Postprint: Construction of a Comprehensive Observation Network for Natural Resource Elements in the Heihe River Basin Based on Space-Air-Ground Integration

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Abstract

In response to new requirements for natural resource management, the comprehensive observation network project for national natural resource elements was fully launched and constructed in 2020. As the second largest inland river basin in Northwest China and located in the core area of the Silk Road Economic Belt, there is an urgent need to conduct pilot studies in the Heihe River Basin. Relying on the existing observation and research foundation in the Heihe River Basin, 13 observation stations were deployed at different watershed scales and levels through three methods: integrated co-construction, renovation and upgrading, and new construction in blank areas, basically covering the main surface resource types in the Heihe River Basin, including grassland, forest, river, lake, desert, wetland, and farmland. Combined with remote sensing observations and manual sample plot surveys, a comprehensive observation network for natural resource elements in the Heihe River Basin has been preliminarily established. Through the establishment of a unified operation, maintenance, and quality management system, the authenticity and reliability of observation data are ensured. In terms of application effectiveness, the comprehensive observation network for natural resource elements in the Heihe River Basin has basically formed a three-dimensional observation capability with local control, which can effectively obtain key data such as coupling processes between resources, change trends, and rates. This is of great significance for improving the understanding, scientific management, and strategic decision-making of natural resources in the Heihe River Basin, and also has important reference and demonstration significance for conducting natural resource observation research in other river basins.

Full Text

Construction of a Comprehensive Observation Network for Natural Resource Elements in the Heihe River Basin Based on Space-Air-Ground Integration

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Abstract

In response to new requirements for natural resource management in China, the National Natural Resource Elements Comprehensive Observation Network Project was fully launched in 2020. The Heihe River Basin, as the second largest inland river basin in northwestern China and a core area of the Silk Road Economic Belt, urgently requires pilot research. Leveraging existing observation and research infrastructure in the Heihe River Basin, we established 13 observation stations across different sub-basins and levels through three approaches: integrated co-construction, reconstruction and upgrading, and new installations in previously unmonitored areas. This network essentially covers the main land surface resource types in the Heihe River Basin, including grassland, forest, river, lake, desert, wetland, and farmland. By integrating remote sensing observations with artificial sample plot investigations, we have preliminarily constructed a comprehensive observation network for natural resource elements in the Heihe River Basin. A unified operation, maintenance, and quality management system ensures the authenticity and reliability of observation data. The network has developed localized three-dimensional observation capabilities that effectively capture critical data on coupling processes, change trends, and rates among resources. This is of great significance for improving understanding, scientific management, and strategic decision-making regarding natural resources in the Heihe River Basin, and provides an important reference and demonstration for natural resource observation research in other basins.

Keywords: Heihe River Basin; natural resources management; space-air-ground integrated observation; field observation stations; comprehensive observation network

1.1 Study Area Overview

The Heihe River Basin is located between 37°42 -42°42 N and 97°06 -102°00 E in the arid and semi-arid regions of western China. As the second largest inland river basin in China, it covers an area of approximately 14.3$\times10^{4}$ km^2. The river originates from the middle section of the Qilian Mountains and extends 821 km from its source to Juyan Lake. The entire basin forms a diverse natural resource landscape of "glacier-forest-grassland-desert-oasis-wetland-Gobi" linked by water. The basin features coexisting cold and arid regions, with stark contrasts between the cryosphere in mountainous areas and the extremely dry river terminal regions, exhibiting typical natural landscape characteristics across upper, middle, and lower reaches [Figure 1: see original paper]. With a long history of development, human activities have significantly influenced the basin' s hydrological environment, as agricultural development and reclamation are intimately connected to water resources. The convergence of natural and human processes makes the Heihe River Basin an ideal pilot site for comprehensive watershed research.

1.2 Previous Research Foundation

Multiple research teams have established numerous field observation stations/networks in the Heihe River Basin according to their specific research needs [10-11,15], covering meteorology, hydrology, forestry, and other ecological fields . Currently, the largest and most comprehensive observation network is the Heihe Watershed Surface Process Comprehensive Observation Network, which is also China' s first multi-element, multi-scale, refined watershed comprehensive observation system, primarily including hydrometeorological observation networks, eco-hydrological sensor networks, and satellite remote sensing [12]. The network now operates 20 observation stations, essentially covering the main underlying surface types in the Heihe River Basin [Figure 2: see original paper], providing an excellent foundation for constructing the natural resource elements comprehensive observation network.

