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Performance Evaluation of Ecological Protection and Restoration Projects Based on the Nature-based Solutions Global Standard and Multi-source Data Fusion

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By combining nature-based solutions (NbS) global standards and Chinese engineering management paradigm, in this paper, we summarize the key points of the NbS criterion system in China's project management process. Integrating multi-source data (satellite remote sensing, project lifecycle governance checklist, social sensing, and ground-based sensing), we established a multi-level performance system for ecological protection and restoration projects under a Decision-making–Management–Output–Effectiveness framework. Validation using 140 national pilot projects in the Qilian Mountain area showed that the multi-source data evaluation system can effectively support performance assessment, monitoring, and the analysis of ecological protection. Lifecycle checklist indicators scored high, reflecting emphasis on fund use and traceable management; checklist, remote sensing, and ground sensor indicators showed satisfactory completion rates relative to national plans; social sensing indicators fell below 90%, indicating a need for greater public recognition. The lowest score—measure optimization and iteration—objectively reflected the slow uptake of NbS in China and revealed a planning-optimization workflow defect. In this paper, we highlight the value of mining remote-sensing-based ecological benefit indicators (e.g., water conservation) and advocate a small-scale, gradual approach to promoting NbS standards and ecological restoration practices.

1. Introduction

As a strategic goal and fundamental requirement of China, ecological civilization has been integrated into the five-in-one overall layout, gaining broad societal consensus.[1,2] The life community concept of mountains, rivers, forests, farmlands, lakes, and grasslands underpins ecological civilization and is a foundational principle of China's territorial spatial governance.[3–5]

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Since 2016, the Chinese government has planned and implemented the Mountain-River-Lake-Forest-Grassland Ecological Protection Project (hereafter referred to as the "Shanshui Project") from the perspective of maintaining ecosystem integrity. The Qilian Mountains Ecological Protection and Restoration Project (hereinafter referred to as the "pilot project") was designated as one of China's first pilot initiatives with its construction tasks completed by 2021. During the same period, nature-based solutions (NbS) have emerged as a prominent approach to addressing climate change and advancing sustainable development. The core principle of NbS involves employing nature-oriented methods to tackle global challenges such as poverty, food security, climate change, biodiversity loss, water scarcity, and land degradation.(6,7) In this context, evaluating the post-implementation performance of the Shanshui Project through the lens of NbS constitutes a critical and timely research endeavor.

Financial investment in China's ecological protection and restoration projects is dominated by public funds, and performance evaluation has become a critical component of the overall budget performance management and comprehensive project acceptance.(8–11) Performance is a multidimensional concept encompassing economy, efficiency, and effectiveness. It not only reflects the comparative relationship between resource inputs and outcomes achieved during implementation but also involves the rationality of resource allocation and the validity of results, covering two dimensions: behavioral processes and behavioral outcomes.

Existing studies have extensively explored project performance evaluation for single-target governance initiatives, including mine environmental governance,(12,13) vegetation restoration,(14,15) watershed water environment management,(16–18) desertification control, wetland protection, and soil and water conservation.(19–22) However, no unified standard exists for evaluation index systems, and most studies focus primarily on outcome evaluations—such as comparative analyses of economic, ecological, and social benefits post-implementation—while paying insufficient attention to process evaluations (e.g., approval procedures, fund disbursement rates, and management constraints) and quantitative output assessments. For the Qilian Mountains region, although numerous long-term sequential change analyses based on experimental data have been conducted, few studies have systematically evaluated the performance of the integrated mountain-river-lake-forest-grassland project as a whole.

A synthesis of the literature reveals three key shortcomings in current performance evaluations of ecological protection and restoration projects. First, evaluation content overwhelmingly emphasizes the compliance and legality of fund usage,(23) lacking assessments of project outputs and social benefits. Second, evaluations are predominantly "penalty-based" with indicators prioritizing qualitative over quantitative criteria, and inconsistent deduction items and standards. Third, source data for indicator scoring are inconsistent, introducing subjectivity into the assessment. Furthermore, multi-source data—including text, tables, databases, atlases, remote sensing, sensors, and social perception data—have been widely applied in ecological assessment, sustainable development, livability evaluation, and land use change analysis.(24–27) Findings indicate that the fusion of multi-source data enables accurate quantitative ecological analyses and can effectively support the performance evaluation of ecological protection and restoration projects.

In this study, we analyzed global NbS standards and established a performance evaluation index system based on multi-source data fusion. Taking a national-level pilot project as a case study, we evaluated the effectiveness of fund utilization comprehensively and objectively. The findings aim to provide a valuable reference for implementing performance evaluations of similar major projects in the future.

