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An Adaptive One Map Framework for Developing the Sanjiangyuan Natural Resource Monitoring Network in High Altitude Cold Regions

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Abstract-Natural resource monitoring in the Sanjiangyuan region faces systemic constraints-scattered stations, incomplete parameters, inconsistent standards, and weak data-sharing-that limit refined management in a globally significant alpine environment. The "One Map" concept, widely applied in territorial spatial planning, offers a framework for spatial unification, data integration, and application synergy. However, its conventional practice rests on three implicit premises-routine data acquisition, infrastructure accessibility, and routine inter-agency coordination-none of which hold in the high-altitude uninhabited areas of Sanjiangyuan. This paper develops an adaptive One Map framework for natural resource monitoring networks in high-altitude cold regions. Drawing on the logical framework approach, it constructs a five-tier analytical system of "objectives–missions–tasks–outputs–inputs," introducing an explicit mission layer covering data assurance, decision support, and scientific understanding. Three adaptive adjustments to the conventional One Map paradigm are proposed: a dual-precision station network responding to seasonal constraints on ground data acquisition; a "data bank plus decision theater" dual-platform architecture responding to communication and computing constraints; and an explicit mission layer anchoring multi-agency

coordination. The resulting pathway-"dual-precision station network + dual platform + multiple applications"-links observational data from collection and quality control through to decision support. The framework offers a transferable reference for natural resource governance in ecologically sensitive high-altitude regions where conventional monitoring paradigms are not directly applicable.

Keywords: Sanjiangyuan; one map; natural resource monitoring; logical framework; adaptive governance

Highlights

1. Introduces "One Map" to alpine monitoring networks under conditions of limited accessibility.

2.Adds a "mission layer" to the logical framework for macro–micro alignment.

3.Proposes a "dual-precision + dual-platform + multi-application" pathway.

Introduction

Sanjiangyuan region, located in the heart of the Qinghai-Tibet Plateau, is the primary source of the Yangtze, Yellow, and Lancang Rivers. It is hailed as the “Water Tower of China” and holds an irreplaceable strategic position in safeguarding national ecological security, water security, and regional sustainable development(Feng 2025; Ma 2025; Zhou 2025;Zhang et al. 2026).The region features diverse ecosystem types, encompassing typical ecological units such as alpine grasslands, wetlands, rivers and lakes, and glacial permafrost. However, its ecological environment is inherently fragile and highly sensitive to climate change, human activities, and land-use changes, making it a critical area for global change research, alpine ecosystem conservation, and integrated natural resource management(Li & Zhao 2025;Yang et al. 2026). In recent years, with the continuous advancement of ecological civilization and the

development of the national park system, the Sanjiangyuan region has achieved positive results in ecological conservation and restoration, natural resource surveys and monitoring, land-use regulation, and comprehensive ecosystem management. However, the existing natural resource observation system still suffers from shortcomings such as a scattered network of observation stations, incomplete observation parameters, inconsistent data standards, and inadequate data-sharing mechanisms, which hinder the improvement of the region's capabilities in refined natural resource management, dynamic supervision, and scientific decision-making.

Against this backdrop, establishing a comprehensive natural resource monitoring and management system centered on the "One Map" initiative has become a key pathway to modernizing resource and environmental governance in the Sanjiangyuan region. The "One Map" concept originates from the informatization practices of territorial spatial planning and natural resource management (Yi 2023; Chen & Zhong 2026;Zhang 2026). It emphasizes the use of unified spatial reference frames, data standards, and technical platforms to facilitate the integrated management, dynamic updating, and collaborative application of multi-source, multi-scale, and multi-type natural resource data, thereby supporting comprehensive analysis and decision-making services across departments, regions, and scales (Sajjad 2021;Li & Zhang 2026). "One Map" is not merely a method for integrating spatial data; it is a technical framework and management paradigm oriented toward systemic governance. Its core lies in integrating the entire process of "survey-observation-assessment-early warning-decision-making" , driving the transformation of natural resource management from the static grasp of baseline data to the dynamic understanding of processes, trend analysis, and risk early warning (Chen et al. 2024; Ren et al. 2025;Zhang & Wei 2026). At the same time, the rapid development of new-generation information technologies-including remote sensing Earth observation, Internet of Things (IoT) sensing, low-altitude UAV monitoring, big data analysis, and artificial intelligence provides crucial support for building

an integrated air-space-ground natural resource observation system (Deng & Ji 2024;Lin 2025). Therefore, combining the “One Map” concept with the ecological observation needs of the Sanjiangyuan region to explore pathways for constructing a natural resource observation network adapted to the characteristics of cold-highland ecosystems holds significant theoretical and practical value.

Building on a review of research progress in the development of natural resource observation networks and spatial information integration both domestically and internationally, this paper focuses on the current status, shortcomings, and governance needs of the natural resource observation system In the Sanjiangyuan region. From the perspectives of system integration and spatial governance, it introduces the “One Map” concept into the development of natural resource observation networks, exploring the construction of an integrated “data-platform-application”technical framework. By incorporating the characteristics of Sanjiangyuan’s alpine ecosystem, the paper proposes a multi-scale, multi-factor, and multi-process collaborative observation approach to enhance the regional adaptability and precision of the observation network. Concurrently, addressing the needs of ecological assessment, risk early warning, and management decision-making, this study explores pathways for transforming observational data from supporting resource surveys to serving comprehensive governance. The aim is to provide a reference model for natural resource governance in ecologically sensitive alpine regions, while also offering scientific support for ecological conservation In the Sanjiangyuan region, refined management of natural resources, and the construction of the national ecological security barrier.

It should be emphasized, however, that the constraints facing the integration of monitoring networks in the Sanjiangyuan region differ fundamentally from those in conventional regions where the "One Map" paradigm has been

primarily developed and applied. Three region-specific constraints deserve particular attention. First, the window for ground-based data acquisition is severely restricted by the alpine seasonal cycle, which invalidates the assumption of "routine, continuous updating" that underpins most existing One Map practices. Second, large portions of the region remain inaccessible in terms of communication and transportation infrastructure, which limits the applicability of IoT-based real-time transmission solutions that are widely adopted in lowland and urban monitoring systems. Third, the management of natural resources in Sanjiangyuan involves multiple administrative actors-including natural resources, forestry and grassland, ecological environment, and national park authorities-operating across provincial, prefectural, and watershed levels, and the coordination mechanisms among them are not yet fully established. Consequently, the three implicit premises of the conventional "One Map" paradigm-routine data acquisition, infrastructure accessibility, and routine inter-agency coordination-do not hold in this high-altitude, ecologically sensitive context. The framework proposed in this paper is therefore not a direct application of the "One Map" concept, but an adaptive adjustment of that paradigm to the specific biophysical and institutional conditions of the Sanjiangyuan region.

This paper does not conduct remote sensing-based index analysis; rather, it examines the institutional and technical integration pathways through which existing multi-source observation data can be systematically linked for regional governance purposes.

Current Status of Research on the Development of Natural Resource Monitoring Networks at Home and Abroad

Current Status of Natural Resource Monitoring and Research Abroad

Overseas countries began developing natural resource observation and integrated monitoring networks at an early stage and have established relatively mature and systematic theoretical frameworks and technical systems. Overall, these networks are shifting from single-factor observation to multi-factor integrated observation, and from data acquisition to intelligent analysis. They exhibit the following four characteristics.

First, regarding observation network systems, as exemplified by the U.S. National Ecological Observation Network (NEON), the use of standardized sensor systems and observation protocols enables long-term, continuous observations across regions and ecological types, thereby establishing an ecological data system with high comparability(Deng et al. 2019;Xue 2020). The Long-Term Ecological Research Network in Europe (LTER-Europe), on the other hand, emphasizes the accumulation of long-term time-series data and interdisciplinary integration, highlighting the collaborative observation of ecosystem structure and functional processes (Zhao 2026). Such observation networks generally share characteristics such as standardized protocols, long-term operation, and open data sharing.

