Establishing Natural Resources Monitoring Systems in China: Situation, Problem and Suggestion

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Abstract: In order to fundamentally support work for achieve "climate action, life below water, and life on land" 3 Sustainable Development Goals of the United Nations, and to realize unified monitoring and refined management of natural resources, this paper collects, organizes, analyzes, and summarizes national policy, management department documents, relevant papers, and the latest industry development trends through the literature induction method. It systematically studies current monitoring networks from the perspectives of land resources monitoring, mineral resources monitoring, forest resources monitoring, grassland resources monitoring, water resources monitoring, wetland resources monitoring, marine resources monitoring. It indicates such problems as inconsistent classification standards and monitoring technical standards for natural resources, lack of smooth connection among monitoring networks, and insufficient high-tech applications. It proposes suggestions of building 1+N monitoring system, coordinating multi-level and multi-category monitoring mechanisms, improving monitoring intelligence level, strengthening the ability to obtain multi-source spatiotemporal data, and constructing an information sharing platform, to better build a unified natural resource monitoring system, and serve the refined management of natural resources.

1. Introduction

The Sustainable Development Goals of the United Nations aim to comprehensively address the developmental issues such as society, economy, and environment from 2015 to 2030, steering towards a path of sustainable development. Among them, "climate action, life below water, and life on land" are 3 key goals. (United Nations, 2018)

Natural resources refer to the sum of environmental factors existing in nature that can be developed and utilized by humans to improve their welfare level under certain temporal conditions. As human cognitive levels improve and society continues to develop, the connotation of natural resources is constantly expanding. Their social utility and relative scarcity to humans are their fundamental attributes. Natural resources are essential for human survival and development and are also the fundamental carriers for building a beautiful China and deepening the reform of the ecological civilization system (Cai, 2016).

Natural resource monitoring is based on the background data of natural resources, relying on existing basic surveying and mapping achievements to construct a unified monitoring technical system. It uses various information collection and processing methods to systematically observe, measure, record, analyze, evaluate, and predict natural resources. It tracks and monitors the dynamic changes of natural resources themselves and the changes caused by human activities, achieving continuous data renewal (Feng, 2003; Huang, 2019; Zhang, 2019).

Natural resource monitoring is a fundamental and critical task that not only provides basic data for natural resource management, thereby contributing to a deeper understanding of the status and value of natural resources, but also dynamically monitors changes in natural resources, facilitating the timely detection and resolution of issues in natural resource utilization. Evidently, natural resource monitoring serves as a fundamental supporting work for achieving the aforementioned 3 Sustainable Development Goals of the United Nations (Li et al., 2019; Cui, 2019; Wu et al., 2019).

When facing natural resources, a one-sided view cannot be adopted; it is essential to establish a holistic perspective. Natural resource monitoring should cultivate systemic thinking, transitioning from fragmented management to coordinated management. To implement the requirements for unified management of natural resources, promoting the construction of a natural resource monitoring system under the background of restructuring the management system is an important guarantee for realizing the "two unifications" of responsibilities. This can achieve unified monitoring and refined management of various types of natural resources, effectively contributing to the improvement of China's territorial spatial planning system and advancing the construction of ecological civilization to a new stage.

Domestic researchers, starting from multiple dimensions, have conducted research on the construction of China's natural resource monitoring system. However, most current studies focus on individual categories of natural resource monitoring methods and data system construction in terms of technical means (Li et al., 2021) (Lin, 2020) (Zhang and You, 2019). There is insufficient research and review on the overall development status of the natural resource monitoring system.

Through the literature review method, we collected, organized, analyzed, and summarized China's policy documents, information from management departments, as well as international journal articles and the latest industry trends. We systematically examined and deeply studied the current construction status of natural resource monitoring systems in China, including land, minerals, forests, grasslands, water, wetlands, and seas. We identified the issues existing in the construction of China's natural resource monitoring system at this stage and proposed policy recommendations for establishing a unified natural resource monitoring system, which not only benefits the ecological civilization construction in China but also promotes the implementation of the United Nations' Sustainable Development Goals in the country.

2. Foreign Natural Resource Monitoring Systems

In terms of ocean monitoring, in 2017, the Defense Advanced Research Projects Agency (DARPA) of the United States proposed the Sea Internet of Things (SIoT) project. Based on a large number of small, low-cost intelligent floating sensors, it collects information on the activity status of ships, aircraft, and marine life, monitors seabed resources and environmental data in real-time, and utilizes satellite network cloud storage and real-time analysis to enhance the U.S. military's continuous ocean situational awareness capabilities. The Australian Institute of Marine Science has collaborated with IoT startup Myriota to monitor ocean information such as location, ocean currents, sea surface water temperature, and air pressure.