1.3 Main Problems with Existing Stations

In response to China' s new natural resource management requirements, comprehensive observation of all natural resource elements in the Heihe River Basin faces several challenges with existing stations: (1) Current observation stations/networks belong to multiple departments and units, lacking systematic top-level design and integrated planning, data integration, and sharing mechanisms; (2) Although the Heihe River Basin has large comprehensive observation stations/networks, they exhibit uneven station distribution, inconsistent observation data, and incomplete observation indicators for natural resource element observation research, making it difficult to systematically support data acquisition for all natural resource elements; (3) Existing stations/networks are primarily oriented toward scientific questions, focusing on specific ecosystem processes or environmental problems, and lack operational observation research for multi-scale, all-element natural resource elements, making it difficult to serve natural resource management needs in the Heihe River Basin.

2.1 Overall Approach

Adhering to the "mountain-river-forest-farmland-lake-grassland" life community concept and the construction principles of "innovative mechanisms, coordinated organizations, green co-construction, open cooperation, and data sharing," we aim to build a natural resource elements comprehensive observation network in the Heihe River Basin oriented toward natural resource problems and management needs. The approach emphasizes uniting existing observation and research forces in the Heihe River Basin, exploring cooperative mechanisms that complement each other, collaborate, and share resources, and fully utilizing existing observation infrastructure. We select and construct scientifically representative observation sites, explore multiple station construction models, and optimize the observation network. Standardization is prioritized to unify observation technologies, indicators, operation and maintenance, and quality control systems, forming a natural resource comprehensive observation quality management system that ensures data precision and quality to provide scientific data support for natural resource management in the Heihe River Basin.

2.2 Construction Objectives

Following a systematic planning, priority-first, step-by-step implementation approach, and considering existing observation station/network foundations, natural resource zoning units, and economic costs, we gradually construct a natural resource elements comprehensive observation network in the Heihe River Basin with a complete observation system, reasonable station network layout, and basically stable operation through multiple methods including integration, co-construction, reconstruction, and self-construction. The ultimate goal is to form multi-scale, all-weather, all-element space-air-ground three-dimensional observation capabilities covering the Heihe River Basin. By producing long-term, continuous scientific data for the Heihe River Basin, we aim to reveal key mechanisms of interaction among natural resource elements, analyze and predict natural resource development trends, and provide high-quality data support and scientific supply for natural resource management in the Heihe River Basin.

2.3 Specific Deployment

Following the natural resource zonal patterns in the Heihe River Basin and using environmental types from resource zoning as units [16], we deployed observation stations through three approaches: integrated co-construction, upgrading and reconstruction, and gap filling. A total of 13 observation stations were established across different basins and levels, essentially covering the main surface resource types in the Heihe River Basin, including grassland, forest, river, lake, desert, wetland, and farmland. Based on these 13 stations, we conduct collaborative observations using aerospace and UAV remote sensing combined with artificial sample plot surveys, enabling mutual comparison, validation, and integration of data to obtain high-quality natural resource elements observation datasets.

2.3.1 Station Observation Following unified observation specifications and technical standards, we integrated and co-constructed 4 stations, upgraded and reconstructed 5 stations, and newly built 4 stations in previously unmonitored areas. In terms of underlying surface types, the upper reaches are primarily characterized by alpine meadow and forest, the middle reaches by desert, farmland, and wetland, and the lower reaches by desert, oasis, and wetland. The station layout essentially covers the main underlying surface resource types across the entire Heihe River Basin .