Second, regarding spatial information integration, the concept of Spatial Data Infrastructure (SDI) was proposed early on in other countries. Through unified data standards, metadata specifications, and service interfaces, it enables the efficient integration and shared application of multi-source spatial data. The National Map, promoted by the U.S. Geological Survey, integrates multi-source data-including topography, hydrology, and land use-to form a unified representation framework, effectively embodying the core concept of “observing a single map”.The EU’s INSPIRE initiative further advances the harmonization of transnational spatial data standards, enhancing data interoperability and sharing capabilities(Eltaş et al. 2019;Gu et al. 2020).

Third, regarding technical systems, integrated air-space-ground observation has become the mainstream development direction. Represented by NASA's Earth Observing System (EOS), this approach achieves global environmental monitoring at multiple scales and frequencies through the synergy of satellite remote sensing, aerial observation, and ground station networks (Ogden 2025;Subbulakshmi & Nanda 2026). Meanwhile, the application of the IoT and smart sensing technologies has endowed ground-based observation with automation and real-time capabilities, significantly enhancing data acquisition efficiency.

Fourth, regarding ecosystem process observation, global flux observation networks such as FLUXNET have deepened our understanding of ecosystem functional processes through the monitoring of carbon, water, and energy fluxes , while providing critical data support for climate change research(Trofimchuk et al. 2025).

Currently, international research is gradually evolving toward an integrated "observation–simulation–prediction" approach, emphasizing big data analysis and model coupling applications to drive the transformation of natural resource observation from data support to decision-making services.

Current Status of Research on the Development and Monitoring System for the "Single Map" of Domestic Natural Resources

Although the development of China's "One Map" for natural resources and its observation system began relatively late, it has progressed rapidly under the impetus of national strategy and has already established a relatively comprehensive policy framework and technical foundation.

In terms of top-level design, the Ministry of Natural Resources has proposed the construction of a "Basic Information Platform for Territorial Space" and a "Single Map of Natural Resources" , clearly defining a unified spatial reference

frame and standard system as the core to achieve the integration and collaborative application of multi-source data (Yi 2023; Chen & Zhong 2026;Zhang 2026). From a theoretical perspective, the “Single Map” is not only a data integration platform but also a foundational framework supporting the entire process of natural resources management (Chaabani et al. 2024;Xu et al. 2024).

In terms of observation system development, China has established a nationwide natural resources survey and monitoring system, including national land surveys, annual change surveys, and title registration, which provides foundational data support for the observation system. Concurrently, ecological and environmental monitoring networks and natural resources monitoring networks are gradually developing in tandem, forming a collaborative observation and research framework involving multiple departments.

Regarding technological advancements, domestic research has focused on multi-source data fusion, the organization of spatiotemporal data, and dynamic update mechanisms. By integrating remote sensing imagery, ground surveys, statistical data, and model simulation results, a multidimensional data system is gradually taking shape. To meet operational application needs, data-driven dynamic monitoring and analysis models are being constructed, driving the transformation of natural resource management from static management to dynamic sensing. Meanwhile, integrated air-space-ground observation has become a key direction. High-resolution Earth observation systems have significantly enhanced remote sensing monitoring capabilities, while Beidou navigation and IoT technologies provide support for real-time monitoring. Territorial spatial information platforms at all levels have been progressively established, enabling multi-tiered data sharing and operational coordination.

However, issues such as inconsistent data standards, imperfect sharing mechanisms, uneven distribution of observation networks, and insufficient dynamic monitoring capabilities still persist . Overall, China is currently in a transitional phase from “data integration” to “system integration and intelligent applications,” and there is an urgent need for further breakthroughs in establishing a unified standard system and optimizing observation networks (″National Technical Committee on Geographic Information Standardization″, 2020;Lu 2026).

While the international networks reviewed above provide important reference models, a critical question must be asked: to what extent can their experiences be transferred to the Sanjiangyuan context? A systematic comparison reveals three structural differences that limit direct transplantation.

Station density and accessibility. NEON is designed around a continent-scale, statistically representative network of standardized sites, with routine field access for maintenance, calibration, and biological sampling (Deng et al. 2019; Xue 2020). This model assumes that sites can be visited regularly and that equipment can be serviced within predictable timeframes. In Sanjiangyuan, however, a substantial proportion of the region consists of uninhabited areas with no road access for much of the year. The cost of maintaining even a modest number of ground stations is disproportionately high, and the logistical burden of routine calibration and sampling is far greater than in temperate or lowland regions. The NEON model of high-density, routinely accessible sites is therefore not replicable at the same scale; what is required instead is a station design that can tolerate intermittent access and extended periods of autonomous operation.

Long-term data accumulation mechanisms. LTER Europe has developed stable, multi-decade institutional arrangements that ensure continuity of observations across political and funding cycles (Zhao 2026). This continuity is not merely a matter of scientific commitment; it is embedded in institutional structures that provide dedicated long-

term funding and dedicated personnel. In Sanjiangyuan, by contrast, existing monitoring efforts are largely project-driven: stations are established and operated under time-bound research programs, and data continuity beyond individual project cycles is not systematically guaranteed (Li & Zhao 2025; Yang et al. 2026). This fragmentation means that the "long-term, continuous, comparable, and traceable" data ideal-which is widely endorsed in principle-cannot be achieved simply by adding more stations. It requires institutional mechanisms that decouple data continuity from project funding cycles, such as dedicated operational budgets, stable technical teams, and standardized data management protocols that persist across projects.

Cross-scale integration and institutional coherence. TERN has developed approaches for linking plot-level observations, transect data, and continental-scale syntheses within a relatively unified national framework (Trofimchuk et al. 2025). This model assumes a degree of institutional coherence: there is a recognized national coordination body, agreed data standards, and a shared understanding of how different scales of observation relate to one another. In Sanjiangyuan, the management landscape is more complex. Responsibilities are distributed across national park authorities, provincial and prefectural governments, and watershed-level agencies, and there is no single entity with clear authority over network-wide integration (Wang et al. 2023; Wang & Pei 2025). The TERN model of cross-scale integration therefore cannot be applied without first addressing the question of who is responsible for integration, under what mandate, and with what resources.

These three differences suggest that the challenge in Sanjiangyuan is not simply one of technological upgrading or network densification. It is a challenge of designing institutional and technical arrangements that can function under conditions of limited accessibility, project-based funding, and multi-actor governance. The "One Map" framework

proposed in this paper is intended to address precisely this gap: it does not assume that the conditions prevailing in NEON, LTER Europe, or TERN can be replicated, but instead asks what forms of integration are feasible given the specific constraints of the Sanjiangyuan region.

Current Status of the Natural Resources Monitoring System In the Sanjiangyuan region

As a critical ecological security barrier for China and a key representative of global alpine ecosystems, the Sanjiangyuan region presents significant regional distinctiveness and systemic complexity in the development of its natural resource monitoring system. In recent years, against the backdrop of the ongoing pilot program for the national park system and the continuous advancement of the ecological civilization strategy, phased progress has been made in establishing the regional natural resource monitoring system.

At the top-level design level, a series of policy documents, including the “Master Plan for Sanjiangyuan National Park,” have been successively issued. These documents explicitly prioritize ecological conservation, emphasize the strengthening of multi-factor ecological monitoring and the construction of comprehensive observation networks, and have preliminarily established a framework for an observation system tailored to the needs of ecological conservation and resource management. This provides the institutional foundation and directional guidance for the systematic development of the regional observation network.

Regarding the construction of the observation network, the Sanjiangyuan region has nowestablished a multi-type observation network comprising ecological observation stations, meteorological stations, hydrological stations, and scientific research observation platforms. Among these, research institutions, led by the Chinese Academy of Sciences,

have deployed multiple fixed ecological observation stations within the region, focusing on long-term continuous observations of alpine grassland ecosystems, water cycle processes, and climate change response mechanisms, thereby providing critical data support for elucidating the patterns of regional ecosystem evolution (Li & Zhao 2025;Yang et al. 2026). At the same time, the meteorological and hydrological observation networks are relatively well-developed in terms of spatial distribution and the accumulation of time series data, laying an important foundation for research on regional climate change and hydrological processes. Overall, the existing observation network has achieved a certain level of multi-parameter observation capability, but there are still shortcomings in terms of system coordination and spatially balanced layout.