In terms of grassland monitoring, the European Union conducts detailed and diverse monitoring, with each member state serving as the information collection unit, using unified data standards to enter the EU database and publish it externally. In 2000, the Australian National Land and Water Resources Audit established the comprehensive Collaborative Pastures Information System (CPIS), which regularly provides grassland ecological environment monitoring data and reports to the Australian government, analyzing the country's grassland ecological environment and livestock production.

In agricultural monitoring, the United States began land monitoring through a national monitoring system in the early 20th century, gradually developing into a complete monitoring and information management structure system. Between 1966 and 2014, the United States introduced six agricultural information-related laws, regulations, and development plans, providing policy support for agricultural monitoring construction. Nowadays, a large amount of agricultural basic data has become an open resource serving agricultural production decision-making, enabling the booming development of agricultural big data companies. In recent years, Australia has been promoting intelligent agriculture that deeply integrates modern information technologies such as the Internet of Things, cloud computing, and mobile internet, enabling information transmission, interpretation, sharing, and real-time understanding of farmland conditions, providing decision support for planting, irrigation, fertilization, pest control, and crop harvesting.

In terms of ecological monitoring, in 2011, the United States launched the Continental-Scale National Ecological Observatory Network (NEON) program to study important ecological issues from regional to continental scales. It deployed an integrated observation network consisting of approximately 15,000 sensors and several remote sensing satellites to monitor 500 types of ecological environment data, including soil, water, plants, and mammals. Australia has constructed the Terrestrial Ecosystem Research Network (TERN) based on the Internet of Things, automatic observation, and the integration of ground and remote sensing observations.

3. Natural Resource Monitoring Systems Construction in China

China initiated its classified natural resource monitoring efforts relatively early and has amassed a vast array of natural resource data, which supports the management of natural resources and provides robust data support for national decision-making and policy deployment, continuously serving the construction of ecological civilization. At the current stage, China is vigorously advancing the construction of the natural resource monitoring system centered around seven types of resources: land, minerals, forests, grasslands, water, wetlands, and maritime areas and islands. The tasks and content of natural resource monitoring have been systematically restructured, resulting in the top-level design for the construction of the natural resource monitoring system.

Resources	Monitoring Networks	Affiliations
Land	Dynamic Remote Sensing Monitoring of Land Use	China Institute of Land Surveying and Planning
	Geographic Condition Monitoring	National Basic Geographic Information Center, China Academy of Surveying and Mapping Sciences
	Cultivated Land Quality Monitoring	National Land Consolidation and Rehabilitation Center of the Ministry of Natural Resources, Center for Cultivated Land Quality Monitoring and Protection of the Ministry of Agriculture and Rural Affairs
	Dynamic Supervision System for the Balance of Cultivated Land Occupation and Compensation	National Land Consolidation and Rehabilitation Center of the Ministry of Natural Resources
	Dynamic Monitoring of National Spatial Planning	China Institute of Land Surveying and Planning
	Monitoring of Resource and Environmental Carrying Capacity	China Institute of Land Surveying and Planning
Mineral	Dynamic Monitoring of Mineral Resources Reserves	Reserves Evaluation Center of the Ministry of Natural Resources
	National Remote Sensing Monitoring of Mineral Resources Development Environment	National Remote Sensing Center for Geological Surveying and Mineral Resources, China Geological Survey
	Remote Sensing Geological Monitoring of National Mine Environment Restoration and Management Status	National Remote Sensing Center for Geological Surveying and Mineral Resources, China Geological Survey
Forest	Forest Resource Management "One Map"	Survey and Planning Design Institute of the National Forestry and Grassland Administration
	National Intelligent Forest Resource Monitoring and Digital Management Platform	Survey and Planning Design Institute of the National Forestry and Grassland Administration
	National Forestry Carbon Sink Measurement and Monitoring System	Carbon Sink Measurement and Monitoring Center of the National Forestry and Grassland Administration
Grassland	National Grassland Monitoring Network	National Comprehensive Survey Command Center of the China Geological Survey, Survey and Planning Design Institute