From a basin distribution perspective, 5 observation stations are deployed in the upper reaches, 4 in the middle reaches, and 4 in the lower reaches, with one secondary station in each basin section [Figure 2: see original paper] and the remainder being tertiary stations [Figure 3: see original paper]. This hierarchical and graded joint observation maximizes station utility while controlling costs [17]. Secondary stations mainly consist of multi-scale surface flux and soil moisture observation systems (lysimeters, eddy covariance systems, scintillometers, soil moisture sensors, cosmic-ray soil moisture probes, wireless soil temperature and moisture sensor networks, etc.), hydrometeorological element observation systems (wind-temperature-humidity profiles, air pressure, precipitation, soil temperature and moisture profiles, four-component radiation, photosynthetically active radiation, soil heat flux, surface radiation temperature, average soil temperature, regional soil moisture, groundwater level, etc.), and vegetation observation systems (phenology, vegetation coverage, leaf area index, reflectance spectra, chlorophyll fluorescence, etc.). Tertiary stations mainly consist of eddy covariance systems and hydrometeorological observation systems (wind-temperature-humidity-pressure, precipitation, soil temperature and moisture profiles, four-component radiation, photosynthetically active radiation, soil heat flux, surface radiation temperature, groundwater level, etc.) and vegetation observation systems (phenology, vegetation coverage).

2.3.2 Remote Sensing Observation Satellite remote sensing observation primarily includes UAV, high-resolution satellite, and medium-high resolution satellite observations. Using long time-series medium-high resolution satellite remote sensing data, high-resolution satellite data, and detailed UAV monitoring data, we integrate and assimilate ground observation data to generate medium-high resolution long time-series dynamic natural resource multi-element remote sensing products for the Heihe River Basin, enabling long-term, dynamic monitoring of regional natural resources [10-11,21]. Main natural resource remote sensing products include: basic elements [land cover/use, digital elevation model (DEM)], vegetation elements (vegetation coverage, leaf area index, vegetation primary productivity, normalized difference vegetation index, grassland biomass, forest stock volume, etc.), hydrological elements (glacier distribution, water body index, soil moisture, surface evapotranspiration, etc.), and spatial distribution and area of resource elements including forest, grassland, farmland, and desert.

2.3.3 Sample Plot Investigation Based on integrated station/network construction, sample plot investigations and sampling analyses are conducted for water, soil, and vegetation resources to supplement parameters difficult to obtain through station and remote sensing observations [22]. Water resource investigation mainly includes surface and groundwater quality, quantity, and physicochemical properties. Soil resource investigation mainly includes land use/cover, soil physicochemical properties, soil fertility, farmland area and quality, and yield. Vegetation resource investigation mainly includes phenology, leaf area index, grassland vegetation coverage and productivity, and forest stock volume [Figure 4: see original paper].

3.1 Observation Standards and Specifications

Technical standards and specifications are fundamental guarantees for standardized construction and scientific operation of field observation stations and are critical for ensuring data quality. Based on domestic field observation station construction standards and specifications and the actual conditions of the natural resource elements comprehensive observation network, we have preliminarily established a natural resource elements standard specification system. This includes the "Natural Resource Elements Comprehensive Observation Technical Specification," "Natural Resource Elements Comprehensive Observation Project Budget Standard," "Natural Resource Elements Comprehensive Observation Data Fusion Procedure," "Natural Resource Elements Comprehensive Observation Data Standard," "Natural Resource Elements Comprehensive Observation Data Collection Guide," and "Natural Resource Elements Comprehensive Observation Station Management Measures" (six standard specification drafts).

3.2 Observation Indicator System

Natural resource elements comprehensive observation employs multiple observation techniques including station observation, remote sensing observation, and artificial sample plot investigation, effectively addressing differentiated precision requirements across temporal and spatial scales. A systematic observation indicator system is the premise and foundation for natural resource observation. Based on fundamental principles for establishing natural resource elements comprehensive observation indicator systems and indicator selection, and using forward and inverse modeling combined with modular combination methods [18], we screen, integrate, and design reasonable observation indicators around natural resource quantity, quality, and interactions . This system can be effectively applied in multi-scale three-dimensional comprehensive observation, addressing compatibility challenges in natural resource elements comprehensive observation data application.