At the technological application level, remote sensing has become the core method for monitoring natural resources in the Sanjiangyuan region. Leveraging multi-source remote sensing data from MODIS, Landsat, and China's domestic high-resolution Earth observation systems, it is possible to conduct long-term monitoring of changes in vegetation cover, the dynamic evolution of water bodies, and glacial retreat processes, effectively supporting analyses of ecological and environmental changes at the regional scale (Chaabani et al. 2024;Xu et al. 2024).. In addition, UAV remote sensing and ground-based sensor technologies are gradually being applied to localized, high-resolution observation scenarios, significantly enhancing the spatial resolution and acquisition flexibility of observational data, and forming the technical prototype of a multi-scale collaborative observation system integrating "air, space, and ground" perspectives.

Regarding data integration and application, the region has initiated foundational explorations of a "single map" approach. By integrating data on land use, ecological protection red lines, and water resource distribution, an ecological

spatial information database has been preliminarily established to provide data support for management decisions. However, at the current stage, the application of the “single map” remains primarily at the data integration level, and dynamic updates and in-depth integration of multi-source observational data have not yet been achieved.

Overall, the Sanjiangyuan natural resource observation system still faces several key bottlenecks. First, the spatial coverage of the observation network is insufficient, with significant observation blind spots remaining in high-altitude areas and regions with complex topography , which limits the overall accuracy and continuity of regional observations (Li & Zhang 2026). Second, the capacity for multi-source data integration is weak; inconsistent data standards and inadequate sharing mechanisms among different departments make it difficult to establish a coordinated and efficient comprehensive observation system(Sajjad 2021;Zhang & Wei 2026). Furthermore, the system of observed variables remains incomplete; current monitoring efforts focus primarily on meteorological, hydrological, and vegetation variables, with insufficient attention paid to key elements such as groundwater processes, biodiversity, and ecosystem functional processes. Additionally, the level of intelligence within the monitoring system needs to be improved; data processing and analysis still rely mainly on traditional methods, and the application of big data and artificial intelligence technologies in the in-depth analysis of observational data remains inadequate (Chen et al. 2024; Ren et al. 2025;Lin 2025).

The Significance of Building the SANJIANGYUAN Natural Resources Monitoring Networks from a“One Map” Perspective

Providing Chinese Data and Solutions to Support Global Sustainable Development

Sustainable development is the central approach to addressing complex challenges such as global climate change,

247 tightening resource constraints, and ecosystem degradation; it is integral to economic resilience, social stability,
248 ecological security, and human well-being. Developed nations such as the United States, the United Kingdom, and
249 Germany are advancing the construction of integrated observation networks spanning space, air, land, and the internet
250 to promote the sustainable use of natural resources. By securing a leading position in natural resource governance and
251 Earth system science research, these nations provide data support and strategic guidance for global sustainable
252 development. The European Network for Ecosystem Observation and Research (TERN) integrates high-precision,
253 multi-scale data to assess greenhouse gas exchange processes ranging from the ecosystem to the continental scale. The
254 U.S. National Ecosystem Observation Network (NEON) has established a highly digitized and automated, integrated
255 terrestrial-aerial-space ecosystem observation platform at the continental scale, quantitatively revealing the impacts of
256 climate change, land-use change, and invasive species, and supporting predictions of ecological and environmental
257 changes at the continental scale(Deng et al. 2019;Xue 2020;Zhao 2026).The Australian Trans-ecological Research
258 Network (TERN) integrates micro-processes within ecosystems, transect observations, and continental-scale
259 comprehensive data, providing support for identifying complex environmental changes and sustainable ecosystem
260 management at the national level (Trofimchuk et al. 2025).

261 The development of China's natural resource observation networks began relatively late and primarily comprises two
262 categories: first, long-term observation networks oriented toward scientific research, such as the Chinese Academy of
263 Sciences Ecosystem Research Network (CERN) and the China Terrestrial Ecosystem Flux Observation Network
264 (China FLUX); second, field observation stations established by relevant national ministries, universities, and research
265 institutes. Due to inconsistencies in construction objectives, observation indicators, technical standards, and data
266 management approaches, existing data suffer from fragmentation, heterogeneity, and insufficient sharing (Chaabani et

al. 2024;Xu et al. 2024).. It is difficult to achieve unified standards, deep integration, and collaborative application through simple aggregation alone, nor can such data effectively support macro-level analysis and comprehensive decision-making at the national level. Therefore, it is necessary to promote three-dimensional observation and collaborative networking under the “One Map” concept to form a comprehensive system that reflects the status of national natural resources and serves major strategic decision-making (Yi 2023; Chen & Zhong 2026;Zhang 2026).

The Service Supports the Two Key Objectives of “Ensuring Resource Security and Maintaining Natural Stability and Harmony”

The advancement of ecological civilization must begin at the source-specifically, in the utilization of natural resources and the governance of territorial space. Currently, China’s resource and environmental carrying capacity continues to approach its limits. Intensive development and extensive utilization not only deplete resources but also exacerbate pressure on the ecological environment, threatening the structural stability and functional integrity of ecosystems. The primary task in managing natural resources is to enhance the level of resource conservation and intensive utilization, thereby curbing the disruption caused by irrational development and exploitation to natural ecosystems. At the same time, we must adhere to the principles of integrated protection and systematic management of mountains, waters, forests, farmlands, lakes, grasslands, and deserts, implement refined governance of territorial space, and restore critical ecological security barriers and ecological functional zones. In the Sanjiangyuan region, processes such as glacier and permafrost degradation, changes in the hydrological cycle, and grassland ecological degradation are mutually coupled, making it imperative to conduct long-term, continuous, and comprehensive multi-factor observations against the backdrop of global climate change. Therefore, establishing a natural resource observation network based on a “single

map” will help enhance our understanding of baseline conditions, process identification, and trend forecasting capabilities. It will provide a scientific basis for ensuring resource security, maintaining natural stability and harmony, and supporting major management decisions, and serve as a crucial pillar for the Ministry of Natural Resources in fulfilling its “dual unification” responsibilities (Lu 2026).

Overcoming Key Technical Challenges by Focusing on the Three Core Missions of “Data Assurance, Decision Support, and Scientific Understanding”

The key shortcoming in the smart governance of natural resources lies in a weak data foundation, which manifests primarily in insufficient observational data, imprecise resource intelligence, and untimely operational services. As natural resource management in the new era shifts from an extensive to a refined and intelligent approach, it is essential to base this transformation on a holistic and systematic understanding of ecosystems, thereby grasping the evolutionary patterns of natural resource elements and their interactions; The key lies in continuously, systematically, and standardly providing high-quality data support to meet national strategic needs, thereby addressing the shortage of foundational data in understanding the mechanisms of ecological change, forecasting trends, and identifying risks (Lu 2026).

To address the critical needs of natural resource management In the Sanjiangyuan region, the observation system should undertake three core missions: first, to acquire long-term, continuous, comparable, and traceable observational data on natural resource elements; second, to support major scientific research on natural resources, as well as spatial governance and management decision-making; third, to deepen scientific understanding of the structure, functions, and process patterns of natural resource ecosystems. Currently, there is a lack of systematic deployment for long-term, multidimensional, and comprehensive observation of natural resource elements In the Sanjiangyuan region. Issues

such as “data being available but difficult to use” and “data being available but underutilized” remain prominent in management practices, hindering a systematic understanding of ecological change patterns and scientific forecasting of future trends. Therefore, there is an urgent need to build a multi-element, multidimensional, and standardized observation indicator system based on existing surveys and monitoring efforts, continuously acquire data on surface and near-surface processes, and develop capabilities for trend analysis, risk early warning, and resource intelligence provision. A comprehensive observation network serving natural resource control and management will become a crucial basis for research on major issues, policy formulation, and decision-making optimization under the new natural resource management system.