		of the National Forestry and Grassland Administration
Water	National Automatic Monitoring System for Surface Water Quality	China Environmental Monitoring Station
	National Surface Water Environmental Monitoring Network	China Environmental Monitoring Station
	National Groundwater Monitoring Project	Geological Environment Monitoring Institute of the China Geological Survey, Hydrology and Water Resources Monitoring and Forecasting Center of the Ministry of Water Resources
	Hydrological Monitoring System for Small and Medium-sized Rivers	Hydrology and Water Resources Monitoring and Forecasting Center of the Ministry of Water Resources
Wetland	Annual Dynamic Monitoring of Internationally Important Wetlands	Wetland Resource Monitoring Center of the National Forestry and Grassland Administration
	Urban Wetland Monitoring	Information Center of the Ministry of Housing and Urban-Rural Development
	Mangrove Dynamic Monitoring	China Institute of Land Surveying and Planning
	Wetland Ecological Dynamic Monitoring	Wetland Resource Monitoring Center of the National Forestry and Grassland Administration
Marine	National Coastal Sea Area Environmental Monitoring Network	China Environmental Monitoring Station
	National Global Ocean Observing Network	National Marine Technology Center
	Offshore Marine Observation and Research Network	Field Stations of the Chinese Academy of Sciences

Table.1 Natural Resources Monitoring Networks in China

3.1 Land Resource Monitoring

At the current stage, land resource monitoring focuses primarily on aspects that are of particular concern to management departments such as land utilization, farmland, and territorial spatial planning. Dynamic remote sensing monitoring of land utilization utilizes satellite remote sensing and other technologies to regularly monitor changes in land use. Currently, it primarily monitors changes in farmland, construction land, and other areas, checks the implementation of annual land use plans, verifies the aggregated data of land change surveys, and conducts daily monitoring of illegal or suspected illegal land use. Geographical condition monitoring utilizes high-resolution aerospace remote sensing images and geographic information system technologies to monitor changes in land cover and geographical elements, reflecting changes in surface resources during the growing season of vegetation and grasping the current status and changes of geographical elements.(Li, 2014) (National Geomatics Center of China, 2019) In terms of farmland quality monitoring, in 2016, the Ministry of Agriculture clarified the construction of a national farmland quality monitoring network with national and local farmland quality monitoring institutions as the mainstay, supplemented by farmland quality monitoring stations of scientific research and teaching institutions. This network conducts dynamic monitoring of quality changes in farmland soil physical and chemical properties, nutrient status, etc. (Office of the Leading Group for the Third National Land Survey of the State Council, 2020) Before 2018, the Ministry of Land and Resources primarily used farmland patches from land use status surveys as evaluation units to comprehensively assess agricultural land in terms of climate conditions, topographic conditions, soil conditions, farmland infrastructure conditions, and land use levels. In 2020, the Ministry of Natural Resources improved the survey and evaluation methods for farmland quality grading, establishing a new classification indicator system that includes natural geographic patterns, topographic conditions, soil conditions, ecological and environmental conditions, crop maturity, and current farmland utilization status. The dynamic supervision system for farmland occupation-compensation balance utilizes satellite imagery technology and indicator linkage to strengthen dynamic monitoring of illegal land use and farmland that should be replenished but has not been replenished, achieving a comprehensive balance in quantity, land type, and productivity, and ensuring that the replenished farmland is authentic and reliable. Territorial spatial planning dynamic monitoring collects and integrates multi-source data in real-time, takes territorial spatial planning as the foundation, relies on the territorial spatial information platform, dynamically monitors territorial spatial protection and development and utilization behaviors, and monitors the implementation of various control boundaries and binding indicators in territorial spatial planning. (The CPC Central Committee and the State Council, 2019) Resource and environmental carrying capacity monitoring relies on resource and environmental carrying capacity monitoring and early warning data, regularly evaluates the entire region and specific areas, conducts comprehensive supervision, dynamic evaluation, and decision support, and conducts real-time dynamic monitoring of key areas to meet the needs of intelligent analysis and dynamic visualization of monitoring and early warning. (The General Office of the CPC Central Committee, 2019) (Zhang and Huang, 2019)

Overall, China's land resource monitoring system is relatively mature. The third national land survey has basically unified land use classification standards, and the results will be used as management base data for various departments. New technologies such as big data and artificial intelligence algorithms have also been applied.

