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## Review of Cryosphere Water Resources Services Functional Zoning: Postprint

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### Abstract

As one of the five major spheres of the climate system, the cryosphere constitutes a crucial water source and solid-state reservoir in China's arid and cold regions, exerting significant impacts on ecology, water resources, environment, and climate. Research on cryosphere products and their socio-economic service functions has long been inadequate, not to mention the zoning of cryosphere water resources service functions from the perspective of territorial principal functions. Water resources service, as a vital function of cryosphere resources, represents a critical breakthrough point for investigating cryosphere service functions and their zoning. This paper, grounded in interdisciplinary theories and methodologies from cryospheric science, human geography, ecology, and related fields, systematically reviews research in three key areas: cryosphere water resources distribution and monitoring, territorial functional zoning, and classification and evaluation of water resources service functions. Furthermore, it proposes a classification system for cryosphere water resources service functions that integrates ecosystem service functions with "production-living-ecological" space research, and an evaluation index system for cryosphere water resources service functions based on the characteristics of cryosphere water resources, supply capacity, water demand for socio-economic development, and utilization efficiency. Finally, drawing upon the research review and the established classification and evaluation systems for cryosphere water resources service functions, and synthesizing existing zoning practices such as comprehensive physical geographical zoning and territorial functional zoning, this paper discusses a prospective research framework for future cryosphere water resources service function studies, thereby providing a theoretical and practical foundation for conducting cryosphere water resources service function zoning at national and global scales.

## Full Text

### Preamble

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### Abstract

As one of the five most important spheres of the global climate system, the cryosphere serves as a crucial water source and solid water reservoir in China's cold and arid regions, exerting significant impacts on ecology, water resources, environment, and climate. For a long time, research on the product and service functions of the cryosphere has been inadequate, particularly regarding the targeted regionalization of cryosphere water resource functions in arid regions from the perspective of major function-oriented zoning. Water resource represents one of the most direct service functions of the cryosphere and can serve as an important breakthrough for cryosphere service function research.

Based on interdisciplinary theories and methods from cryosphere science, human geography, ecology, and other related subjects, this paper reviews existing scientific research across three main aspects: (1) the distribution and monitoring of water resources, (2) function-oriented regionalization, and (3) the classification and evaluation of water resource services. Additionally, this paper proposes a cryosphere water resource service function classification system built upon ecosystem service function evaluation and the division of ecological-production-living spaces. Furthermore, by considering the characteristics of cryosphere water resources, supply capacity, socio-economic development water demand, and water resource utilization efficiency, this paper constructs an evaluation index system for cryosphere water resource service functions. Finally, integrating practices from comprehensive physiographic regionalization, comprehensive human geography regionalization, ecological function regionalization, major function-oriented zoning, and other related research, this paper puts forward a feasible plan for cryosphere water resource service function regionalization, providing theoretical and practical foundations for future research on cryosphere service function regionalization in China and worldwide.

**Keywords:** cryosphere; water resource service function; function-oriented regionalization; literature review

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## 1. Introduction

The cryosphere constitutes approximately 75% of freshwater resources on Earth. For a long time, research has focused on cryosphere water resources from perspectives such as glacier water resources, snow water resources, frozen soil water resources, and river runoff. The distribution and monitoring of cryosphere water resources represent fundamental research areas, while function-oriented regionalization serves as a critical application direction. Previous studies have established monitoring networks and evaluation systems for cryosphere water resources, though systematic regionalization research remains limited.

Cryosphere water resource service functions encompass multiple dimensions including supply, regulation, and ecological maintenance. The evaluation of these functions requires comprehensive consideration of natural attributes, socio-economic demands, and ecological constraints. Current research gaps include the lack of unified classification standards, insufficient integration of multi-source data, and inadequate attention to regional differentiation characteristics.

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## 2. Distribution and Monitoring of Water Resources

Cryosphere water resource monitoring relies on ground-based observation networks, remote sensing technologies, and model simulations. Ground observations provide accurate point-scale data, while remote sensing enables large-scale spatial monitoring. The integration of these approaches facilitates the construction of spatiotemporal databases for cryosphere water resources.

The distribution patterns of cryosphere water resources in China show significant spatial heterogeneity, with concentrated distribution in the Tibetan Plateau, Tianshan Mountains, and Altai Mountains. Climate change has substantially altered the distribution and supply capacity of these resources, necessitating dynamic monitoring and evaluation systems.

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## 3. Function-Oriented Regionalization

### 3.1 Regionalization Principles

Function-oriented regionalization of cryosphere water resources should follow principles of spatial heterogeneity, functional integrity, and management feasibility. The regionalization framework needs to incorporate both natural charac-

teristics and socio-economic demands, emphasizing the matching of water supply capacity with utilization requirements.

The classification system comprises primary, secondary, and tertiary functions. Primary functions include water supply, ecological regulation, and disaster prevention. Secondary functions further differentiate specific service types, while tertiary functions address detailed local characteristics.

### 3.2 Evaluation Index System

The evaluation index system for cryosphere water resource service functions includes four components: resource endowment, supply capacity, demand intensity, and utilization efficiency. Resource endowment indicators encompass glacier area, snow cover duration, and frozen soil thickness. Supply capacity indicators include meltwater runoff, seasonal regulation capacity, and sustainable yield.

Demand intensity indicators cover agricultural, industrial, and domestic water consumption patterns, while utilization efficiency indicators address water use efficiency, recycling rates, and economic output per unit of water. The integrated evaluation model can be expressed as:

$$V_{ij} = F(S_{ij}, D_{ij})$$

where  $V_{ij}$  represents the service function value of region  $i$  and function type  $j$ ,  $S_{ij}$  denotes the supply capacity, and  $D_{ij}$  indicates the demand intensity.

### 3.3 Regionalization Methods

Regionalization methods combine qualitative analysis with quantitative modeling. Qualitative analysis identifies functional boundaries based on expert knowledge and physical geography characteristics. Quantitative methods employ cluster analysis, principal component analysis, and spatial overlay techniques to delineate functional zones.

The System of Integrated Environmental and Economic Accounting (SEEA) provides a framework for valuing cryosphere water resource services. The SEEA-2003 framework has been applied to evaluate cryosphere water resources, integrating environmental and economic accounts.

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## 4. Classification and Evaluation of Water Resource Services

The classification system distinguishes between supply services, regulation services, and cultural services. Supply services include direct water provision for consumption and irrigation. Regulation services encompass runoff regulation,

climate modulation, and soil conservation. Cultural services involve aesthetic, recreational, and scientific values.

Evaluation methods include physical quantity assessment, value assessment, and comprehensive index methods. Physical assessment measures water volume and quality, while value assessment employs contingent valuation and replacement cost methods. The comprehensive index method integrates multiple indicators through weighted summation.

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## 5. Research Prospects

Future research should strengthen interdisciplinary collaboration, improve monitoring networks, and develop high-resolution regionalization schemes. The integration of big data, artificial intelligence, and cloud computing platforms will enhance regionalization precision. Additionally, establishing dynamic updating mechanisms for regionalization results will better support water resource management and climate change adaptation strategies.

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