# Post-print: Study on Delimitation of Ecological Redlines in Key Water Source Areas of the Yellow River

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## Abstract

Based on the analysis of ecological and environmental characteristics of the Yellow River' s important water source replenishment area, an evaluation system for ecological red line demarcation was constructed from three aspects: ecological resilience, ecological sensitivity, and socio-economic influence. GIS spatial analysis technology was employed to construct a spatial attribute database for the Yellow River' s important water source replenishment area, the analytic hierarchy process was adopted to determine the weight of each indicator, and spatial analysis and overlay analysis techniques were utilized to divide the Yellow River water source replenishment area into ecological red line zones, ecological yellow line zones, and ecological green line zones, ultimately determining the ecological protection priorities and management countermeasures for each zone. Research results indicate that ecological red line zones account for 38.4% of the entire region, mainly distributed in the source areas of the Yellow River and its tributaries within Maqu County, the farming-pastoral ecotone of Gannan and Linxia prefectures, and along the Bailong River basin. Ecological red line zones should implement the strictest control measures, strictly prohibiting various development activities. Ecological yellow line zones occupy 39.1% of the entire region, primarily distributed in southern Linxia Prefecture, and northwestern and southern Gannan Prefecture. Due to their important ecological strategic position, these zones should focus on ecological restoration and governance, strictly prohibiting development and construction activities that would impair dominant ecological functions. Ecological green line zones comprise 22.5% of the entire region, mainly distributed in northern Linxia Prefecture and central Gannan Prefecture. These areas may undergo moderate development, driving a positive interaction between economic transformation and upgrading and environmental protection through the development of ecological industries.

## Full Text

## Preamble

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# 2. Study Area and Methods

### 2.1 Study Area

The study area comprises the important water supply region of the Yellow River, located in the upper reaches of the basin. This region includes the main stream of the Yellow River in Maqu County and its tributary source areas, the ecotone between agriculture and animal husbandry in Gannan and Linxia prefectures, and the riparian zones of the Bailongjiang River. The geographical location and spatial extent of the study area are illustrated in [Figure 1: see original paper].

**FIGURE:1** Location of the important water supply region of the Yellow River

The region encompasses critical water conservation areas, including the Yellow River water source conservation zone in Maqu County, soil and water conservation and biodiversity protection areas in the farming-pastoral ecotone of Gannan and Linxia, wetland conservation areas in Luqu and Hezuo counties, headwater conservation areas of the Daxia and Taohe rivers, soil and water conservation zones along the Bailongjiang River, and the water conservation area of the Liujiaxia Reservoir.

### 2.2 Data Sources and Processing

The spatial database was constructed using GIS techniques with the following primary data sources:

1. **Topographic Data:** Digital Elevation Model (DEM) data were used to derive terrain parameters including elevation, slope, and aspect. These data support the analysis of topographic influences on hydrological processes and ecological sensitivity.

2. **Remote Sensing Data:** MODIS NDVI products from 2016 were utilized, with a spatial resolution of 1 km and a temporal resolution of 16

days. These data provide continuous vegetation coverage information for assessing ecological conditions and land use patterns.

3. **Meteorological Data:** Daily observations from 16 weather stations covering the period 2007–2016 were collected, including precipitation (0.1 mm), temperature (0.1°C), wind speed (0.1 m · s ¹), sunshine duration, and evaporation. The de Martonne index was applied for climate classification [21].
4. **Socioeconomic Data:** Statistical yearbooks and administrative records provided information on population density, land use intensity, and economic activities.

All spatial data were projected to a unified coordinate system and resampled to consistent spatial resolution for integrated analysis. The GIS platform enabled multi-layer overlay analysis and spatial modeling of ecological parameters.

### 2.3 Evaluation Index System

An Analytic Hierarchy Process (AHP) was employed to determine the weights of assessment factors. The evaluation framework integrated three main components: ecological resilience, ecological sensitivity, and socioeconomic influence. This approach considers both natural environmental characteristics and human activity impacts, evaluating from the dual perspectives of ecological pressure and active transformation.