Theoretical and Technical Foundations

The Sanjiangyuan region is characterized by diverse natural resources, complex ecological processes, and significant spatial heterogeneity. Traditional approaches relying on single factors, single scales, and single technical methods are no longer sufficient to meet the comprehensive needs of ecological conservation, resource regulation, and territorial spatial governance. Therefore, by providing a spatial governance framework through a “single map,” a technical implementation pathway via integrated air-space-ground observation, and a regional application logic based on the Sanjiangyuan ecological adaptability theory, this study lays the theoretical and technical foundation for refining the research on the development path of the Sanjiangyuan natural resource observation network.

The Concept of the “Single Map” for Natural Resources and Territorial Spatial Planning

The “Single Map” is a fundamental concept underpinning the digital transformation of natural resources management and the modernization of territorial spatial governance in China. Its core lies in integrating, dynamically updating, and

collaboratively managing multi-source, multi-scale, and multi-type natural resource data-including land, minerals, water, forests, grasslands, wetlands, glaciers, and ecological spaces-supported by unified spatial references, data standards, and application platforms, thereby achieving “common sources, common standards, common maps, and common use” of natural resource data (Yi 2023; Chen & Zhong 2026;Zhang 2026). Essentially, the “One Map” initiative is not merely an integration platform for geospatial data; it is a spatial governance paradigm that facilitates the coordinated operation of various functions, including natural resource surveys and monitoring, territorial spatial planning, land-use control, ecological conservation and restoration, and resource and asset supervision. By overcoming long-standing constraints such as departmental fragmentation, data dispersion, and inconsistent standards, it drives the transformation of natural resource management from traditional decentralized, static, and experience-based approaches toward integrated, dynamic, and intelligent management(“National Technical Committee on Geographic Information Standardization”, 2020;Lu 2026). Its role extends beyond data aggregation and spatial visualization; more importantly, by unifying base maps, standards, and interfaces, it achieves end-to-end integration across the entire process of natural resource survey, monitoring, evaluation, early warning, decision-making, and feedback, thereby providing fundamental support for optimizing the development and protection patterns of territorial space. From a theoretical perspective, the“One Map” initiative primarily encompasses the following three dimensions:

First, spatial uniformity. Spatial uniformity is a fundamental prerequisite for the “One Map” initiative. By adopting a unified coordinate system, a unified spatial datum, and a unified geographic coding system-such as the China Geodetic Coordinate System 2000 (CGCS2000)-it is possible to achieve spatial alignment and precise overlay of data from remote sensing imagery, ground surveys, ecological monitoring, planning and control, and administrative management. For regions like Sanjiangyuan which are vast, topographically complex, and characterized by strong ecological spatial

continuity-a unified spatial datum is a necessary condition for conducting cross-basin, cross-type, cross-scale natural resource monitoring and comprehensive analysis.

Second, data integration. Data integration involves the fusion and organization of multiple data types, including remote sensing imagery, basic geographic information, natural resource survey results, ground observation data, statistical survey data, model simulation results, and management operational data. In the observation of natural resources In the Sanjiangyuan region, relying on a single data source alone makes it difficult to comprehensively characterize complex ecological processes such as the degradation of alpine grasslands, wetland evolution, glacial retreat, permafrost changes, and fluctuations in water conservation functions. Therefore, it is necessary to use the“One Map”as the data foundation to form a comprehensive data system covering the quantity, quality, structure, functions, and dynamic processes of natural resources(Jiao 2019; “Ministry of Natural Resources”, 2022).

Third, application synergy. Application synergy is the key to transforming the“One Map”from a data platform into a governance tool. By establishing unified data service interfaces, operational coordination mechanisms, and analytical evaluation models, the“One Map”can support multi-scenario applications such as the formulation of national spatial planning, natural resource supervision, management of ecological protection red lines, assessment of ecological restoration effectiveness, disaster risk early warning, and national park management. In the Sanjiangyuan region, the“One Map”initiative should not only serve the understanding of natural resource baselines but also support the evaluation of ecological conservation outcomes and the identification of major ecological security risks.

Therefore, building a natural resource observation network for Sanjiangyuan region under the guidance of the“One Map”initiative will help achieve systematic integration-from understanding resource baselines to monitoring

ecological processes, and from analyzing spatial patterns to supporting management decisions.

Integrated Space–Air–Ground Observation: From Technical Capability to Governance Function

Integrated space–air–ground observation provides the technological basis for natural resource monitoring in Sanjiangyuan. Rather than reviewing specific platforms or sensors, this section focuses on the governance functions that each observation layer can serve, the barriers to their integration, and the management conditions required for that integration to be realized.

Three observation layers and their governance functions. Space-based observation, primarily through medium- and high-resolution optical and radar remote sensing, provides the only feasible means of achieving repeated, region-wide coverage in a vast and sparsely accessible area. Its governance function is to support regional-scale pattern analysis: detecting changes in vegetation cover, water body distribution, wetland extent, snow and glacier conditions, and land use. Radar observation is particularly relevant in Sanjiangyuan because cloud cover and snowfall limit optical data availability for much of the year, and because it can capture surface deformation and moisture conditions that optical sensors cannot. Air-based observation, including UAV and airborne platforms, serves a different governance function: detailed identification and verification in key areas where regional-scale data are insufficient for management decisions, such as delineating degraded grassland patches, verifying wetland boundaries, or assessing localized disturbance. Ground-based observation, including meteorological, hydrological, soil, permafrost, and ecological monitoring sites, provides the reference data against which remote sensing products are validated and the process-level information needed to interpret ecological change. Its governance function is to ensure that the data used for decisions are accurate, traceable, and mechanistically interpretable.

Barriers to integration. The technical feasibility of integrating these three layers is well established. The barriers are primarily institutional. First, data collected by different agencies-natural resources, forestry and grassland, ecological environment, meteorology, hydrology, and national park management-are organized according to different standards, formats, and metadata specifications. This makes routine integration difficult even when data are nominally available. Second, data-sharing mechanisms remain largely project-based rather than institutionalized. Agencies often lack clear mandates, incentives, or protocols for sharing data beyond specific collaborative projects, and concerns about data ownership and attribution further discourage open sharing. Third, the responsibility for integration itself is unclear. No single entity currently has the authority or resources to maintain a region-wide, multi-source observation data system on a sustained basis. These barriers are not technical problems that can be solved by better sensors or faster networks; they are governance problems that require institutional solutions.

Management conditions for integration. Three conditions are necessary for the technical potential of integrated observation to be realized in Sanjiangyuan. First, a designated coordinating entity with a clear mandate for network-wide data integration is required. This does not necessarily mean creating a new agency; it could involve assigning this responsibility to an existing body, such as the national park management authority or a designated unit within the provincial natural resources department, with the authority to establish data standards and coordinate among agencies. Second, sustained funding for data management-not only for data collection-is needed. International experience indicates that the cost of maintaining data infrastructure, quality control, and sharing platforms is often underestimated relative to the cost of installing sensors. Third, incentive structures must be established that make data sharing beneficial for the agencies and researchers who collect the data, rather than merely obligatory. This may include recognition mechanisms, co-authorship arrangements, or reciprocal access to integrated data products. Without these

conditions, the integration of space, air, and ground observations will remain a technical aspiration rather than an operational reality.

Theory of Adaptation for Ecological Conservation and Monitoring In the Sanjiangyuan region

Located in the heart of the Qinghai-Tibet Plateau, Sanjiangyuan Region serves as the primary source of the Yangtze, Yellow, and Lancang Rivers and is hailed as the "Water Tower of China." This region is characterized by its typical alpine ecosystem, critical ecological functions, and sensitivity to environmental changes, making it a key area within China's ecological security framework. Its ecosystems are dominated by alpine grasslands, wetlands, rivers and lakes, glaciers and snow-capped mountains, and permafrost environments. Ecological processes are influenced by multiple factors, including climate change, water and heat conditions, topography, human activities, and conservation policies. Therefore, the construction of a natural resource monitoring network In the Sanjiangyuan region must adhere to the principles of ecological conservation objectives and regional adaptability, establishing a monitoring theoretical framework that aligns with the structure, functions, and processes of alpine ecosystems (Feng 2025; Ma 2025).