2. Study Area and Data Sources

2.1 Study area overview

The Qilian Mountains constitute a crucial ecological barrier in western China. In December 2016, the region was selected as one of China's first batch of pilot areas for ecological protection and restoration. The pilot project covers two prefecture-level cities and comprises 140 projects.

City A has implemented a total of 75 projects, consisting of 103 subprojects. These projects fall into 5 major categories and 12 subcategories, including mine ecological environment restoration and rehabilitation, high-standard farmland construction, ecological resettlement, comprehensive water environment management, watershed management and wetland protection, water conservation area protection, shelterbelt construction, characteristic economic forest base construction, desertification control, agricultural incentive and subsidy demonstration, comprehensive grassland management, and scientific research projects.

A total of 65 projects, with 83 subprojects in total, have been implemented in City B. These projects are classified into 5 major categories and 10 subcategories, specifically including mine ecological environment restoration and rehabilitation, the renovation of abandoned rural homesteads, ecological resettlement, comprehensive water environment treatment, comprehensive soil and water conservation, the protection of water conservation areas, shelterbelt construction, ecological management and wetland protection, closed hillsides for afforestation, and geological disaster control.

2.2 Data sources

The data adopted in this paper mainly fall into four categories.

2.2.1 Project lifecycle governance checklist data

Projects in China that are mainly funded by fiscal funds exhibit clear phased characteristics, which are generally divided into three stages: planning, implementation, and acceptance. In accordance with the whole process of project management, the management and control checklist data adopted in this paper mainly include the following: project implementation plans and approval documents, subproject approval documents, fund allocation documents, feasibility study reports, design reports, multi-level completion reports, acceptance reports, fund expenditure reports, and financial audit reports.

Since the departments involved and the formats of data vary across different stages, data cleaning was performed to extract key information from the whole-process data of individual projects. Finally, whole-process information data for 140 projects were constructed, with one record corresponding to each project. The data were stored in .xlsx and .accdb formats.

2.2.2 Social sensing data

A questionnaire survey was conducted among local residents and organizations to evaluate the implementation effect of the projects. The samples covered 10 counties where the projects were implemented. A total of 550 questionnaires were distributed, and 537 valid questionnaires were recovered.

The questionnaire consisted of three dimensions: satisfaction with resettlement life (including 6 items), social awareness (including 5 items), and the satisfaction of the public and stakeholders (including 9 items). The percentage of positive responses was calculated for each item, and the arithmetic mean of the positive percentages of all items was used as the score for the evaluation index.

2.2.3 Satellite remote sensing data

Remote sensing technology has been widely used by scholars worldwide in the monitoring of ecological protection and restoration projects owing to its macro, rapid, and objective characteristics.[28] In this paper, ENVI software was used to mosaic, fuse, and reproject MODIS data for 2017 and 2021 (data format: .img, spatial resolution: 500 m, cloud cover < 5%), and the average annual change rate of net primary production (NPP) in the project area from 2017 to 2021 was calculated. Sentinel-2 satellite data during the growing season (June–September) of 2017 and 2021 were mosaicked, fused, and reprojected (data format: .img, spatial resolution: 10 m, cloud cover < 5%), and the average annual change rate of normalized difference vegetation index (NDVI) in the project area from 2017 to 2021 was calculated. On the basis of China's land use remote sensing monitoring data product (spatial resolution: 30 m) and annual land use change survey, land use databases for the end of 2017 and 2021 were established (format: .shp, 1:10000 vector database). By the spatial overlay analysis of the two-year layers, the average annual change rates of forest land, grassland, wetland, and sandy land in the project area were calculated.

2.2.4 Ground-based sensing data

The effectiveness of monitoring and analysis was evaluated using water quantity monitoring data from the Caiqi Section of the Shiyang River and water quality monitoring data from the upper reaches of the Heihe River in 2017 and 2022.

3. Evaluation Methods

3.1 NbS global standards

For the English version, the NbS global standards released by the International Union for Conservation of Nature (IUCN) in July 2020 were adopted. The Chinese version was used by the Ministry of Natural Resources in June 2021. The NbS global standards comprise 8 criteria and 28 indicators, which were further aggregated into 5 categories in this paper.

(1) Objectives and targets. NbS criteria 1, 3, and 6 focus on social-ecological systems. Criterion 1 requires identifying environmental/social challenges and generating benefits; criterion 3 adds biodiversity conservation and ecosystem connectivity; criterion 6 addresses the entire social-ecological system.

(2) Scale hierarchy. Scale refers to spatiotemporal characteristics of natural processes, with different objectives at different scales. At the regional/watershed scale: improve dominant ecosystem services (e.g., ecological corridors, and spatial patterns). At the ecosystem scale: focus on ecological processes (composition, structure, function, and stress). At the site scale: design a restoration plan on the basis of local light, temperature, water, and soil conditions.

