

## Research on Patterns of Vegetation Ecological Water Requirement in Yanchi County, Central Arid Zone of Ningxia (Postprint)

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### Abstract

Taking Yanchi County in the central arid zone of Ningxia as the research object, this study first analyzed the connotation and type classification of regional vegetation ecological water requirements. The monthly potential evapotranspiration of regional forest and grass vegetation was then estimated using the Penman-Monteith model, and the soil moisture correction coefficient was determined using the Jensen formula combined with measured regional soil characteristic curves, thereby establishing a foundation for quantifying vegetation ecological water requirements. Analysis of the proportional distribution of ecological water requirements among different forest and grass vegetation types reveals that the ecological water requirement of grassland in Yanchi County substantially exceeds that of forestland, representing the principal component of the county's ecological water demand. Further analysis of the temporal variation in the balance between vegetation ecological water requirements and precipitation indicates that, with the exception of July, August, and September, all categories of forest and grass vegetation in Yanchi County experience severe water deficit, with April exhibiting the most acute shortage. From the perspective of vegetation types, both ecological water deficit and surplus are most pronounced in shrub forestland among forest categories, and in natural grassland among grassland categories. Additional analysis of water demand characteristics across various ecological zones in Yanchi County demonstrates that, at the primary ecological zone level, the proportion of ecological water requirement in aeolian sand areas far surpasses that in loess hilly regions; at the secondary ecological zone level, the proportions of ecological water requirement in descending order are Huamachi Town, Wanglejing Township, Dashuikeng Town, Gaoshawo Town, Hui'anbao Town, Fengjigou Township, Qingshan Township, and Mahuangshan Township. At the primary ecological zone level, both the ecological water requirement coefficient and modulus in aeolian sand areas exceed those in loess

hilly areas; at the secondary ecological zone level, the ecological water requirement coefficients and moduli in descending order are Huamachi Town, Wanglejing Township, Dashuikeng Town, Hui'anbao Town, Gaoshawo Town, Qingshan Township, and Fengjigou Township, with Mahuangshan Township being the lowest. The minimum value of rainfall-consumed ecological water requirement in Yanchi County accounts for 30.51% of total evaporation, while the suitable value accounts for 72.91% of total evaporation, both representing relatively high proportions. The remaining evaporation constitutes ineffective evaporation, which still occupies a certain proportion, thereby leaving some scope for regional vegetation construction, though this must be realized through rational water resource regulation measures.

## Full Text

### Study Area and Data Sources

This study focuses on Yanchi County, located in the arid region of central Ningxia, China, with geographical coordinates of 106°30' -107°41' E and 37°04' -38°10' N, covering a total area of 6,620 km<sup>2</sup>.

The primary data sources include: (1) meteorological data from 2010-2020 obtained from the China Meteorological Data Sharing Service System; (2) vegetation data derived from remote sensing interpretation and field surveys; and (3) soil data from the Soil Survey Database of Ningxia. The data processing and analysis methods follow established protocols for ecological water requirement assessment in arid regions [?].

## Methods

### 2.1 Calculation of Potential Evapotranspiration

The Penman-Monteith model was employed to calculate reference crop evapotranspiration ( $ET_0$ ). The formula is expressed as:

$$ET_0 = \frac{0.408 \times \Delta \times (R_n - G) + \gamma \times \frac{900}{T+273} \times u_2 \times VPD}{\Delta + \gamma \times (1 + 0.34 \times u_2)}$$

where  $ET_0$  represents reference evapotranspiration ( $\text{mm} \cdot \text{d}^{-1}$ );  $\Delta$  is the slope of the saturation vapor pressure curve ( $\text{kPa} \cdot ^\circ\text{C}^{-1}$ );  $R_n$  denotes net radiation ( $\text{MJ} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ );  $G$  is soil heat flux density ( $\text{MJ} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ );  $\gamma$  is the psychrometric constant ( $\text{kPa} \cdot ^\circ\text{C}^{-1}$ );  $T$  is mean air temperature ( $^\circ\text{C}$ );  $u_2$  is wind speed at 2 m height ( $\text{m} \cdot \text{s}^{-1}$ ); and  $VPD$  is vapor pressure deficit ( $\text{kPa}$ ), calculated as  $VPD = e_a - e_d$ , where  $e_a$  and  $e_d$  are saturation and actual vapor pressure, respectively.

The ecological water requirement for vegetation was calculated using:

$$ET_{C_i} = ET_{0_i} \times K_c \times K_s$$

where  $ET_{C_i}$  is the ecological water requirement for vegetation type  $i$  (mm);  $ET_{0_i}$  is the reference evapotranspiration for vegetation type  $i$  (mm);  $K_c$  is the crop coefficient; and  $K_s$  is the soil moisture correction coefficient.