First, the theory of ecosystem integrity provides a foundation for selecting observation targets and constructing an indicator system. Ecosystem integrity emphasizes the unity of ecosystem structure, function, and processes, requiring that the observation system focus not only on quantitative changes in individual resource elements but also on the interactive relationships among different ecological units(Yang et al. 2026). In the Sanjiangyuan region, grasslands, wetlands, rivers, lakes, glaciers, permafrost, and wildlife habitats are closely interconnected. For example, the degradation of alpine grasslands manifests not only as a decline in vegetation cover and changes in community structure but may also affect soil moisture retention, water conservation, carbon cycling, and forage production

capacity; permafrost degradation, in turn, may alter surface hydrological processes, wetland recharge mechanisms, and ecosystem stability. Therefore, the observation network should shift from single-factor monitoring to multi-factor collaborative observation, forming a comprehensive indicator system that encompasses resource baseline conditions, ecological structure, ecological functions, and ecological processes.

Second, the theory of scale adaptation provides a methodological basis for the spatial layout of observation networks. At the regional scale, observations cover areas on the order of 10^2–10^4 km²; at the watershed scale, 10^0–10^2 km²; and at the plot scale, 10^{-4}–10^{-2} km².The Sanjiangyuan region has complex natural geographical conditions, and its ecological processes exhibit distinct scale effects. At the macro-scale, it is necessary to understand regional ecological patterns, land cover changes, water conservation capacity, and ecological security patterns; at the watershed scale, it is necessary to analyze hydrological processes, wetland evolution, grassland degradation and restoration, and changes in glacial snow cover; and at the plot scale, it is necessary to obtain detailed data on vegetation communities, soil water and heat conditions, species diversity, and ecosystem productivity. Therefore, a three-tiered observation system linking“region-watershed-plot”should be established to facilitate the transmission, validation, and coupled analysis of observational data across different scales (Xiao et al.2023; Jiang et al.2026). Among these, satellite remote sensing is suitable for continuous monitoring at the regional scale, while UAV and aerial observations are suitable for detailed identification in key areas; ground plots and automated stations are used for process validation and mechanistic interpretation .

Third, the theory of ecological vulnerability and sensitivity response serves as the key basis for identifying priority observation factors. Alpine ecosystems are characterized by low temperatures, low productivity, long recovery cycles,

and weak resistance to disturbances, making them highly sensitive to climate change and human-induced disturbances. Existing research indicates that rising temperatures, changes in precipitation patterns, permafrost degradation, and extreme weather events may significantly impact vegetation growth, soil moisture, river and lake recharge, glacial snowpack, and ecosystem carbon and water cycles. Therefore, the Sanjiangyuan observation system should focus on the coupled relationships among climate factors, permafrost conditions, hydrological processes, vegetation dynamics, biodiversity, and changes in ecosystem functions, and establish an indicator system capable of reflecting ecosystem sensitivity, vulnerability, and resilience.

Fourth, the theory of “conservation first and sustainable use” determines the service objectives of the observation network. The development of the Sanjiangyuan National Park adheres to the fundamental principle of “conservation first and natural restoration as the primary approach.” Consequently, the observation system must not only support baseline surveys and change monitoring of natural resources but also serve the oversight of ecological protection red lines, national park management, evaluation of ecological restoration outcomes, biodiversity conservation, assessment of water conservation functions, and ecological risk early warning. At the same time, given the region’s ongoing practical needs,such as pastoral production, community development, and ecotourism-the observation network should also provide scientific evidence to facilitate coordination between ecological conservation and sustainable use. Through dynamic monitoring of grassland carrying capacity, ecotourism pressure, changes in forage resources, and the intensity of human activities, the network can support differentiated regional management and eco-friendly development models(Cheng & Guan 2026; Wang & Pei 2025).

Fifth, adaptive management theory provides the decision-making logic for the operational mechanisms of the

observation network. Adaptive management emphasizes that, under conditions of ecosystem complexity and uncertainty, the scientific rigor and effectiveness of ecological conservation decisions can be continuously enhanced through continuous monitoring, scientific assessment, management adjustments, and feedback-based optimization. In the construction of the Sanjiangyuan Natural Resources Observation Network, the observation system should not be viewed merely as a data collection tool but rather as an integral component of the ecological conservation decision support system. By establishing a closed-loop mechanism of"monitoring - evaluation - early warning - decision making - feedback,"it is possible to continuously track ecological trends, risk factors, and conservation outcomes, and dynamically optimize conservation and restoration measures, spatial management strategies, and resource utilization methods based on monitoring results (Wang et al.2023; Wang 2026).

In summary, the theory of ecological conservation and observation compatibility In the Sanjiangyuan region emphasizes that the observation system must align with regional ecosystem types, ecological process characteristics, conservation management objectives, and spatial governance needs. Only by organically integrating theories such as ecosystem integrity, scale adaptation, vulnerability response, conservation priority, and adaptive management can a natural resource observation network be established that both conforms to the laws of alpine ecosystems and serves the national ecological security strategy.

Research Methodology

This paper employs the Logic Framework Approach (LFA) to conduct a systematic analysis of the development of observation networks (Chen & Ge 2012; Wang et al.2026). First proposed by the U.S. Agency for International Development (USAID) and applied to development aid project management, this method is a results-oriented,

structured analytical tool that emphasizes clarifying the implementation pathways and evaluation criteria for complex system development through the logical relationships among objectives, activities, outputs, inputs, and external assumptions. This method is suitable for comprehensive engineering research involving multiple levels of objectives, diverse stakeholders, complex construction content, and the need for long-term, sustained implementation.

The construction of the Sanjiangyuan Natural Resources Monitoring Network exhibits significant systemic complexity. On the one hand, the network must serve multiple objectives, including ecological conservation, resource regulation, territorial spatial governance, risk early warning, and scientific research; on the other hand, its construction involves numerous technical components, such as satellite remote sensing, UAV monitoring, ground stations, IoT sensing, data platforms, model analysis, and management decision-making. Relying solely on empirical induction or single-factor evaluation methods makes it difficult to reveal the progressive relationship among“objectives - tasks - projects - support”in the construction of the observation network. Therefore, this paper introduces the logical framework approach, treating the construction of the Sanjiangyuan Natural Resources Observation Network as a composite system driven by strategic objectives, supported by key tasks, implemented through project outputs, and secured by foundational investments, thereby enhancing the systematic nature, operability, and policy applicability of the research methodology.

The logical framework matrix typically comprises two dimensions: vertical and horizontal logical relationships, as shown in Table 1. Vertical logical relationships primarily reflect the causal progression between different levels, that is, the step-by-step decomposition of macro-level objectives into specific goals, tasks, outputs, and inputs, emphasizing “why to build, what to build, how to build, and on what to rely.” Horizontal logical relationships, on the other hand,

497 are primarily used to clarify the corresponding evaluation indicators, information sources, and external assumptions
498 for each level, emphasizing how construction outcomes are measured, where data is sourced, and the key external
499 conditions required to achieve the objectives. By combining these two dimensions, abstract strategic goals can be
500 transformed into identifiable, evaluable, and implementable construction tasks.