(3) Iterative optimization. Ecosystem restoration is long-term. Criterion 8 requires decades-long design for self-sustaining ecosystems. Criterion 7 adopts adaptive management with monitoring and iterative optimization to minimize negative impacts. Stakeholder participation (criterion 5) is essential, especially respecting local residents' rights to development and benefits.

(4) Technological integration. NbS requires integrated, cross-disciplinary approaches. Criterion 8 combines practices with policies, laws, and economic measures (criterion 4). Considering natural patterns and site conditions, multidisciplinary knowledge—ecology, bionics, hydraulic engineering, and landscape architecture (criterion 2)—strengthens ecosystem functionality and biodiversity (criterion 3). Adaptive management uses remote sensing for rapid monitoring (criterion 7). Dissemination employs policy promotion, academic exchanges, self-media, and socialized data sharing.

(5) Multi-stakeholder engagement. NbS involves a wide range of stakeholders. Criterion 5 requires involving them in decision-making to reduce conflicts and enhance social acceptability. Stakeholders (governments, authorities, investors, implementers, supervisors, and local residents) should be clearly identified in the pre-management stage. It is necessary to establish a feedback mechanism during implementation for adaptive management and iterative optimization.

3.2 Selection of evaluation indicators

The content of performance evaluation includes the completion of planned objectives and tasks, relevant institutional construction, fund allocation and utilization, project implementation progress, and economic and social benefits. The indicators in this paper are set as follows.

(1) Project Decision (M1): Under NbS criteria 1, 3, and 6, decision-making is evaluated via implementation scheme completeness (Z1), subproject preliminary design approval (Z2), and fund allocation (Z3).

(2) Project Management (M2): According to NbS criteria 5 and 7, the evaluation focuses on fund disbursement (Z4) and organization and implementation (Z5).

(3) Project Output (M3): Under NbS criteria 3, 6, 7, and 8, consistency with implementation scheme objectives and each subproject's approvals (Z6) is evaluated from three aspects: output quantity, quality, and timeliness.

(4) Project Effectiveness (M4): According to NbS criteria 5, 7, and 8, the evaluation focuses on monitoring and analysis (Z7), socialized services (Z8), and the iterative optimization of measures (Z9).

The performance evaluation indicator system and data used in this paper are presented in Table 1.

3.3 Method for integrating remote sensing data into monitoring and analysis

3.3.1 Land cover area change (Z71–Z74)

Land cover types refer to the categories of land cover, and changes in land cover area reflect the direction and magnitude of land cover conversion. The research techniques for interpreting land cover types using remote sensing data are relatively mature. The Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, has established a national-scale multi-period land use database mainly based on remote sensing image data from the U.S. Landsat satellites through manual visual interpretation. The land use classification system includes 6 first-level classes and 23 second-level classes. On the basis of land use databases interpreted from remote sensing images in 2018 and 2020, we adjusted the classes of "tidal flat", "beach land", and "marshland" by "China land use change survey databases" in 2017 and 2021 (Fig. 1). The spatial distributions of woodland, grassland, wetland, and sandland in 2017 and 2021 were extracted separately and stored in shapefile format.

Spatial intersection analysis was performed on the data layers of 2017 and 2021 to identify the outflow areas (woodland, grassland, wetland, or sandland in 2017 but other land cover types in 2021) and inflow areas (other land cover types in 2017 but woodland, grassland, wetland, or sandland in 2021). The projected area of each patch was then calculated accordingly.

3.3.2 NPP change (Z75)

NPP refers to Net Primary Production, which is the portion remaining after deducting the energy consumed by autotrophic respiration from the total organic matter produced by plants through photosynthesis. As the material basis for the survival and reproduction of other biotic components in the ecosystem, NPP plays a decisive role in maintaining the stability of the entire ecosystem and is commonly used to quantitatively analyze the changing trends of ecosystems.

