Ecological Optimization of Spatial Patterns of Water Conservancy landscape in Qilian Mountains based on land processes: a case study of Zamu River Basin in Upper Shiyang River Basin

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Abstract: Based on the relation of the ecological landscape to its ecological function, this paper takes Zamu river basin in upper Shiyang river as an example, which located in the cold region of Qilian Mountains in northwestern of China. With the use of the remote sensing data, the spatial information processing technology of GIS, suitability evaluation with the overall optimization of land use pattern is applied to ascertain the function zoning and ecological pattern components of land use, to develop approaches to the ecological optimization of the spatial pattern of water conservation landscape in the mountains region. The results show that: With Zamu river basin as the research object, based on the source of the water conservation ecological landscape of frozen soil and water conservation forest, considering the zonal distribution of the frozen soil and water conservation forests in order to classification of factors such an slope, elevation, vegetation cover type and so on, we divided Zamu river valley into five ecological function regions. There are the water conservation core, water conservation buffer, water conservation excessive area, water conservation area and human development and utilization of the edge area. Also we put forward the countermeasures for protecting the each function.

1. Introduction
The change of land use and land cover change in a basin can cause both the soil and water loss and eco-environment destruction, further leading to the degradation of eco-environment system in the basin[1-2]. The core of the study of eco-remediation technology for improving water conservation efficiency in basins is to enhance the connectivity of water flow in different land uses by adjusting the utilization of land and land cover patterns. Thus, the utilization of land and land cover can be maintained in a good and harmonious symbiosis state. The Qilian Mountain is one of the most important water sources in the inland areas of northwest China. Mountain precipitation and snowmelt water are the important sources for both some inland rivers, such as the Shiyang River, the Heihe, the Shule River and so on, and some major tributaries of the Yellow River like the Datong River, the Huangshui River, etc. Forest for water conservation and permafrost in mountains play an important role in maintaining river runoff and supporting the sustainable ecological, social and economic development in the middle and lower reaches of the mountains. However, as a result of massive deforestation and destruction by human and natural factors such as climate change, forest for water conservation and permafrost have shrunk in large areas[3-4]. Therefore, rational protection and reconstruction of forest for water conservation and seasonal permafrost in the mountainous area of
Qilian have become a research focus of ecological protection in arid areas. Aiming at protecting the natural ecological environment of the basin and maintaining the healthy development of the water conservation forest, this paper comprehensively utilizes the landscape ecological planning method developed on the basis of the landscape ecology in recent years with the help of the spatial information processing technology of remote sensing (RS) and geographic information system (GIS) to study the Zamu River basin in the mountainous area of Qilian in the northwest of the Shiyang River in China. The ecological suitability evaluation model is set up to explore the practice of ecological optimization of water conservation landscapes in alpine mountain areas, which will provide an attempt for the ecological optimization of water conservation.

2. Survey of the Research Area

The Zamu River basin is located at 102°00′ to 102°35′ E and 37°23′ to 37°44′ N, and is one of the eight tributaries in the upper reaches of the Shiyang River basin, as well as the water conservation area. The main stream in the mountainous area is about 60 kilometers long and its basin area is 851 km². Moreover, its altitude is 2050 to 4830 meters. There is permafrost in the upper reaches of the main stream in the mountainous area. Precipitation and melt-water are its major water supply sources, with 80% of the runoff for Maozangsi. Among the total annual runoff, the direct runoff from precipitation accounts for 65.2% while the groundwater which comes from precipitation to the rivers is 30.7%. Besides, the snowmelt in spring accounts for 2.6%, in summer 1.5%. The vegetation in the headwater area of the basin is good, including types such as alpine meadow, alpine grassland, shrub, tree and so on. There is little water and soil loss in the area. The annual sediment runoff of the basin reaches 165 thousand tons and its erosion modulus is 194 t/km². There’re 4 soil classes and 7 types of soil in the research area. Among the ten soil types, the proportion of alpine soil and calcareous accounts for 80.84% and 16.82% respectively. The types of land use of the Zamu River are shown in Fig. 1.

![Figure 1. Map of the Types of Land Use in the Zamu River Basin](image)

3. Acquiring, Processing and Researching of the Basic Data of the Research Area

3.1. Data Collection

1:100,000 topographic maps and other land survey data of the research area are collected, which come from the Gansu Provincial Bureau of Surveying and Mapping and the Wuwei Bureau of Statistics respectively. The 2012 land-use type map of the Zamu River basin comes from the achievements of Gansu Water Conservancy Research Institute.
3.2. Generation of Digital Elevation Model (DEM)

The 1:100,000 topographic map of the research area is digitized in GIS, and its Digital Elevation Model (DEM) is generated by surface interpolation.