3.3 Operation and Maintenance System

Developing a detailed operation and maintenance system and process is fundamental for achieving long-term stable operation of observation stations. We train professional operation and maintenance management teams to maintain observation instruments at daily, ten-day, monthly, and annual scales [Figure 5: see original paper]. Daily tasks include browsing real-time transmitted observation data from stations, checking data continuity and stability, and monitoring instrument conditions and operational status through surveillance equipment. Every ten days, continuous data variation plots generated by the system must be reviewed to check for persistent anomalous values. Monthly tasks require operation and maintenance technicians to conduct on-site inspections, including field data collection, equipment testing, sensor cleaning, site photography, and recording vegetation phenology and underlying surface conditions. Annually, data from the previous year must be preprocessed and checked, while comprehensive equipment inspection and calibration are required in spring and autumn (vegetation growth and dormancy periods) [19].

3.4 Quality Control System

Integrating remote sensing observation, station observation, and ground survey data with unified standard specifications, precision requirements, and data formats, we establish observation data processing and quality control procedures [20] to implement automatic, semi-automatic, and manual quality control modes. This constructs a full-process observation station management system based on observation technology, instrument calibration, and operation and maintenance. Through data verification and quality analysis at the Heihe River Basin Observation Data Processing Center, we ensure observation data are accurate, standardized, and complete, producing high-quality natural resource elements observation datasets for the Heihe River Basin. These datasets are then submitted to the National Natural Resources Comprehensive Observation Integration Platform [21] for online management and terminal sharing services [Figure 6: see original paper].

4 Cases and Effectiveness

Through remote sensing observation, we obtained distribution ranges and spatial location information of natural resource elements within 5 km of five stations (A' rou, Dashalong, Huazhaizi, Daman, and Sidaoqiao). Combined with automatic observations at these stations and artificial surveys of typical sample plots, we effectively acquired information on natural resource element types, quantities, and quality [Figure 7: see original paper] [Figure 8: see original paper]. The results demonstrate that through reasonable station deployment combined with remote sensing observation and other technical methods, we can effectively obtain key information on spatial distribution, types, quantities, and quality of multiple natural resource elements. The constructed natural resource elements comprehensive observation network has initially formed localized space-air-ground three-dimensional observation capabilities.

5 Conclusions

Through extensive cooperation with the Northwest Institute of Eco-Environment and Resources, Beijing Normal University, and Lanzhou University, and utilizing existing observation infrastructure in the Heihe River Basin, we constructed 13 observation stations through integrated co-construction, upgrading and reconstruction, and gap filling. Combined with remote sensing observation and artificial sample plot investigation, we preliminarily established a natural resource elements comprehensive observation network in the Heihe River Basin that has basically formed localized three-dimensional observation capabilities. However, natural resource elements comprehensive observation is a long-term and exploratory systematic construction project involving station construction, funding guarantees, operation and maintenance, quality control, and other aspects. To achieve full network operation, we recommend strengthening the following aspects:

1) Enhance organizational leadership, establish and improve organizational structures, coordinate observation network system construction, and ensure scientific station operation and management.
2) Explore cooperation mechanisms, break industry barriers, and extensively develop cooperative station construction and data sharing with existing observation stations. Establish long-term cooperation mechanisms with agriculture, forestry, animal husbandry, and other relevant departments to promote market-oriented services across social sectors.
3) Secure stable funding by establishing a diversified funding guarantee system. Establish special funds for the observation network and actively explore social capital investment mechanisms.
4) Create scientific and technological innovation platforms such as key laboratories, strengthen talent cultivation, and conduct cross-departmental, cross-disciplinary, and cross-disciplinary scientific research to provide scientific support for solving major resource and environmental problems in the Heihe River Basin region.

References

[1] Wu Guoxiong, Zheng Du, Yin Weilun, et al. Insights: Building a national comprehensive observation system of natural resource elements from the perspective of multidisciplinary integration[J]. Resources Science, 2020, 42(10): 1839-1848.

[2] Yan Jingxin, Yin Xiaoqing, Chen Jun, et al. Analysis of the developments of

standards for natural resources investigation and monitoring[J]. Standardization of Surveying and Mapping, 2019, 35(4): 1-4.

[3] Shen Lei, Zhang Hongli, Zhong Shuai, et al. Strategic thinking on the security of natural resources of China in the new era[J]. Journal of Natural Resources, 2018, 33(5): 721-734.

[4] Li Xin, Cheng Guodong. On the watershed observing and modeling systems[J]. Advances in Earth Science, 2008, 23(7): 756-764.