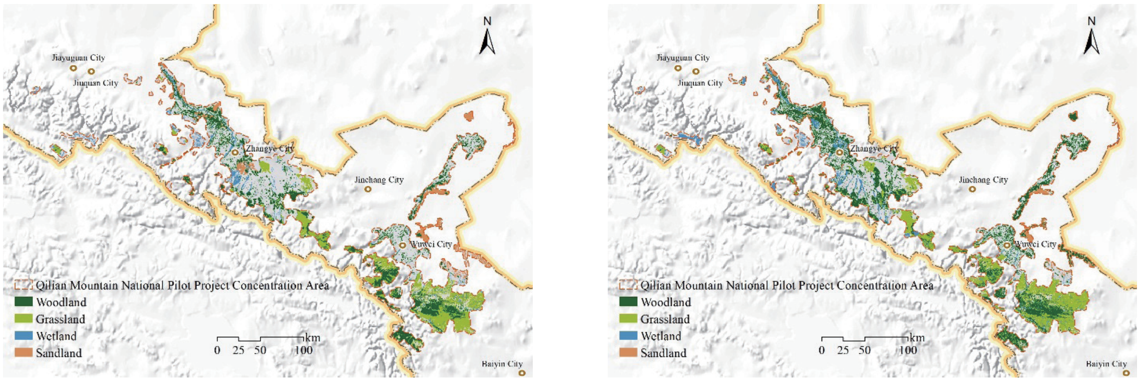
In this paper, the NPP data were derived from the MOD17A3HGF.V006 dataset, covering tiles h24v04, h24v05, h25v04, h26v04, h26v05, and h27v05. Data preprocessing included mosaicking, projection conversion, and clipping. With a spatial resolution of 500 m and a temporal resolution of 1 year, annual NPP datasets for 2017 and 2021 were generated (Fig. 2).

The annual average NPP in the project area was calculated using the weighted method shown in the equation $NPP_{year} = \left(Value \times Num_{value}\right) / \sum Num_{value}$. *Value* represents the NPP value of a pixel (values ranging from 32761 to 32767 have been excluded). Num_{value} represents the number of pixels corresponding to the NPP value. Annual changes were analyzed using the subtraction operation of raster data.

Table 1
Performance evaluation indicator system.

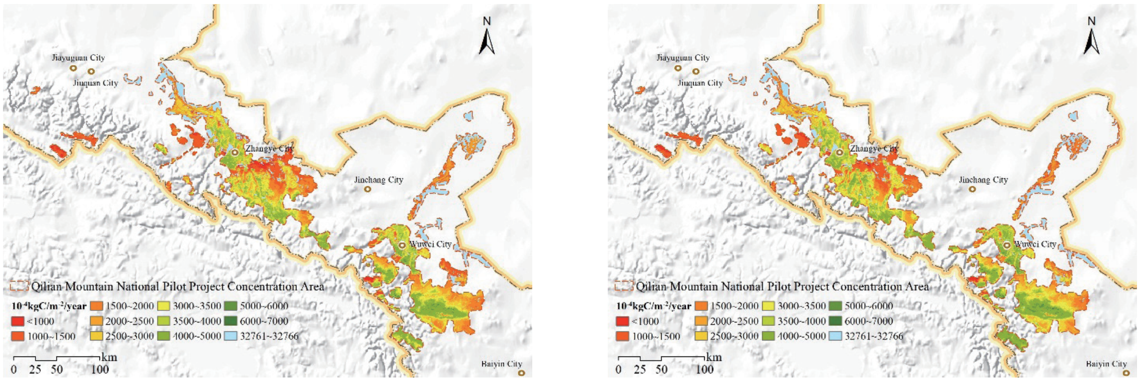
Objective	Criterion	Indicator	Data type	Data source
Project Decision (M1)	Completeness of the implementation scheme (Z1)	Depth of ecological problem identification (Z11)	Type A	Implementation Plan in the Heihe River Basin of Qilian Mountains, City A Implementation Plan in Qilian Mountains, City B
		Completeness of scale hierarchy analysis (Z12)	Type A	
		Extensiveness of public participation (Z13)	Type A	
		Matching degree of cost-benefit analysis (Z14)	Type A	
		Orientation of ecological and social development (Z15)	Type A	
	Approval of the preliminary design of subprojects (Z2)	Completeness of approval process (Z21)	Type A	Provincial govt reply on implementation plan & dept approvals for 140 projects
		Completeness of key contents (Z22)	Type A	
	Fund allocation (Z3)	Allocation method (Z31)	Type A	Fund allocation measures
		Transparency of allocation results (Z32)	Type A	Fund allocation result document
Project Management (M2)	Fund disbursement (Z4)	Disbursement rate of central fiscal funds (Z41)	Type A	Disbursement documents of central fiscal funds
		Timeliness of central fiscal funds disbursement (Z42)	Type A	
		Disbursement rate of local funds (Z43)	Type A	Statistical table of fund utilization for 140 projects
		Timeliness of local funds disbursement (Z44)	Type A	Final accounts reports for 140 projects
	Organization and implementation (Z5)	Organization (Z51)	Type A	Municipal and county leading group establishment documents
		Project management system (Z52)	Type A	Project process management documents
		Daily supervision (Z53)	Type A, Type D	Supervision records and monitoring data at municipal and county levels
		Mid-term evaluation (Z54)	Type A	Municipal mid-term evaluation report
Project Output (M3)	Goal consistency (Z6)	Project completion volume (Z61)	Type A	Project approval and completion reports of the 140 projects
		Project quality (Z62)	Type A	Project recheck report
		Project on-time completion rate (Z63)	Type A	Project final acceptance report
Project Effectiveness (M4)	Monitoring and analysis (Z7)	Woodland area change (Z71)	Type C	China's land use remote sensing monitoring data product and annual land use change survey data for 2017 and 2021
		Grassland area change (Z72)	Type C	
		Wetland area change (Z73)	Type C	
		Sandland area change (Z74)	Type C	
		NPP change (Z75)	Type C	MODIS data for 2017 and 2021
		Growing season NDVI change (Z76)	Type C	Sentinel-2 satellite data for 2017 and 2021
	Socialized services (Z8)	Ecological knowledge training (Z81)	Type A	Project summary report
		Social awareness (Z82)	Type B	Questionnaire
		Satisfaction of the public and stakeholders (Z83)	Type B	Questionnaire
	Iterative optimization of measures (Z9)	Adjustment of technical measures (Z91)	Type A	Technical summary
		Policy promotion for NbS (Z92)	Type A	Work and evaluation summary of administrative departments
		Experience sharing (Z93)	Type A	Media and newspaper introductions or reports on the pilot program

