite and non-carbonatite are distributed. Their soil layers are relatively thick, and the vegetation cover types are mainly forests and grasslands, with good conditions for water and soil conservation. The protection of soil conservation work in these areas should be the focus, reasonable allocation of water and soil resources, and comprehensive forbiddance implemented for a large area for land reclamation and vegetation damage.

- Water source conservation red-line areas

There is one water source conservation red-line area (61.06 km2) mainly distributed in Chengzhai Village of Xishui County. This area is one part of the national-level mid-subtropical evergreen broad-leaved forest nature reserve, which has good basic conditions and natural conditions for water source conservation. Reinforcing the forbiddance, management, and protection of the nature reserve area are important measures for protecting water source conservation red-line areas.

- Biodiversity red-line areas

One biodiversity protection red-line area is mainly distributed in most parts of Chishui City and the Xishui nature reserve area located in southwestern Xishui County. The area is 787.86 km2 in size and occupies 6.92% of the total basin area. This area has superior heat-quantity conditions, with clear characteristics of plant diversity and various old and endemic plants. It is of great research value and ecological protection significance for biodiversity protection, especially for rare animals and plants. The government should prohibit capturing and killing of wild animals, as well as ban destruction of the environment of rare animals and plants by explicit order.

- Nature reserve/scenic spot red-line areas

There are six types of red-line areas mainly distributed in nature reserve areas and scenic spots in Chishui City, Xishui County, Renhuai City, and Tongzi County totaling 273.54 km2. The protection of nature reserve areas/scenic spots needs to rationally deal with the relationship between tourism development and nature reserve, develop suitable tourism destinations, develop ecological tourism, and protect the integrity of the eco-system within the reserve areas.

- Exploitation-prohibited area red-line area for wine production

There is one exploitation-prohibited red-line area for wine production that is mainly located in the wine production base of Renhuai City and the surrounding areas, which totals 254.24 km2 and occupies 2.23% of the total basin area. This red-line area is the wine production base and forbids development of new enterprises with serious pollution based on original construction, discharge of industrial sewage and domestic sewage into the Chishui River, and reinforces the protection of the water source environment in the Chishui River.

- Special water source conservation red-line area for national wines

One special water source conservation red-line area for national wines is located in the upper reaches of the Chishui River in Renhuai City and the surrounding areas of production base, which totals 254.24 km2 and occupies 4.30% of the total basin area. The protection of this red-line area is of great significance to the production of "Guizhou Moutai" national wine. This area has the water sources necessary for a national wine brewery and provides qualified water environment for national wine production. Environmental and eco-environmental water protection should be intensified on the upper reaches. Furthermore, the development of chemical industries and high-pollution industries, such as mining, metallurgy, and papermaking, all of which affect water quality, should be forbidden, water pollution discharge standards should be tightened, and enterprises that pollute water should be shut down.

- Comprehensive ecological protection red-line areas

As some areas have various red-line areas that mutually overlap in geographical spaces, these areas are extremely significant comprehensive protection areas because of their multiple protection objectives including comprehensive protection red-line area consisting of eight major red-line areas, water and soil loss sensitivity and exploitation-prohibited red-line areas for wine production, water source conservation and biodiversity protection red-line areas, and soil and water source conservation red-line areas. These overlapping areas are mainly distributed in the national-level Cyathea spinulosa nature reserve area and the mid-subtropical evergreen broad-leafed forest nature reserve area, which are at the border between Chishui City and Xishui County, and RenHuai City and its surrounding areas. This type of red-line area covers 2,719.88 km2, which occupies 23.80% of the total basin area. Protection of the eco-environment in this area should aim at biodiversity and the special habitat of C. spinulosa nature reserve area to completely eradicate interference and damage from human activities.