501 Table 1. Basic schema of the logical framework matrix

Objective Level	Indicator	Information Source	Assumption
Purpose	Purpose Indicator	Verification Method or Means	--
Task	Task Indicator	Verification Method or Means	Key External Conditions for Task Completion
Output	Output Indicator	Verification Method or Means	Key External Conditions for Achieving the Output
Input	Input Indicator	Verification Method or Means	Key External Conditions for Ensuring Inputs

502

503 In the course of this study, this paper first examines the practical challenges facing the natural resource monitoring
504 system In the Sanjiangyuan region to identify the current monitoring network's primary shortcomings in terms of
505 spatial layout, monitoring parameters, data standards, data-sharing mechanisms, and intelligent analysis capabilities.
506 Second, it establishes the overall objectives for building the monitoring network by integrating the "two unifications"
507 of natural resource management responsibilities, national park development, ecological conservation and restoration,
508 and territorial spatial governance requirements. Third, a task framework for the development of the observation
509 network is established around three core needs: data assurance, decision support, and scientific understanding. Finally,
510 corresponding implementation pathways are proposed covering station networks, indicator systems, data platforms,

quality control, model analysis, application of results, and institutional safeguards.

Given that the construction of a natural resources observation network differs from general engineering projects,as its objectives are long-term, public-interest oriented, strategic, and cannot be achieved within a single project cycle which this paper introduces moderate modifications to the traditional logical framework approach. Traditional logical frameworks typically consist of four levels: “Objectives - Tasks - Outputs - Inputs”.This paper, however, introduces a “Mission Layer”between the Objectives and Tasks levels to facilitate the logical transition between macro-level strategic objectives and specific construction tasks. The Mission Layer primarily encompasses three aspects: Data Assurance, Decision Support, and Scientific Understanding. Data Assurance emphasizes the continuous acquisition of long-term, continuous, and standardized natural resource observation data; decision support emphasizes serving ecological conservation, resource regulation, territorial spatial governance, and risk early warning; and scientific understanding emphasizes deepening our understanding of the structural, functional, and process-related patterns of high-altitude cold ecosystems. By adding the mission layer, we can address the issue of insufficient alignment between macro-level objectives and specific engineering measures, making the path for observation network construction more focused, clear, and actionable. The results are shown in Table 2.

Table 2. Analysis of observation network construction based on logical framework matrix approach

	Descriptions	Indicators	Resources	Assumptions
Goals	1. Harmony with nature and stability 2. Resource security	1. Level of natural resource management 2. Capacity for territorial spatial governance	Sustainable Development Goals	--

Missions	1. Data Assurance 2. Decision Support 3. Scientific Understanding	1. The capacity of relevant departments within the Support Division to provide operational support 2. The level of data openness and sharing 3. The domestic and international influence of the comprehensive observation network	1. Early Warning and Safeguarding of Natural Resource Security 2. Relevant data cited in central government documents	1. Building an Ecological Civilization 2. The Concept of a Community of Life
Objects	1. Three-dimensional observation network for natural resource elements 2. Platform for managing and sharing observation data 3. Decision-making services and support for natural resource management	1. Number of stations at all levels 2. Validity and coverage of data acquisition 3. Accuracy and utilization rate of observational data 4. Big data computing capabilities	1. Analysis Report on Observation Data 2. Policy Recommendations 3. Research Report	1. The strictest ecological and environmental protection system 2. The “two unifications” of natural resources functions 3. Natural resource baseline accounting
Outputs	1. National Ground-Based Observation Station Network 2. Comprehensive Observation Indicator System for Natural Resource Elements 3. Data Quality Control Management System 4. Application System for the Comprehensive Observation Network of Natural Resource Elements 5. Calibration and Validation System for Land and Marine Observation Networks 6. Production and Application of Trend Analysis Outputs 7. Scientific Research Collaboration and Data Sharing Platform 8. Complete Sets of Observation Equipment	1. Natural Resource Security Objectives Module 2. Monitoring Indices 3. Monitoring Indicators Module	1. Inclusion in the “One Map” of Natural Resources 2. Data from the Statistical Yearbook 3. Blue Book on Comprehensive Monitoring of Natural Resource Elements 4. Research Papers	1. Strong leadership support and direct oversight by government ministries 2. Smooth channels for direct dissemination of results 3. Sustainable innovation capabilities 4. Network operations and maintenance capabilities

Inputs	1. Organizational Management 2. Funding 3. Research Personnel 4. Collaboration Mechanisms 5. Sustainable Innovation	1. Departmental budget items 2. Major national science and technology projects 3. Investment in talent development 4. Investment by partner organizations	1. National-level and ministerial-level talent 2. National-level and ministerial-level key laboratories 3. National-level and ministerial-level observatories	1. Cooperation mechanisms among ministries, provincial governments, and institutions and universities 2. Sustained funding 3. A stable workforce and the involvement of high-caliber teams 4. Development of key technologies and equipment

Based on the refined logical framework, this paper defines the objective level of the Sanjiangyuan Natural Resources Observation Network as serving the two core goals of “harmony with nature and stability” and “resource security”; summarizes the mission level as “data assurance, decision support, and scientific understanding”; and divides the task level into the construction of a three-dimensional observation network for natural resource elements, the development of a platform for managing and sharing observation data, and the establishment of a system for natural resource management, decision-making services, and support. The output layer is implemented through a network of ground observation stations, a comprehensive observation indicator system, a data quality control system, an observation network application system, a calibration and validation system, trend analysis results, a scientific research collaboration and sharing platform, and a complete set of observation equipment; the input layer is summarized as supporting conditions such as organizational management, funding, talent teams, cooperation mechanisms, and sustainable innovation capabilities. This logical chain comprehensively reveals the entire process of the Sanjiangyuan Natural Resources Observation Network, from strategic needs to project implementation and ultimately to application services.

Through the aforementioned approach, this paper not only systematically analyzes the hierarchical objectives and task structure of the Sanjiangyuan Natural Resources Observation Network but also identifies the constraints and supporting relationships among different construction phases. The introduction of the logical framework approach shifts this study from a general description of the path forward to the design of a structured, hierarchical, and evaluable construction plan, thereby enhancing the scientific rigor, practicality, and policy-relevance of the research conclusions. This method also provides a referenceable analytical framework for the construction of natural resource observation networks in other ecologically sensitive alpine regions, national parks, and key ecological functional zones.

Key Pathways for Building the SANJIANGYUAN Natural Resource Monitoring Network form A "Single Map" Perspective

Based on the significance of the aforementioned observation network construction and in response to the needs of integrated natural resource management and territorial spatial governance, the key to building Sanjiangyuan observation network lies in resolving unconventional management challenges and critical technological bottlenecks related to "resource security" and "natural stability and harmony." Focusing on the three missions of "data assurance, decision support, and scientific understanding," implementation can be advanced according to the approach of "one dataset, two platforms, and three service windows."

Establish a "Dual-precision" Network of Natural Resource Observation Stations

Obtaining data on natural resource elements is the primary task in establishing an observation network. The Sanjiangyuan Natural Resource Observation Network should focus on comprehensiveness and representativeness, establishing an interconnected "dual-precision" ground-based observation network (Figure 1).