Note: The "Data type" in the above table includes project lifecycle governance checklist data (Type A), social sensing data (Type B), satellite remote sensing data (Type C), and ground-based sensing data (Type D).



(a) (b)

Fig. 1. (Color online) Land cover map (a: 2017, b: 2021).



(a) (b)

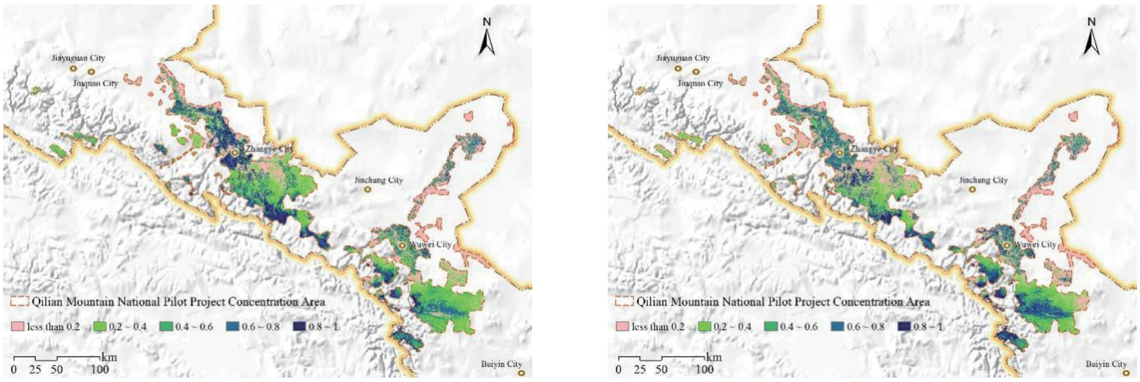
Fig. 2. (Color online) NPP distribution map (a: 2017, b: 2021).

3.3.3 Growing season NDVI change (Z76)

Vegetation is a vital component of terrestrial ecosystems. Numerous remote-sensing-based methods are used to estimate vegetation coverage. Among them, the NDVI has been widely applied in the qualitative and quantitative assessments of vegetation coverage and growth vigor, and can effectively reflect the basic status of surface vegetation growth.

In this paper, the NDVI data were derived from Sentinel-2 satellite imagery with a spatial resolution of 10 m. Images from the plant growing season (June to September) of 2017 and 2021 were mosaicked (52 scenes in 2017 and 45 scenes in 2021, with cloud content below 5%). Through atmospheric correction, band composition, data format conversion, mosaicking, and clipping, the 2017 and 2021 NDVI spatial distribution datasets covering the key project area were generated (Fig. 3).

The annual average NDVI of the project area was calculated using the same formula as for NPP. The NDVI value ranges from −1 to 1, with values of 0.2–1 for vegetated areas and negative values representing reflectance from water, snow, and so forth. Annual changes were analyzed using the subtraction operation of raster data.



(a) (b)

Fig. 3. (Color online) NDVI distribution map (a: 2017, b: 2021).

3.4 Indicator weight

The weights of the performance evaluation index system were determined using the fuzzy analytic hierarchy process (FAHP), with the determination steps as follows:

(1) Establish the fuzzy matrix $F = (f_{ij})_{m \times m}$, where f_{ij} is the quantitative description for judging the relative importance of each indicator, and the 0.1–0.9 scale method is adopted.