3.3. Classification of Land Use

Due to the sensitivity of remote-sensing image to land vegetation, it is used to classify the land use of the research area by the land surface vegetation coverage together with ground investigation. The land-use data of the Zamu River basin in 2015 is used in this study. In order to better reflect the real situation of the research area, site investigation is conducted to compare and analyze the data and the real situation. As a result, the land-use types are integrated into five, which are forest, shrub land, grassland, cultivated land and the others. Their system characteristics are shown in Table 1.

| Categories     | Characteristics                                                        |
|----------------|------------------------------------------------------------------------|
| Forest         | Referring to all the forest land, including timber forest, economic forest and good well-grown shrubbery land |
| Shrub Land     | Referring to the shrub-dominated shrub land and shrubby grassland       |
| Grassland      | Referring to the herbaceous-plant-dominated shrub grassland and grassland |
| Cultivated Land| Referring to dry land, terraced dry land, irrigated fields and rained paddy |
| Other Land     | Referring to water bodies, construction land, bare rock and bare soil   |

3.4. Method

Combined with the existing theories and practices of landscape ecological planning [9-10], the process of landscape ecological optimization of forest for water conservation in Qilian Mountains is analyzed by suitability evaluation.

The following model is used:

\[ Y_i = H_i \times (S_i + T_i) \]  

\( i = 1, 2, 3, \ldots, n \)  

In the formula: \( i \) represents the number of the evaluation units while \( n \) means the number of the evaluation units. \( Y_i \) means the suitability grade of the evaluation unit \( i \), which is also the resistance parameter. \( H_i \) means the elevation limiting factor of the evaluation unit \( i \). Moreover, \( S_i \) and \( T_i \) represent the slope gradient and the type of coverage of the evaluation unit \( i \) respectively.

4. Study on Ecological Optimization of Water Conservation Forest

4.1. Evaluation Principles

The distribution of frozen soil and forest land in Qilian Mountains obviously follows the law of zonality. According to the study on the distribution of frozen soil in the middle-east section of Qilian Mountains, the reference [4] shows that the frozen soil of Qilian Mountains is continuously distributed above 3,600 meters above sea level. The reference [3] shows that the water conservation forest in Qilian Mountains is mainly distributed above an attitude of from 2,600 to 3,600 meters while the landscape structure is relatively simple in the low elevation zone below 2,600 meters and the high elevation zone above 3,600meters. Landscape types, such as Gobi desert, bare rock land and low-cover grassland, account for a large proportion due to little rainfall, sparse vegetation and unreasonable grazing and cultivation in the low elevation zone. There’re few human activities in the high elevation zone, but there’s still little vegetation with singe type in the high elevation zone due to the cold climate there, which means shrub forest, bare rock and bare land, and the snow landscape account for a larger proportion. According to the findings of the reference mentioned above, the evaluation principles of water conservation in Qilian Mountains are formulated as follows:

1. It is not suitable to develop forest for water conservation in the region at the altitude of 4,000
meters due to the perennial snow cover or the distribution of glacier and frozen soil. However, as the main supply of the downstream runoff, it boasts a higher priority for developing forest for water conservation.

② The region whose altitude is below 2,600 meters has a lower priority of developing forest for water conservation due to the scarce precipitation.

③ Among the regions whose altitude ranges from 2,600 to 4000 meters, those places whose altitude ranges from 3,000 to 3,600 meters have higher priorities of developing forest for water conservation;

④ Among the regions whose slope gradient is within 45°, the larger its slope gradient is, the higher priority it will have to develop forest for water conservation.

⑤ As the main protection objects, the existing forestlands and the steep slope wastelands should be taken as the prior regions for developing water conservation forest.

⑥ Gentle slope farmlands, especially those in the low elevation area, should be well protected as the basic farmlands.

4.2. Evaluation Factors
In the northwestern region of Qilian Mountains, topography and land cover types are the two basic factors that influence the changes of landscape and its ecological functions. They not only control the differences of soil development and hydrological conditions, but also decide the spatial differences of land use. In order to identify the key areas of developing forest for water conservation, this paper takes elevation, slope gradient and cover type as the indexes to evaluate the suitability of developing forest in landscape sample areas.

The elevation of regions in the research area mainly ranges from 2,200 to 4,400 meters. The restoration resistance of developing forest for water conservation is divided into seven levels according to elevation (Table 2).

| Grade  | Level One | Level Two | Level Three | Level Four | Level Five | Level Six | Level Seven |
|--------|-----------|-----------|-------------|------------|------------|-----------|-------------|
| Elevation Resistance Value | >4000 | 3800~4000 | 3600~3800 | 3000~3600 | 2600~3000 | 2200~2600 | <2200        |

According to the local grading standard of slope gradient, the restoration resistance of developing forest for water conservation is divided into seven levels (Table 3).

| Grade  | Level One | Level Two | Level Three | Level Four | Level Five | Level Six | Level Seven |
|--------|-----------|-----------|-------------|------------|------------|-----------|-------------|
| Elevation Resistance Value | >45° | 40~45° | 35~40° | 30~35° | 25~30° | 19.37~25° | <19.37°   |

Based on the above landscape classification, the following five types are evaluated:
T1: Forestland; T2: Grassland; T3: Cultivated land; T4: Urban and rural settlements and industrial and mining land; T4: Unused land.