3.2 Mineral Resource Monitoring

Mineral resource monitoring is primarily divided into field monitoring and remote sensing monitoring. Dynamic monitoring of mineral resource reserves employs mine geological survey techniques to capture data on mining, losses, and retained reserves of mining enterprises, providing insights into changes in mineral resource reserves and their causes. Remote sensing monitoring of the mineral resource development environment utilizes high-resolution remote sensing technology to oversee the utilization, planning implementation, and geological environment of mineral resources. This includes real-time monitoring of key mining areas, establishing a comprehensive, all-weather remote sensing monitoring system for the mineral resource development environment, and accumulating data on five types of mines nationwide, including those under construction, in production, and abandoned, since 2010. Remote sensing geological monitoring of mine environmental restoration and management utilizes remote sensing to conduct nationwide mine environment monitoring, providing real-time and dynamic oversight of mine environments in key mining areas. Currently, the mineral resource development status and suspected illegal mining areas in 2019 and 2020 have been identified nationwide, and ecological restoration monitoring of abandoned mines in key regions such as the Yangtze River Economic Belt, Beijing-Tianjin-Hebei, and surrounding areas, as well as emergency monitoring of coal mining subsidence areas, have been carried out. (Yao, 2019)

The mineral resource monitoring system established by the state differs from that of production enterprises, primarily serving resource management and safety supervision. Due to the relatively independent operation of relevant management departments and the specificity of monitoring content and management, monitoring results are often not easily made publicly available.

3.3 Forest Resource Monitoring

Forest resource monitoring encompasses the management of forest resources and the quantification of carbon sinks. The annual work for the "one map" approach to forest resource management involves establishing a comprehensive enforcement and monitoring regulatory system that combines remote sensing techniques with on-the-ground verification. This system establishes a normalized mechanism for forest resource monitoring and law enforcement, which is characterized by a tiered responsibility structure, vertical and horizontal linkage, and a collective management approach. It enables the timely detection of illegal activities that damage forest resources, thereby protecting and developing these resources. The national intelligent forest resource monitoring and digital management platform, based on the "one map" of forest resource management, consolidates and integrates business data from various years, including remote sensing imagery, forest resource inventories, and forestland updates, into an open and shared national database for forest resources. Following the model of "1 platform + N business applications," it has developed business application systems for forest monitoring and evaluation, forest supervision and management, public welfare forest management, and natural forest conservation management. These systems allow for online, timely updates of data, enabling regularized supervision, digital operation, and intelligent management. (Tian et al, 2020) The national forestry carbon sink measurement and monitoring system, which regularly provides reliable and authoritative carbon sink measurement and monitoring data, is composed of four regional forestry carbon sink measurement and monitoring centers: East China, Central South, Northwest, and Southwest. The first national forestry carbon sink measurement and monitoring achievement report has been completed. (Li, 2019)

It can be observed that the responsibility for forest resource monitoring was primarily within the forestry sector and, after many years of development, has formed a relatively independent and systematic monitoring system. Following the restructuring of institutions and the proposal of unified investigation and monitoring of natural resources, forest resource monitoring still needs to better integrate with other resource monitoring efforts.

3.4 Grassland Resource Monitoring

National grassland monitoring primarily focuses on key surveillance of grassland resources, ecology, vegetation, productivity, utilization status, and disaster conditions. Since 2005, monitoring has been conducted annually, and a national grassland monitoring report is published each year. The "Several Opinions on Strengthening the Protection and Restoration of Grasslands" issued by the General Office of the State Council in 2021 calls for the enhancement of grassland monitoring network construction. It advocates for the full utilization of data resources such as remote sensing satellites to establish an integrated space-ground-sky grassland monitoring network and to strengthen dynamic monitoring of grasslands. The document also calls for the improvement of the data exchange, regular release, and information sharing mechanisms for grassland monitoring and evaluation. (The General Office of the State Council, 2021) After 2018, the function of grassland resource monitoring was transferred from the agricultural departments to the forestry and grassland departments and the natural resources departments. A unified grassland monitoring standard system and work mechanism are currently being formulated.

Overall, the construction of the grassland resource monitoring system in China started late and has developed slowly, with relatively lagging technology.