(2) Transform the matrix F into a fuzzy consistent matrix R using the formulas $r_i = \sum_{k=1}^{m} f_{ik}, i = 1, 2, \cdots, m$ and $r_{ij} = (r_i - r_j) / 2m + 0.5$.

(3) Calculate the indicator weights according to the formulas $l_i = \sum_{j=1}^{m} r_{ij} - 0.5, i = 1, 2, \cdots, m$ and $\omega_i = l_i / \sum_i l_i = 2l_i / [m(m-1)]$.

(4) Test the consistency of the weight sequence ω_i by using the maximum eigenvalue method.

The indicator weight results are presented in Table 2.

4. Verification of the Indicator System

4.1 Evaluation results of the indicator system integrated with remote sensing data

Remote sensing technology plays an important role in quantitative assessment.

4.1.1 Land cover area change

According to the calculations, from 2017 to 2021, the areas of woodland, grassland, and wetland within the project area all showed an increasing trend, with annual average growth rates of 7.1, 3.4, and 34.5%, respectively. The area of sandland decreased, with an annual average reduction rate of 9.7% (Fig. 4 and Table 2).

4.1.2 NPP change

From 2017 to 2021, the annual average NPP in the project area increased from 2772.2 to 2916.1, with a change rate of +5.19%, representing a slight increase (Fig. 5 and Table 3).

Table 2
Land cover change in the pilot project concentration area.

	2017 (ha)	2021 (ha)	Change (ha)	Annual mean change rate (%)
Woodland	234544.89	301144.61	+66599.72	+7.1
Grassland	411934.71	467686.91	+55752.19	+3.4
Wetland	27990.52	66594.25	+38603.73	+34.5
Sandland	144872.11	88394.34	−56477.77	−9.7

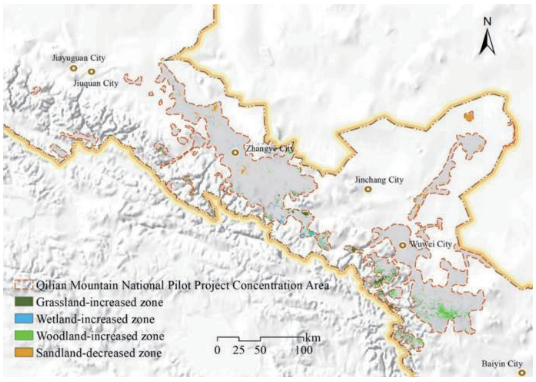


Fig. 4. (Color online) Land use change (2017 to 2021).

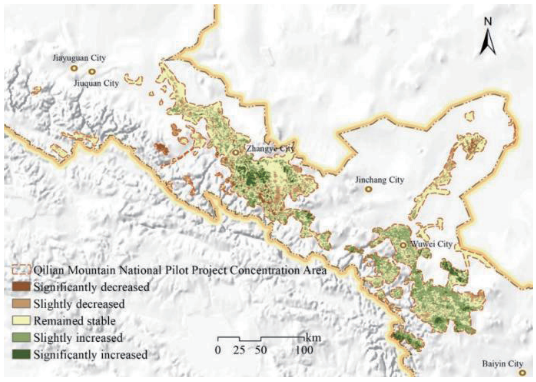


Fig. 5. (Color online) NPP distribution change (2017 to 2021).

Table 3
NPP change in the pilot project concentration area.

	Pixel value range (10^{-4} kgC/m^2/year)	Pixel value level	Annual average NPP (10^{-4} kgC/m^2/year)
2017	274–6519	4869	2772.2
2021	321–6829	5019	2916.1

From a spatial distribution perspective, areas with significant and slight increases were primarily concentrated in the southeastern and central parts of the project area. These regions are strongly affected by water systems and watersheds, where ecological projects—such as small watershed management and the construction of water conservation forests—have exerted a significant positive impact on vegetation growth. In contrast, areas with a significant decrease were mainly located in the northern desert region, where poor soil conditions have constrained vegetation growth.

4.1.3 NDVI change

From 2017 to 2021, the annual growing season NDVI in the project area increased from 0.5172 to 0.5408, with a change rate of +4.56%, representing a slight increase (Fig. 6 and Table 4).