## 2.2 Determination of Soil Moisture Correction Coefficient

The Jensen formula was combined with measured regional soil characteristic curves to determine the soil moisture correction coefficient. The calculation considered six key parameters: field capacity, wilting coefficient, bulk density, saturated hydraulic conductivity, soil layer thickness, and 2 m wind speed. Meteorological data from 2014 were used as baseline inputs [?].

The soil moisture correction coefficient was determined for five vegetation types: forest land, sparse forest land, shrub land, natural grassland, and artificial grassland. The coefficient values were 0.76 for forest land, 0.61 for sparse forest land, 0.48 for shrub land, and 0.70 for natural grassland, with corresponding adjustments for artificial grasslands.

## Results and Analysis

### 3.1 Vegetation Coverage Statistics

presents the existing forest land and grassland coverage in Yanchi County. The total area of forest land is 4774.72 km<sup>2</sup>, comprising 144.44 km<sup>2</sup> of dense forest, 288.89 km<sup>2</sup> of medium-density forest, and 317.19 km<sup>2</sup> of sparse forest. Grassland covers 1021.09 km<sup>2</sup>, including 67.56 km<sup>2</sup> of high-coverage grassland, 11.15 km<sup>2</sup> of medium-coverage grassland, and 1.22 km<sup>2</sup> of low-coverage grassland.

### 3.2 Monthly Potential Evapotranspiration

shows the monthly vegetation potential evaporation calculated using the Penman-Monteith model. Annual total potential evaporation reaches 1116.38 mm, with peak values occurring in June (161.75 mm) and May (150.91 mm). The lowest values occur in January (21.82 mm) and December (34.24 mm).

### 3.3 Soil Moisture Characteristics

The soil moisture characteristic curve for the loess hilly region was established based on field measurements [Figure 1: see original paper]. presents soil moisture parameters under different matrix potentials, showing that soil water content decreases nonlinearly with decreasing matrix potential. At  $-15 \times 10^5$  Pa, water content is 18.16%, while at  $-0.3 \times 10^5$  Pa, it increases significantly.

### 3.4 Ecological Water Requirement by Vegetation Type

Comparative analysis reveals that the ecological water requirement for existing grassland substantially exceeds that of forest land [Figure 2: see original paper]. Among forest land types, shrub land exhibits the largest water requirement, followed by sparse forest land and dense forest land. For grassland, the descending order is: natural grassland > perennial artificial grassland > annual artificial grassland [Figure 3: see original paper].

### 3.5 Temporal Variation of Water Balance

Monthly rainfall and ecological water requirement analysis indicates serious water deficits for all vegetation types throughout most of the year, except during July, August, and September. April demonstrates the most severe deficit conditions. The balance analysis shows that shrub land from forest vegetation and natural grassland from grassland vegetation are particularly prominent in terms of water demand .

### 3.6 Ecological Zoning Analysis

Primary ecological division reveals that the windy and sandy area has a significantly greater ecological water requirement proportion than the loess hilly region. For secondary ecological division, the descending order based on ecological water requirement proportion is: Huamachi Town > Wanglejing Town > Dashuikeng Town > Gaoshawo Town > Hui' anpu Town > Fengjigou Town > Qingshan Town.

The minimum value of existing rainfall consumptive ecological water requirement accounts for 30.51% of total evaporation, while the suitable value accounts for 72.91% of total evaporation . These proportions are notably high, indicating that the remaining evaporation component may be consumed through non-forest land soil evaporation, which constitutes ineffective water consumption yet occupies a substantial proportion.

## Discussion

The results demonstrate that vegetation ecological water requirements in Yanchi County vary significantly across vegetation types and spatial zones. The soil moisture correction coefficient plays a crucial role in adjusting theoretical calculations to reflect actual field conditions. The serious water deficits during spring months (particularly April) highlight the critical period for vegetation survival and growth in this arid region.

The finding that grassland requires more water than forest land has important implications for ecological restoration and water resource management. The high proportion of ecological water requirement relative to total evaporation suggests that current vegetation patterns may be unsustainable under existing water availability conditions.

## Conclusion

This study quantified the ecological water requirements for different vegetation types in Yanchi County using the Penman-Monteith model combined with soil moisture correction. Key findings include: (1) grassland ecological water requirement exceeds that of forest land; (2) shrub land dominates forest water demand, while natural grassland dominates grassland water demand; (3) severe water deficits occur from April to June; and (4) spatial variation is significant between windy sandy areas and loess hilly regions. These results provide a scientific basis for sustainable vegetation management and water resource allocation in arid regions.

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

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