4.3. Evaluation Process
(1) Based on the Digital Elevation Model (DEM) of the Zamu River, the elevation and slope classification maps of the basin are made. Space vector layers and vector information table are used to evaluate the effect of land use types, slope gradient and elevation of the regions on the resistance level of restoring forest for water conservation;

(2) Based on the assessment principle of water conservation as well as the land adaptability assessment, the relatively prior results of developing ecological landscape for water conservation are put forward.
(3) Natural segmentation method is used to decide the ecological pattern zoning of forest for water conservation.

Table 4 Ranking of the Priority Level of the Regions Based on the Comprehensive Evaluation of Land Use Type and Slope Gradient in Zamu River Basin

| Priority Level | Slope Gradient and Land Use Type |
|----------------|----------------------------------|
| 1              | T₁+S₁, T₂+S₂, T₃+S₂, T₅+S₃      |
| 2              | T₂+S₃, T₃+S₃, T₅+S₄             |
| 3              | T₃+S₄, T₄+S₅, T₂+S₆, T₇+S₇      |
| 4              | T₄+S₆, T₇                      |
| 5              | T₃+S₆, T₇                      |
| 6              | T₂+S₁, T₃+S₁, T₅+S₁, T₇+S₁, T₅+S₅, T₇+S₇ |

4.4. Functional Zoning of Water Conservation
This paper will use the natural segmentation method of George F. Jenks to decide the inflection points for different ecological functional zones. [11]

The natural segmentation method of George F. Jenks is used to classify the relatively priority levels of the ecological landscape areas and then decide the boundaries of the different ecological functional zones, as shown in Figure 2.

4.5. Ecological Protection Countermeasures for Different Forestlands for Water Conservation
Core zone of water conservation: It is suggested that study on the effect of climate change on snow and ice cover and frozen soil in the northwest mountains should be enhanced so as to put forward comprehensive and systematic measures to protect snow-covered areas. With the increasing protection consciousness and the greater investment, forest for water conservation in the regions at an altitude of below 4,000 meters in the basin can grow well under suitable topography and climate conditions. Therefore, these places should be regarded as the core ecological protection zone for the development of forest for water conservation in the Zamu River basin. As the different hydrological effects of plants under different site conditions are taken into account, the vegetation combination model with the largest hydrological effect can be recovered according to the reference [5].

Buffer zone of water conservation: Due to the disturbance of climate, topography and human activities, it is difficult to develop more water conservation forestlands with the same investment in this zone. So it is an inefficient zone for developing forestlands. However, the development of the buffer zone of water
conservation is closely related to that of the core zone. Whether this zone can be well protected or not will decide the healthy development of the core zone and it is sensitive to both development and protection. It can be neither regarded as a protected area nor developed into cultivated land. Moreover, the zone plays a key role in maintaining the connectivity of the landscape. So it can be treated as a buffer zone for the development of shrubbery or grassland ecosystems.

Transition area of water conservation: With the increase of human activities, the original grassland ecosystem in the zone has been seriously damaged; the topography and climatic conditions have determined that the zone is suitable for the development of grassland rather than forestland. Therefore, higher ecological protection investment works little for restoring forest for water conservation in this zone, and the zone is not suitable for developing natural vegetation. As a result, it should be regarded as the transition zone of forest for water conservation and the current ecological status there should be maintained.

Marginal zone of water conservation: It’s mainly for the development and utilization of wood by human beings. Thanks to the stable water supply from the upstream forest for water conservation, moderate-scale timber forest and economic fruit forest can be developed in gentle slope zone and flat ground in the valley.

Other development zones of human beings: The efficiency of natural vegetation development tends to zero. It can be used as the main land for habitation and living. Since the Zamu River basin is located in the upper reaches of the Shiyan River, it is appropriate to maintain a reasonable population and a clean mode of human production and life.

5. Conclusion and Suggestions
The ecological suitability assessment and the minimum consumption surface model of land use based on GIS spatial analysis technology can be well utilized in the process of ecological landscape optimization. However, due to the high altitude of the western mountains, the suitability evaluation principles, evaluation factors and resistance levels of the zoning of ecological landscape pattern for water conservation should follow the natural geographical characteristics of the western mountain system. Starting from forest for water conservation and frozen soil, combined with slope, this paper takes Qilian Mountains in the northwest as a research object. According to the factors that will influence the restoring of forest for water conservation, such as slope gradient, elevation and vegetation cover type, ecological optimization pattern of water conservation can be well planned when the natural factors such as the distribution of frozen soil and vegetation for water conservation and geographical features, as well as the human will, are greatly considered.

The mountain system in the inland area of northwest China provides abundant water resources for maintaining the sustainable social and economic development in the northwestern area. The ecological environment protection of this area plays an important role in maintaining the sustainable development of water resources. Therefore, the impact of human activities on the development and utilization of mountain areas should be reduced to the lowest level while the protection and restoration of natural ecological landscape should take the lead.

The ecological landscape suitability assessment boasts the characteristics of easy operation and simple method in optimizing the ecological landscape pattern \([1]\), but the determination of the inflexion points of the ecological zoning should be conducted based on the statistical method. The natural segmentation method proposed by George F. Jenks is a beneficial experiment.

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