From the perspective of spatial distribution, the changing areas of NDVI and NPP are correlated. Areas with significant and slight increases are mainly distributed in the southeastern and central parts of the project area, while areas with significant decreases are located in the

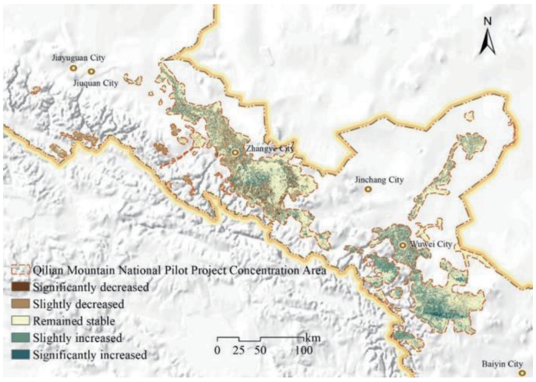


Fig. 6. (Color online) NDVI distribution change (2017 to 2021).

Table 4
NDVI change in the pilot project concentration area.

	Maximum pixel value	Minimum pixel value	Growing season NDVI
2017	1	0.2008	0.5172
2021	1	0.2078	0.5408

interior of the rocky mountainous region. Meanwhile, owing to the differences in the spatial resolution of remote sensing data, the analysis results of NDVI changes show more fragmentation characteristics. For ecological monitoring at the macro scale, higher image resolution is not necessarily better.

4.2 Performance evaluation results

According to the calculations, 21 out of 32 indicators scored higher than 75 (Table 5). Based on the NbS global standard and multi-source data fusion, the performance evaluation score of the pilot project was 83.76, corresponding to a “Good” grade.

According to the evaluation results (Table 5), the indicators for the completeness of the implementation scheme (Z11–Z15) achieved relatively low scores. Owing to the short period since the popularization of the NbS global standard, scale hierarchy and costbenefit analysis were rarely mentioned in the implementation plans. Since the project was mainly funded by financial investment and organized by the government, the pilot project scored high in terms of the procedural compliance of design approval and the transparency of fund allocation, reflecting an emphasis on procedural norms during project implementation. In terms of the key contents of the approval documents, requirements for public participation and safeguard measures were relatively weak.

Indicators related to fund disbursement (Z41–Z44) scored high, indicating sufficient fund guarantee. Municipal and county-level organizations were relatively sound. However, owing to cross-departmental implementation and inconsistent systems among different regions and departments, the pilot project that features multi-element collaborative governance currently lacks clear consistent requirements for process supervision. Regarding mid-term evaluations, there was a common problem of emphasizing project completion rates while neglecting the impacts of phased evaluations and recommendations for measure optimization.

Project output indicators are the main tasks of the implementing agencies. Based on quantitative statistics using before-and-after comparison, both indicators scored above 90. Project quality is generally assessed through sampling inspection, which requires heavy fieldwork and must be supported by professional teams familiar with various sectors and special funds.

Among the monitoring and analysis indicators for project effectiveness (Z71–Z76), the increases in grassland area, NPP, and NDVI all ranged from 3 to 6%, indicating a positive ecological succession trend in pilot project region. Such an achievement is hard-won for the ecologically fragile areas of Northwest China. Measure optimization and iteration are key components of adaptive management under the NbS principles. The low score on the iterative optimization indicator—which reflects the 'look-back' adjustment of measures—shows that there is still substantial space for improvement in project implementation, particularly for projects supported by fiscal funds.

Table 5
Performance evaluation results.

Objective	Weight of objective	Score of objective	Criterion	Weight of criterion	Score of criterion	Indicator	Weight of indicator	Score of indicator
M1	0.200	78.27	Z1	0.383	52.83	Z11	0.210	76.96
						Z12	0.165	46.35
						Z13	0.200	7.46
						Z14	0.195	46.05
						Z15	0.230	80.65
			Z2	0.317	88.44	Z21	0.550	100.00
						Z22	0.450	74.30
			Z3	0.300	100.00	Z31	0.500	100.00
						Z32	0.500	100.00
M2	0.225	86.79	Z4	0.400	100.00	Z41	0.233	100.00
						Z42	0.183	100.00
						Z43	0.301	100.00
						Z44	0.283	100.00
			Z5	0.600	77.99	Z51	0.217	100.00
						Z52	0.283	67.63
						Z53	0.267	67.63
						Z54	0.233	81.93
M3	0.300	95.25	Z6	1.000	95.25	Z61	0.450	98.77
						Z62	0.283	90.00
						Z63	0.267	94.90
M4	0.275	72.74	Z7	0.384	71.96	Z71	0.157	80.00
						Z72	0.160	60.00
						Z73	0.147	100.00
						Z74	0.147	80.00
						Z75	0.199	60.00
						Z76	0.190	60.00
			Z8	0.283	83.89	Z81	0.283	76.90
						Z82	0.367	87.96
						Z83	0.350	85.28
			Z9	0.333	64.16	Z91	0.333	49.00
						Z92	0.300	50.00
						Z93	0.367	89.50

5. Conclusion

On the basis of the NbS global standard and China's engineering management paradigm, we proposed a technical route integrating multi-source data (satellite remote sensing, project whole-process control lists, social perception, ground sensors) for the performance evaluation of ecological restoration projects. Using the Qilian Mountain National Pilot Project as a case study, we established an index system covering decision-making, management, outputs, and effectiveness, with a focus on applying remote sensing data to effectiveness evaluation and its quantitative assessment role.