3.5 Water Resource Monitoring

Water resource monitoring is spatially divided into surface water monitoring and groundwater monitoring, and by type, it is categorized into water environment monitoring and hydrological monitoring. The national surface water quality automatic monitoring system, composed of a network center and water quality automatic monitoring substations, has established 100 automatic water quality monitoring stations at key locations such as provincial boundaries of important rivers, the mouths of significant tributaries, and estuaries. These stations conduct real-time monitoring and remote surveillance of water quality, and provide early warnings for major or regional water quality contamination incidents. (Huang, 2019) The national surface water environmental quality monitoring network, during the "Fourteenth Five-Year" period, will deploy 3,646 national control sections across the country, covering the main streams and major tributaries of important basins nationwide. It will monitor according to the "9+X" approach, which includes nine basic indicators such as water temperature, pH, turbidity, conductivity, dissolved oxygen, ammonia nitrogen, permanganate index, total phosphorus, and total nitrogen, along with dynamically adjusted indicators. It also integrates data from the water environmental quality monitoring network and the water function zone monitoring network. (Xia, 2019) The national groundwater monitoring project, co-built by the Ministry of Natural Resources and the Ministry of Water Resources, utilizes the Internet of Things and Beidou communication, big data, and cloud computing technologies. It has established a comprehensive groundwater monitoring network that covers major plains and basins across the country and some ecologically fragile areas, with 67,000 monitoring sites and a monitoring area of 400,000 square kilometers. For the first time, a national three-dimensional automatic groundwater monitoring network has been constructed, and a multi-level data sharing and remote collaborative work model has been established between the national, provincial, and city-county levels. (Liu et al., 2020) The small and medium-sized river hydrological monitoring system has seen the construction and renovation of 38,867 hydrological stations, 408 hydrological information center stations, 229 hydrological patrol bases, as well as the establishment of 39 hydrological emergency monitoring teams and the construction of flood warning and forecasting software systems for 5,186 rivers.

It can be observed that before the institutional reform, the functions of water resource monitoring were scattered across various departments. The monitoring of surface water and groundwater alone involved the Ministry of Water Resources, the Ministry of Environmental Protection, and the Ministry of Land and Resources. The situation of "multiple authorities managing water" has to some extent hindered the construction and development of the water resource monitoring system.

3.6 Wetland Resource Monitoring

Wetland resource monitoring currently focuses on various special topics such as urban wetlands, mangroves, and ecology. The annual dynamic monitoring of internationally important wetlands involves observing the ecological characteristics and influencing factors of wetlands. To date, 39 wetland ecosystem observation and research stations have been established, and local ecological monitoring stations have been set up in key areas, including some internationally important wetlands. Since 2018, annual dynamic monitoring has been implemented for 56 internationally important wetlands, and the "White Paper on the Ecological Status of Internationally Important Wetlands in China" has been published. For urban wetland monitoring, the Ministry of Housing and Urban-Rural Development has incorporated urban wetlands into strict management under the urban blue line and green line, while also promoting the protection and restoration of urban wetlands in conjunction with the construction of sponge cities and the management of black and odorous water bodies. Dynamic monitoring of mangroves was initiated by the Ministry of Natural Resources in 2020 for mangrove forests with a canopy density of not less than 0.2, revealing an overall expansion with some local reductions in the distribution range of mangroves across the country. Wetland ecological dynamic monitoring involves continuous or seasonal dynamic monitoring of changes in wetland ecological resources and environmental elements, measuring the spatiotemporal patterns of change in the structure and function of wetland ecosystems. (Feng et al., 2021)

In summary, the management of wetland resources in China is still in its early stages, with significant room for development in terms of technical standards, funding, and team building.

3.7 Marine Resource Monitoring

Marine resource monitoring can be divided into coastal monitoring and global monitoring. The National Coastal Marine Environmental Monitoring Network primarily conducts water quality monitoring, with a secondary focus on sediment monitoring. It is progressively expanding to include monitoring of marine biology, ecology, and the total amount of pollutants entering the sea. The network has achieved routine monitoring of the total amount of land-source pollutants entering the sea, standardized monitoring of the coastal marine environment, rapid monitoring of sudden pollution incidents in coastal areas, and integrated monitoring of land-source pollution and marine environmental conditions. The Offshore Marine Observation and Research Network includes four newly established observation and research stations by the Chinese Academy of Sciences, three existing national coastal ecological environment monitoring stations, and transect surveys of offshore open voyages. It has achieved multi-element synchronous observation that combines points, lines, and surfaces, providing real-time data for marine environmental forecasting and disaster early warning. The National Global Ocean Observing Network, with its core being the national and local basic marine observation networks, collects data on marine space, environment, ecology, and resources to achieve high-density, multi-element, all-weather, and fully automatic global ocean three-dimensional observation. This aids in marine monitoring work such as marine ecological early warning. In 2019, 204 observation sites in seven coastal provinces (cities) were included as the first batch of local marine observation sites in the network. (Wu et al., 2020)

Overall, with the introduction of the strategy to become a strong maritime nation, the construction of the National Global Ocean Observing Network is accelerating. However, due to limitations in technology and funding, as well as actual management needs, current marine resource monitoring is more focused on coastal areas. There is still a significant gap in financial investment and technological level compared to maritime powers such as the United States and Norway.