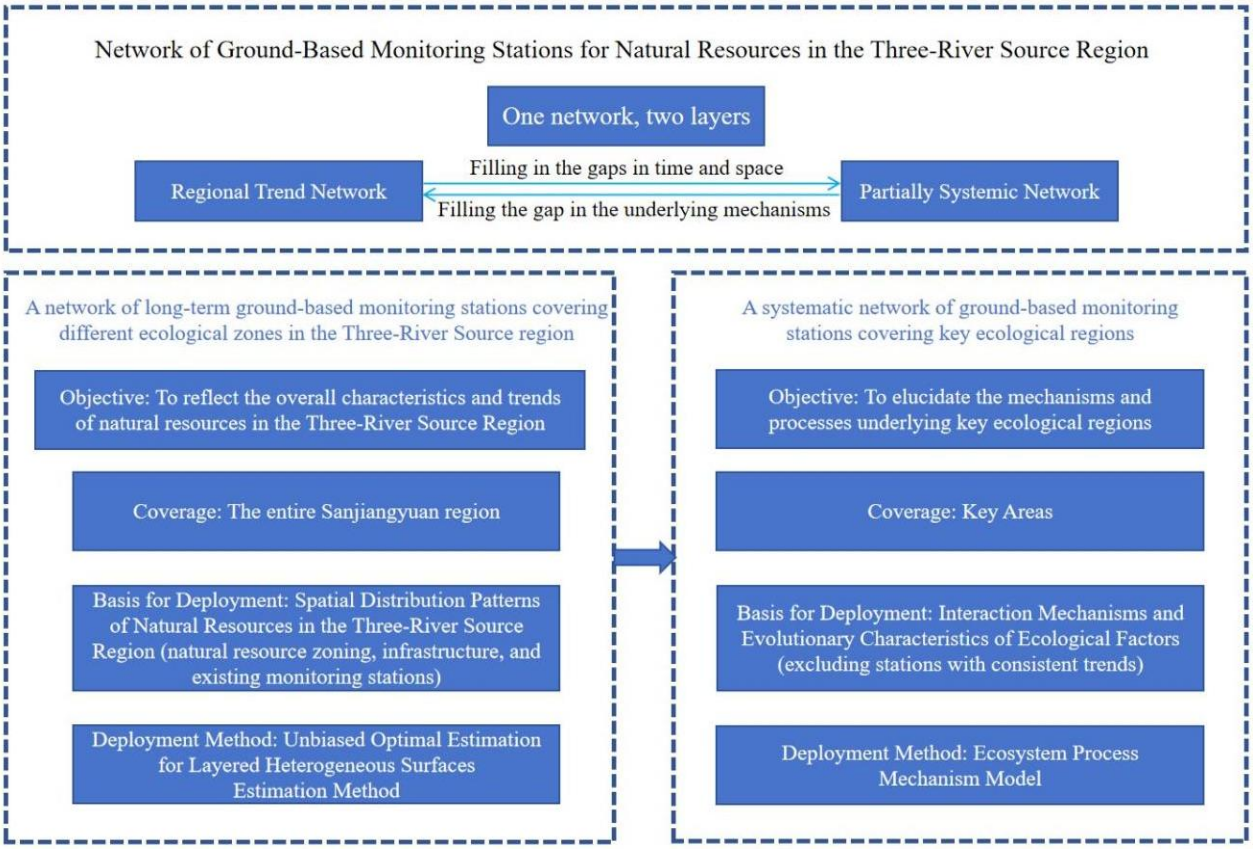


Fig. 1. the idea and method of "double precision" network layout

First is the basic network, which should fully integrate the results of natural resource zoning to establish observation stations (or points) that are highly representative and exhibit distinct regional characteristics. The layout and construction standards of these stations (or points) should be optimized to maximize our understanding of the overall characteristics and trends of natural resources in the Sanjiangyuan region. Second, the incremental network should“densify”observations in key ecological functional zones of Sanjiangyuan region on top of the basic network. Targeting the regional and watershed characteristics of natural ecosystems, this network should focus on exploring and researching the operational mechanisms and processes of ecosystems.

We should strengthen three-dimensional collaborative observation integrating space, air, and ground resources to obtain a comprehensive set of all-weather, multi-parameter observational data covering the entire country. We should

utilize ground-based array stations in full conjunction with space-based observation technologies to conduct calibration and validation of land and marine observation networks. We should explore the construction of an integrated processing and intelligent sensing technology system to achieve the effective integration of satellite remote sensing, aerospace, and ground station networks, revealing regional patterns of natural resources and the organic connections between sampling points or observation sites. Point data will be used to validate and describe the spatial distribution patterns of regional natural resources, moving from point to area and integrating both to achieve the effective fusion of multi-channel, multi-dimensional natural resource data.

Building a Dual Platform for "Data Management and Decision Support"

In addition to data collection, it is necessary to strengthen data quality control to achieve standardized and regulated management; through research on the mechanisms, processes, predictions, and visualization of natural ecological changes, we can conduct future scenario simulations and optimize decision-making (Figure 2).

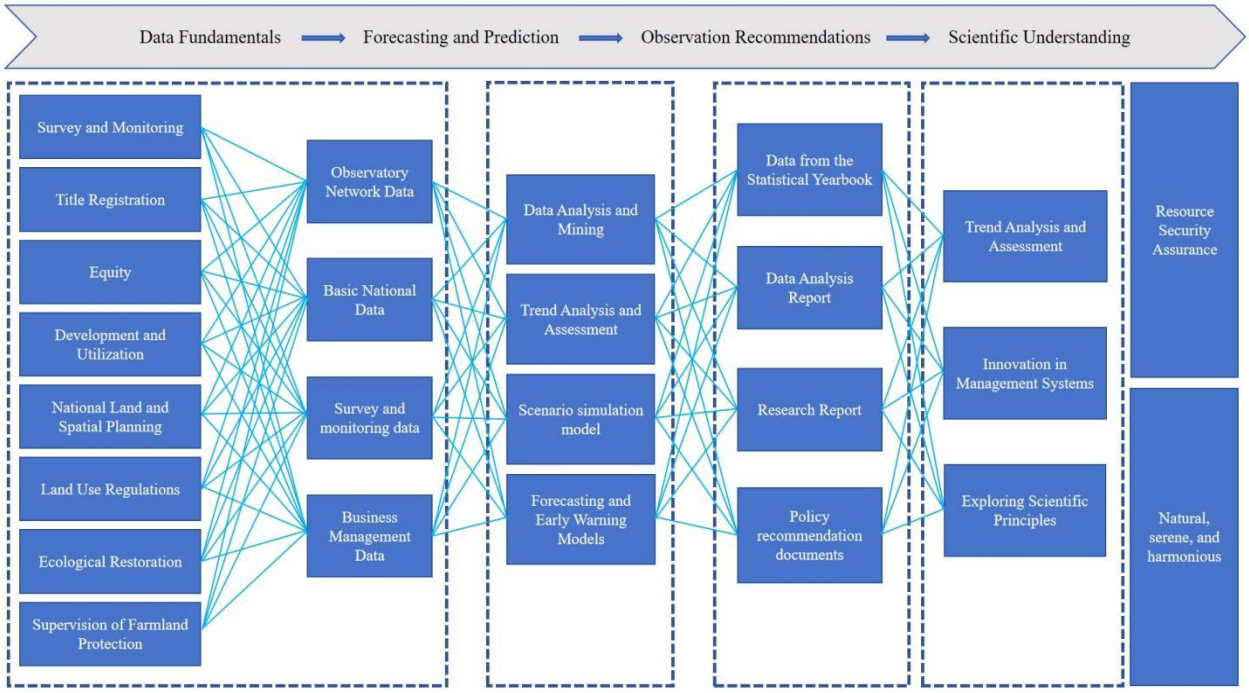


Fig. 2. Natural resource survey data management and analysis mining

Leveraging information technologies such as big data, cloud computing, and artificial intelligence, we will aggregate scientific observational data on natural resource elements to establish a“data bank.”Establish a multi-tiered quality management system to unify and standardize data specifications across multiple sources and monitoring networks. Strengthen quality control throughout the entire process-from data collection, submission, and storage to sharing and service provision-to ensure the quality of observational data. Second, utilize high-performance computing clusters and visualization technologies to comprehensively integrate human-machine collaborative decision-making, simulation, and scenario-based decision-making, thereby constructing a “Natural Resources Decision Theater.” Based on observational data, and drawing upon physical, chemical, and biological process models of natural ecosystem evolution, as well as the migration patterns and cyclical transformation characteristics of key elements such as water, soil, air, biota, and rock, construct a digital twin model of the watershed. Research the integrated application of multi-agent systems, cellular automata, and system dynamics models in the evolution of complex “human-land” systems. Simulate a natural resource management decision-making test platform, anticipate different scenarios under natural evolution and human disturbance, and provide a visual simulation environment. This collaborative decision-support platform offers an interactive, multidimensional, and intuitive decision-making environment to assist the government in formulating major natural resource policies.