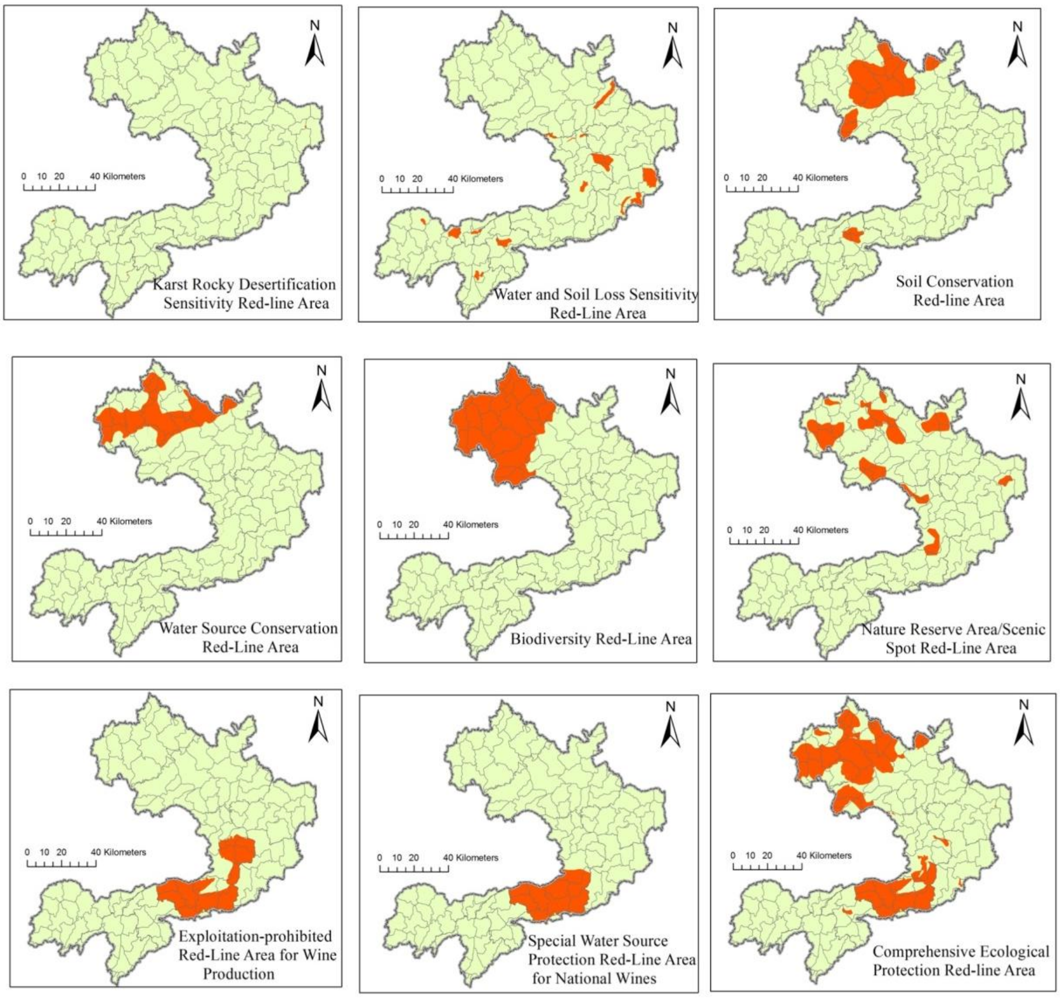

Figure 3. Distribution diagrams of all types of ecological red-line areas.

4. Conclusion and suggestions

Taking into consideration the comprehensive features of natural factors and human activities in the Chishui River Basin, as well as the objective requirement of industry and life, this study specified nine major ecological red-line areas with a total area of 5,030.58 km^2. This area makes up 44.16% of the total basin area. Owing to the particularity of the physico-geographical environment in the Chishui River basin, red-line areas are mainly ecological service red-line areas and exploitation-prohibited red-line areas, which are liberally distributed in Chishui City, the national-level nature reserve area in Xishui County, Renhuai City, and its surrounding areas.

According to features of the distribution situation for all types of ecological red-line areas, the principle of "priority given to special water source protection, equal attention paid to ecological protection and ecological construction" must be prioritized. This principle must be combined with a sorting management and comprehensive administration of ecological red lines in the Chishui River. Access to industrial development must be restricted and a mechanism for ecological benefit compensation must be established to give priority to organizing land use in red-line areas, implementing agricultural production on the condition that eco-environmental quality is not affected, and constructing environmentally-friendly land use modes. Importantly, a sustainable development path must be achieved to realize healthy and harmonious existence between the regional economy and the environment.

This study discussed the technical method of ecological red-line partitioning, which basically reflected the ecological features of the study region in a theoretical sense. For practicability of ecological red-line areas, it is necessary to conduct further study according to the population and social and economic development situation of the study region. By combining suggestions of the local government, harmony between red-line areas and regional ecological protection planning, as well as land use planning can be guaranteed. This study was an objective embodiment and scientific presentation of the local ecological environment, but the far-reaching significance of partitioning ecological red-line areas is not limited to this. More detailed protection regulations and measures should be formulated during subsequent real life management of red-line areas. Tangible ecological red-line protection assessment indexes must also be established to truly embody the science and authority of ecological red lines, as well as their core values, which are essential for social development and environmental protection.

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