4. Current Issues

4.1 Inconsistency in Natural Resource Classification Standards Leads to Data Conflicting

For a long time, there has been no consensus on the classification of natural resources among academic, legal, and administrative management sectors. Relevant departments have established their own working bodies and set monitoring standards for natural resource monitoring according to their management functions. For instance, the scope of wetlands managed by different departments is inconsistent. The National Forestry and Grassland Administration refers to the broad definition of wetlands in the "International Convention on Wetlands," which includes river and lake shores and nearby tidal flats, overlapping with the management of the water resources and maritime departments. In contrast, the Ministry of Natural Resources, considering the practical situation of land management, defines wetlands in the third national land survey as: "mangrove land, natural or artificial, permanent or intermittent swamps, peatlands, salt fields, tidal flats, etc." At present, the monitoring standards for wetland resources are mainly formulated based on their own management needs, without a unified technical specification. The Ministry of Natural Resources is in the process of constructing a unified wetland survey and monitoring standard system, having only preliminarily compiled technical specifications for special wetland surveys. Similarly, the definition of forestland varies between different departments. The "National Technical Regulations for Continuous Forest Resource Inventory" includes not only land where trees, bamboo, and shrubs grow but also land that has failed to be afforested, planned for afforestation, and other suitable land that does not have trees growing on it, which is inconsistent with the definition of forestland in the third national land survey as "land where trees, bamboo, and shrubs grow." As a result, data obtained from different monitoring networks exhibit issues such as gaps, overlaps, conceptual inconsistencies, and contradictory indicators. The data outcomes cannot be effectively coordinated and used, failing to form an effective monitoring system, which hinders the progress of systematic governance of mountain, water, forest, farmland, lake, and grassland ecosystems.

4.2 Inconsistency in Monitoring Technical Standards Hinders Integrated Management and Application of Data

From a practical application perspective, the technical standards used by various monitoring networks are not uniform, leading to issues where the same monitoring content may have different monitoring standards. For example, in the case of remote sensing monitoring of land use, the dynamic remote sensing monitoring of land use primarily follows the "Technical Specification for Dynamic Remote Sensing Monitoring of Land Use" (TD/T 1010-2015), while the monitoring of geographical conditions is based on the "Basic Statistical Technical Specification for Geographical Condition Monitoring" (20170310-T-466). The use of different remote sensing image base maps results in inconsistent monitoring resolutions and measurement accuracies. In the monitoring of arable land quality, the Ministry of Agriculture and Rural Affairs mainly relies on the "Technical Specification for Arable Land Quality Monitoring," whereas the Ministry of Natural Resources primarily uses the "Technical Specification for the Quality Grading of Agricultural Land." The criteria for the grading and evaluation of arable land differ between these departments. Regarding water environment monitoring standards, the Ministry of Water Resources adheres to the "Water Environment Monitoring Standards," while the

Ministry of Ecology and Environment follows the "Technical Specification for Surface Water and Wastewater Monitoring," and the "Technical Specification for Groundwater Environmental Monitoring." The use of different technical standards leads to discrepancies in the outcomes of similar data obtained from different monitoring networks, preventing their integrated management and application. This also results in the redundant collection of similar categories of data, reducing work efficiency and leading to financial waste.

4.3 Insufficient Application of High-Tech Leads to Room for Improvement in Monitoring Standards

The current level of automation and intelligence in survey and monitoring is inadequate, necessitating a significant expenditure of human, material, and financial resources. The technological levels employed by different monitoring networks are uneven, and some networks, due to technical limitations, lack higher monitoring accuracy and automated monitoring methods. This necessitates the continuous investment of additional human resources to complete monitoring tasks. For instance, the efficiency of accurately extracting remote sensing monitoring targets remains to be enhanced, with manual visual interpretation still being the primary method. There is a need for further research and development and application of automated high-precision extraction technology for remote sensing image information. Additionally, in water resource monitoring, the application of IoT technology is not fully utilized, and continuous automatic monitoring of water resources has not yet been widely implemented. Many old monitoring sites have not been updated with new equipment; in the national control sections of surface water, the vast majority of sites still rely on manual sampling for monitoring. Accelerating the widespread application of high-tech in natural resource monitoring, improving monitoring accuracy and efficiency, and promoting the construction of an intelligent natural resource monitoring system are urgent priorities.