Developing Eight Major Projects to Support Eight Key Management Applications

Centered on the objectives of establishing an observation network, and following the three-tiered service model of“data services-intelligence services-knowledge updates,”we will support current natural resource management needs in eight key areas. First, we will establish observation stations covering Sanjiangyuan region to obtain long-term, continuous,

and stable site-level observational data, thereby addressing gaps in natural resource survey data; Second, we will establish a natural resource simulation and modeling technology system to forecast and assess the future state of natural resources, thereby supporting the adjustment and optimization of territorial spatial structure; third, we will implement a territorial spatial issue diagnosis project to analyze key factors influencing natural resource ecosystems, enhancing the comprehensiveness and systematic nature of territorial spatial ecological restoration; fourth, we will implement a security situation identification and risk early warning project to analyze the impacts of natural resource ecosystem evolution, strengthening the scientific basis for territorial spatial land-use control; Fifth, we will establish a scenario analysis and decision-support project to decipher the operational patterns of the "natural resources–socioeconomic" system and assist in major decision-making regarding the development and utilization of territorial space; Sixth, we will establish a smart management and control project for arable land to track changes in arable land resources from the perspectives of "quantity, quality, and ecology as a trinity" and enhance the scientific basis for the protection and utilization of arable land resources; Seventh, we will make the value of natural resources explicit by refining scientific methods for the valuation and accounting of natural resource assets; Eighth, we will establish a technical system for data aggregation, integration, and in-depth analysis; build a multi-factor resource observation data center to facilitate the unified management and public sharing of observation data.

Furthermore, the observation network should be open to the public and serve the nation. On the one hand, it should align with major national strategies to support the management of key regions and critical resource issues, as well as research into patterns of change. On the other hand, it should serve as a platform for gathering talent, data, and think tank expertise to support major theoretical research on natural resource development strategies.

Establishing an Institutional Framework to Strengthen Sustainable Innovation Capacity

The construction of the Sanjiangyuan Natural Resources Observation Network is a pioneering, long-term, and ongoing project that requires innovative mechanisms and the establishment of an institutional framework to strengthen sustainable innovation capacity. To this end, this paper recommends strengthening foundational capacity-building across multiple dimensions-including organizational capacity, financial resources, human resources, collaborative capabilities, and creativity-while increasing policy support and intensifying reform and innovation efforts to ensure the smooth achievement of construction objectives.

First, innovate organizational management mechanisms. We should establish a high-level, centralized leadership and coordination mechanism to comprehensively address major issues, key matters, and long-term planning in the construction of the observation network. Additionally, establish direct reporting channels for major findings, urgent intelligence, and risk warning information to enhance the efficiency of results translation and management response capabilities.

Second, we should improve the funding mechanism. Establish a long-term funding security system centered on dedicated national fiscal allocations, supplemented by diversified and market-based investments. Explore mechanisms for stable growth in operational and maintenance funding to ensure the continuous operation of the observation station network, equipment upgrades, and data platform maintenance. Concurrently, align with science and technology programs and research funds to establish specialized support initiatives for comprehensive natural resource observation. Clearly define key scientific questions and technological breakthrough tasks to continuously enhance the scientific and technological capacity of the observation network to support decision-making.

Third, we should build a sustainable team of innovative talent. Focusing on key areas such as comprehensive natural resource observation, data governance, model simulation, and intelligent analysis, we will strengthen the cultivation of interdisciplinary talent and the recruitment of high-level professionals. This will foster a professional team with an international perspective, field observation capabilities, engineering and organizational skills, and data mining expertise, thereby providing the human resources necessary for the long-term operation and innovative development of the observation network.

Fourth, we should explore mechanisms for collaborative construction. During the advancement of the observation network project, fully integrate the existing foundations of relevant government agencies, research institutes, universities, and national park management bodies. Through joint construction, collaborative development, supplementary construction, and resource sharing, promote the optimization of station layout, standardization, and resource coordination to accelerate the implementation and collaborative operation of the station network.

Fifth, strengthen support for scientific and technological innovation. Focused efforts should be made to tackle core theories, key models, intelligent algorithms, sensing equipment, and devices suitable for high-altitude cold regions in the construction of the observation network. we should deepen domestic and international scientific research cooperation and open sharing to produce original research outcomes and a comprehensive system of technical equipment. This will propel China's comprehensive observation capabilities for natural resources from"playing catch-up"to"keeping pace"and ultimately"leading the way",thereby enhancing its international influence.

Conclusions

This paper takes Sanjiangyuan region as its subject of study and, guided by the"One Map" concept, systematically explores the construction of a natural resource observation network from three perspectives: theoretical foundations,

technical systems, and implementation pathways. The study indicates that the Sanjiangyuan observation system is currently at a critical stage of transition from decentralized development to systematic integration. The core challenges lie in the difficulty of effectively integrating multi-source data, the uneven spatial distribution and element allocation of the observation network, and the insufficient capacity to translate observation results into decision-making services. By introducing the“One Map” framework-which emphasizes “spatial unification, data integration, and application synergy”,it is possible to transform natural resource observation from static data integration to dynamic process understanding and comprehensive governance support. At the methodological level, this paper employs the logical framework approach to construct a multi-level analytical model. It refines the objectives of observation network development into three core missions“data assurance, decision support, and scientific understanding”and further breaks these down into key tasks such as the construction of observation station networks, the development of data platforms, and the improvement of decision-support systems, thereby establishing a development pathway characterized by strong structural coherence and operational feasibility. Technologically, the integrated air-space-ground observation system achieves multi-scale, multi-element collaborative monitoring by integrating remote sensing, UAVs, and ground-based observation methods, providing crucial support for elucidating the structural and functional processes of alpine ecosystems. In terms of implementation pathways, the proposed “dual-precision station network + dual-platform + multi-application” overall architecture helps enhance the systematic nature, continuity, and intelligence of the observation system.

Nevertheless, the construction of the Sanjiangyuan natural resource observation network still faces several challenges. Future research should focus on the following areas: First, further improving the multi-source data standard system and sharing mechanisms to promote cross-departmental and cross-regional data interoperability and enhance data governance capabilities; second, deepening the application of artificial intelligence and data assimilation technologies to improve the intelligent analysis and prediction capabilities of observation data and enhance ecological risk early warning levels; third, building a digital twin watershed and ecosystem simulation platform to enable dynamic simulation and scenario modeling of natural resource state evolution; and fourth, strengthening institutional safeguards and collaborative innovation mechanisms to ensure the long-term stable operation and continuous optimization of the observation network.

Overall, with the deep integration of next-generation information technologies and ecological science research, the natural resource observation system will gradually evolve toward intelligence, collaboration, and decision-making

orientation, providing a more robust data foundation and scientific support for ecological conservation and sustainable development in the context of global change.

CRediT author statement

1.Conceptualization: Dong Bai; Methodology: Jianli Qian, Dong Bai; Formal analysis and investigation: Jianli Qian, Yaohua Li; Writing - original draft preparation: Jianli Qian, Yaohua Li ,Dong Bai; Writing - review and editing: Dong Bai; Funding acquisition: Guozhen Zhang; Resources: Jianli Qian, Guozhen Zhang.

2.Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Some data may be subject to confidentiality restrictions imposed by the data provider. All processed data used for the analysis are presented in the supplementary materials accompanying this article.

3.A Clinical Trial Number: not applicable

4.Publishing declaration

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5.Ethics approval and consent to participate

If human participants were involved: All procedures involving human participants were performed in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments. This study did not involve human participants, human data, or human tissue.

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Author Contribution

Conceptualization:Dong Bai; Methodology: Jianli Qian, Dong Bai; Formal analysis and investigation: Jianli Qian, Yaohua Li; Writing - original draft preparation: Jianli Qian, Yaohua Li , Dong Bai; Writing -review and editing: Dong Bai; Funding acquisition: Guozhen Zhang; Resources: Jianli Qian, Guozhen Zhang.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Ethics approval and consent to participate

All authors have read, understood, and agreed to comply with the statement on Authors' Ethical Responsibilities in the Author Guidelines.The study did not involve human participants, human data, or animals; therefore, ethical approval was not required. Not applicable.This study used a publicly available dataset, and ethical approval was not required. Informed consent was collected by the original dataset. As this research involves secondary analysis of publicly available data, no additional participant consent or ethical approval was required.

Publishing declaration

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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