**TABLE:1** Weight of assessment factors for the water supply region of the Yellow River

| Assessment Factor | Weight |
|---|---|
| Water supply function | 2.62 |
| Water quality | 0.66 |
| Water quantity | 0.54 |
| Soil conservation | 0.98 |
| Ecological sensitivity | 5.65 |
| Climate index | 2.68 |
| Land use intensity | 2.13 |
| Vegetation coverage | 0.84 |
| Population pressure | 1.73 |
| Economic density | 0.49 |
| Management effectiveness | 0.90 |

The weight determination process involved expert consultation and consistency checking to ensure the reliability of the pairwise comparison matrix. Factors with higher weights, such as ecological sensitivity (5.65) and water supply function (2.62), indicate greater importance in the comprehensive assessment.

### 2.4 Spatial Analysis Methods

The spatial analysis employed a grid-based evaluation model. Each grid cell was assigned composite scores based on the weighted sum of normalized factor values. The evaluation function can be expressed as:

$$E = \sum_{i=1}^{n} w_i \cdot f_i$$

where $E$ is the comprehensive ecological index, $w_i$ represents the weight of factor $i$, and $f_i$ denotes the normalized value of factor $i$.

Ecological carrying capacity was assessed by integrating pressure indicators (population density, land use intensity) with state indicators (vegetation health, water quality). The pressure-state-response framework guided the classification of ecological zones. Spatial autocorrelation analysis identified clusters of high and low ecological values, informing the delineation of management boundaries.

## 3. Results

### 3.1 Ecological Zoning

Based on the comprehensive evaluation, the study area was classified into three management zones:

1. **Ecological Red Line Region (38.4% of total area):** This zone primarily includes the Yellow River source area in Maqu County, critical tributary headwaters, the farming-pastoral ecotone in Gannan and Linxia, and Bailongjiang riverside areas. Subcategories include water source conservation, soil and water conservation, biodiversity protection, and wetland conservation areas. The strictest control measures must be implemented, prohibiting all development activities that may compromise ecological functions.
2. **Ecological Yellow Line Region (39.1% of total area):** Distributed mainly south of Linxia and in northwestern and southern Gannan, this zone serves an important ecological strategic function. The focus should be on ecological rehabilitation and governance, with strictly prohibited activities that damage ecological functions while allowing controlled restoration projects.
3. **Ecological Green Line Region (22.5% of total area):** Located north of Linxia and central Gannan, these areas are suitable for moderate development. The strategy emphasizes promoting industrial transformation and upgrading through ecological industry development, ensuring positive interactions between environmental protection and economic activities.

## 4. Discussion and Management Implications

The delineation of ecological red lines provides a scientific basis for balancing water resource protection and sustainable development in the Yellow River basin. The integrated evaluation methodology, combining GIS spatial analysis with multi-criteria decision making, offers a replicable framework for similar regions.

Key management recommendations include:

1. **For Red Line Zones:** Implement absolute protection measures, including grazing bans, construction prohibitions, and strict water quality monitoring. Establish ecological compensation mechanisms for affected communities.
2. **For Yellow Line Zones:** Prioritize ecological restoration projects, including degraded grassland rehabilitation, soil erosion control, and wetland restoration. Limit intensive land use and promote sustainable pastoral practices.
3. **For Green Line Zones:** Encourage eco-friendly industries such as organic agriculture, eco-tourism, and clean energy. Strengthen environmental impact assessments for all development projects.

The systematic view of human-ecosystem integration reflected in this evaluation framework ensures that management strategies account for both natural processes and anthropogenic pressures. Future research should incorporate dynamic modeling to assess long-term impacts of climate change and land use policies on water supply security.

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*Note: Figure translations are in progress. See original paper for figures.*