4.4 Lack of Interconnectivity Among Monitoring Networks and the Urgent Need for a Unified Monitoring System

As can be seen from the previous context, the current natural resource monitoring is primarily focused on individual resource types and has not yet formed a unified monitoring system that effectively integrates various resource categories. The construction of data sharing mechanisms and platforms is still incomplete, and a seamless interconnected monitoring system has not been established. This creates barriers to interconnectivity and smooth communication among monitoring networks of various departments, preventing the effective integration and sharing of monitoring data. Consequently, issues such as "information silos" and "data barriers" arise, making it difficult to effectively apply monitoring outcomes in management operations and significantly reducing the effective utilization of monitoring results. For example, forest resource monitoring and land resource monitoring have developed rich data outcomes over time, but due to issues between departments, it remains challenging to deeply integrate the two sets of data and apply them. Relevant laws and regulations in China have stipulated the sharing of monitoring data, but there are still significant obstacles in the implementation process. For instance, the "Water Law" and the "Marine Environmental Protection Law" provide for the sharing of water resource monitoring data, but in actual work, there are substantial data barriers between departments.

5. Recommendations

The development and construction of a natural resource monitoring system require a multifaceted approach and strategic planning across various levels. At the policy level, it is essential to develop a top-level plan and introduce guiding overall plans; at the execution level, it is necessary to coordinate and advance uniformly, standardizing classification and technical standards, and clarifying the responsibilities and boundaries of all parties and levels; at the technical level, it is crucial to fully utilize high-tech to enhance the level of automation and intelligence; at the data level, it is important to manage the acquisition, processing, management, and application of multi-source and heterogeneous monitoring data; at the platform level, it is advisable to apply advanced information technology to manage, mine, analyze, display, and share data resources.

5.1 Construct a 1+N Monitoring System

Aim to serve national production and ecological protection and restoration as the guiding principle, and take the "Overall Plan for the Construction of the Natural Resources Survey and Monitoring System" as the main reference. Consider the development of related technologies and the current status of policy implementation to build a "1+N" natural resource monitoring system. This system uses the results of national land change surveys as the baseline data, unifies the accuracy of temporal and spatial scales, and includes comprehensive remote sensing monitoring as the "1" routine monitoring, and thematic monitoring such as element monitoring, regional monitoring, and emergency monitoring as the "N" specialized monitoring. Among them, the results of national land change surveys serve as the baseline data, which are updated annually based on the results of the "Third National Land Survey" to ensure the annual temporal accuracy of the baseline data and maintain its basic stability. Comprehensive remote sensing monitoring should integrate existing national routine remote sensing monitoring and gradually incorporate new satellite remote sensing image results to achieve quarterly temporal accuracy, ensuring the effectiveness of the data. Thematic monitoring should focus on monitoring land, minerals, forests, grasslands, water, wetlands, oceans, and ecological elements, considering the coupling of natural elements such as forests and grasslands, as well as wetlands and oceans, and clarify the monitoring results' temporal update frequency based on the characteristics of the elements and actual needs. Regional monitoring should be based on the national regional development strategy layout, focusing on key areas such as urban clusters, nature reserves, and major grain-producing areas, deploying corresponding monitoring networks and constructing corresponding monitoring indicator systems according to different emphases on production, living, and ecology, thus achieving categorized regional monitoring objectives. Emergency monitoring should assess high-risk disaster areas and corresponding high-incidence times of disasters, deploy corresponding monitoring facilities in advance, emphasize the timeliness and reliability of monitoring results, and ensure rapid acquisition, transmission, processing, and provision of monitoring results.