[5] Cheng Guodong, Li Xin. Integrated research methods in watershed science[J]. Science China: Earth Sciences, 2015, 45(6): 811-819.

[6] Jiang Enhui, Wang Yuanjian, Tian Shimin, et al. Exploration of watershed system science[J]. Journal of Hydraulic Engineering, 2020, 51(9): 1026-1037.

[7] Liu S M, Xu Z W, Wang W Z, et al. A comparison of eddy covariance and large aperture scintillometer measurements with respect to the energy balance problem[J]. Hydrology and Earth System Sciences, 2011, 15(4): 1291-1306.

[8] Li X, Li X W, Li Z Y, et al. Watershed allied telemetry experimental research[J]. Journal of Geophysical Research: Atmospheres, 2012, 114(19): 2191-2196.

[9] Li X, Cheng G D, Liu S M, et al. Heihe watershed allied telemetry experimental research (HiWATER): Scientific objectives and experimental design[J]. Bulletin of the American Meteorological Society, 2013, 94(8): 1145-1160.

[10] Li Xin, Ma Mingguo, Wang Jian, et al. Simultaneous remote sensing and ground based experiment in the Heihe River Basin: Scientific objectives and experiment design[J]. Advances in Earth Science, 2008, 23(9): 987-914.

[11] Li Xin, Liu Shaomin, Ma Mingguo, et al. HiWATER: An integrated remote sensing experiment on hydrological and ecological processes in the Heihe River Basin[J]. Advances in Earth Science, 2012, 27(5): 481-498.

[12] Xu Ziwei, Liu Shaomin, Che Tao, et al. Operation and maintenance and data quality control of the Heihe integrated observatory network[J]. Resources Science, 2020, 42(10): 1975-1986.

[13] Gao Chundong, He Honglin. Great importance should be attached to development potential of field scientific observation and research[J]. Bulletin of Chinese Academy of Sciences, 2019, 34(3): 344-348.

[14] Zheng Du, Ou Yang, Zhou Chenghu. Understanding of and thinking over geographical regionalization methodology[J]. Acta Geographica Sinica, 2008, 75(6): 563-573.

[15] Wang Jinfeng. The national natural resources comprehensive observation site layout report[R]. Beijing: Institute of Geographic Science and Nature Resources Research, Chinese Academy of Sciences, 2020.

[16] Li Qian. China will establish a unified survey and monitoring system for natural resources[J]. Land Resources, 2018, 35(8): 14-15.

[17] Zhang Yujie, Wang Ninglian, Yang Xuewen, et al. Dynamic monitoring of Balkhash Lake from 1970 to 2020 based on multi source remote sensing data[J]. Arid Land Geography, 2022, 45(2): 499-511.

[18] Yang Ping, Bai Yongfei, Song Changchun, et al. Construction of long term ecological research sites in field station: Status, progress and prospect[J]. Bulletin of Chinese Academy of Sciences, 2020, 35(1): 125-135.

[19] Lu Chengkuan. A comprehensive observation system for natural resource elements has been established[EB/OL]. [2020-06-01]. http://www.mnr.gov.cn/dt/mtsy/201912/t20191218_{2490

[20] Liu Xiaohuang, Liu Xiaojie, Cheng Shubo, et al. Construction of a national natural resources comprehensive observation system and key technologies[J]. Resources Science, 2020, 42(10): 1849-1859.

[21] Zhang He, Wang Shaoqiang, Wang Liang, et al. Discussion on the indicator system of comprehensive observation of nature resource elements[J]. Resources Science, 2020, 42(10): 1883-1899.

[22] Liu Jiufen, Gao Yang, Feng Xin, et al. Construction of the quality management system for comprehensive observation of natural resources[J]. Resources Science, 2020, 42(10): 1944-1952.

[23] Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences. Heihe Remote Sensing Experimental Research Station, Chinese Academy of Sciences[J]. Bulletin of Chinese Academy of Sciences, 2020, 35(11): 1424-1426.

[24] Sun Yi, Fang Mengyang, He Jianning, et al. Construction of a comprehensive observation platform for natural resource elements based on internet of things and open data processing service technology[J]. Resources Science, 2020, 42(10): 1965-1974.

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