5.2 Unify Standards and Coordinate Multi-Level and Multi-Category Monitoring Mechanisms

Only by integrating and forming a comprehensive monitoring system that covers multiple categories such as mountains, waters, forests, farmlands, lakes, grasslands, deserts, and seas, as well as multiple levels including the national, provincial, municipal, and county levels, can the transformation of natural resource monitoring from decentralized governance to integrated management be achieved. This involves the implementation and promotion of various aspects such as standard systems and organizational models. The first step is to implement a universal standard system, unify the classification standards of natural resources, integrate existing indicator systems, and maximize the integration of data between different monitoring systems to ensure that resource data is neither duplicated nor omitted. Unify the technical standards for natural resource monitoring, construct a full-process technical system for multi-source data acquisition, processing, quality inspection, management, and analysis, clarify the content of monitoring indicators, and reduce redundant monitoring. The second step is to clarify the division of labor among various levels of departments according to the division of responsibilities between the central and local governments, establish a hierarchical monitoring mechanism, coordinate and divide monitoring tasks, reorganize and reconstruct the business system, establish a national-provincial-municipal-county four-level organizational model with clear responsibilities for each resource category, clarify the task list and key tasks at each level, and appropriately guide social forces to participate, encourage localities to carry out pilot studies according to local conditions, and promote replicable and mature practices.

5.3 Improve the Intelligence Level of Monitoring

Fully utilize modern digital technologies such as remote sensing, artificial intelligence, Internet+, IoT, cloud computing, and big data to comprehensively enhance the intelligence level of each link in data acquisition, processing, management, and application, thereby improving the modernization level of natural resource monitoring. In the data acquisition phase, build a coordinated air-sky-ground-sea monitoring network, comprehensively apply satellite remote sensing data such as optical, hyperspectral, SAR, gravity, and laser altimetry, aerial photography data from aircraft, high-altitude tethered balloons, and low-altitude drones, land observation data from IoT, observation stations, vehicle-mounted measurements, and mobile terminals, marine monitoring data from marine stations, floats, coastal radar, and deep-sea observations, and crowd-sourced information from web crawlers, mobile signalling, and public opinion monitoring to form a full-space, full-element, all-weather, and full-scale natural resource data coordinated monitoring capability. In the data processing phase, set up distributed big data processing centers, apply artificial intelligence technology to construct automated and semi-automated pre-processing flows for massive multi-source heterogeneous data, achieving information filtering, screening, and classification; build in business statistics modules to manage and summarize indicator information in real-time, reducing manual processing workload and enhancing the timeliness of monitoring data. In the data management phase, apply cloud computing technology to store and manage PB-level data, achieving millisecond-level response for massive data; apply 5G, IoT, and other information technologies to achieve fast and secure information transmission; use spatial data intelligent retrieval technology to efficiently extract and utilize data; establish data firewalls to ensure data security. In the data application phase, use big data mining technology to quickly discover and intelligently extract key information; integrate various spatiotemporal analysis models to meet the personalized analysis needs of different businesses; apply spatiotemporal visualization technology to quickly generate reports and charts to support the evaluation and management of natural resources.

5.4 Strengthen the Capability of Acquiring Multi-Source Spatiotemporal Data and Standardize the Management Process of Spatial Big Data

Build an integrated air-sky-ground-sea monitoring network to obtain multi-source data such as aerial satellite remote sensing data, aerial drone photography data, terrestrial IoT monitoring data, and marine fixed and mobile monitoring station data. Break down barriers to temporal data sharing, fully utilize past historical data, current real-time data, and future trend evolution data to form spatiotemporal spectral data, thereby forging a fully capable and efficient monitoring data collaborative acquisition capability. And take the national basic geographic database as the spatial positioning framework, and use the "three surveys" and annual change survey data of the land as the "base version." Use spatial location, semantic relationships, deep learning, and other means to fuse multi-source heterogeneous data, and distribute, store, and manage multi-source, multi-scale, multi-temporal, high-precision, and high-frequency monitoring big data.

5.5 Build an Information Sharing Platform to Enhance Data Service Capabilities

Utilize information technologies such as cloud computing, big data, artificial intelligence, and machine deep learning to build a natural resource monitoring data information platform for managing, mining, analyzing, displaying, and sharing data resources. Construct a spatial data search engine to achieve real-time access and rapid retrieval of monitoring data; intelligently extract effective management information through big data mining for high-precision information extraction and reliable parameter inversion, achieving emergency early warning and decision support; apply spatiotemporal statistical analysis model methods, according to the indicator system, to analyze and evaluate natural resources; pay attention to the visualization expression and comprehensive display of various monitoring data; design a multi-permission data exchange mode to ensure data security while ensuring smooth data circulation. Thus, achieving data that is easy to find, manage, view, and use, ultimately leveraging the value of monitoring data resources and achieving effective utilization and instant sharing of data.

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