Through the construction of an evaluation index system and case validation, we drew three conclusions.

(1) Fiscally funded and government-organized, the Shanshui Project achieved high scores on whole-process management indicators, reflecting engineering projects' emphasis on fund use and process documentation. However, the early Shanshui Project had clear shortcomings in indicators related to NbS standards, and indicators such as "Completeness of the implementation scheme", "Monitoring and analysis", and "Iterative optimization of measures" scored low. Future project implementation should give focused consideration during the planning and summary stages, especially the breadth of public participation, adjustment of technical measures based on monitoring and evaluation, and the coordination between social and ecological systems.

(2) Remote sensing data enables the rapid acquisition of land use, vegetation status, and quantitative change analysis. With growing data sources, RS-based ecological effectiveness assessment is becoming more refined and diverse. Long-term monitoring data (e.g., water/soil conservation, ecosystem service value, carrying capacity) better measure regional ecological benefits from restoration projects. This provides richer empirical data for Shanshui Project performance evaluation, supports optimization of similar projects in the same region, and promotes evidence-based mainstreaming of NbS.

(3) NbS and ecological restoration require slow, long-term thinking. The evolution of natural ecosystems is a long-term and gradual process, and relevant research and "letting nature work" should not follow a rapid approach. In goal-setting, the NbS standard emphasizes multi-stakeholder consideration and gradual implementation, and communication and consultation with stakeholders constitute a long-term process of negotiation. NbS demands interdisciplinary knowledge (ecology, succession, watershed linkages, symbiosis, aesthetics, landscape design, engineering). Effective implementation needs decadal-scale monitoring. Public acceptance and policy mainstreaming also take time.

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References

1 S. Wu, X. Cheng, and Y. Chen: J. Beijing For. Univ. (Soc. Sci. Ed.) **20** (2021) 1 (in Chinese). https://doi.org/10.13931/j.cnki.bjfuss.2021105
2 J. Liao and R. Ma: Chongqing Soc. Sci. (2021) 45 (in Chinese). https://doi.org/10.19631/j.cnki.css.2021.012.004
3 X. Wang, J. He, S. Rao, and H. Jiang: Environ. Prot. **46** (2018) 17 (in Chinese). https://doi.org/10.14026/j.cnki.0253-9705.2018.z1.003
4 Y. Zhou, Y. Chen, L. Ying, and C. Yang: Earth Sci. Front. **28** (2021) 14 (in Chinese). https://doi.org/10.13745/j.esf.sf.2020.10.23
5 X. Huang and D. Yang: Shanghai Land Resour. **37** (2016) 1 (in Chinese). https://doi.org/10.3969/j.issn.2095-1329.2016.03.001
6 Y. Zhou, J. Wang, and Y. Chen: China Land (2025) 50 (in Chinese). https://doi.org/10.13816/j.cnki.ISSN1002-9729.2025.06.13
7 B. Fu and J. Wang: Bull. Chin. Acad. Sci. **40** (2025) 1157 (in Chinese). https://doi.org/10.3724/j.issn.1000-3045.20250513005
8 L. Mu: Commer. Account. (2022) 90 (in Chinese). https://doi.org/10.3969/j.issn.1002-5812.2022.11.022
9 Y. Gong, B. Li, and P. Zhu: Commer. Account. (2021) 72 (in Chinese). https://doi.org/10.3969/j.issn.1002-5812.2021.24.017
10 Y. Liu: Caizheng Jiandu (2021) 75 (in Chinese). https://czjd.chinajournal.net.cn/WKG/WebPublication/paperDigest.aspx?paperID=281fd846-9517-4ed1-a7e2-4fece7fcb0de#
11 H. Wang, X. Zhang, X. Wang, Y. Cao, Q. Chen, X. Wang, and X. Kang: Res. Soil Water Conserv. **18** (2011) 276 (in Chinese). http://stbcyj.paperonce.org/oa/DArticle.aspx?type=view&id=20110361
12 X. Jin and X. Cao: Resour. Ind. **18** (2016) 76 (in Chinese). https://doi.org/10.13776/j.cnki.resourcesindustries.20160315.004
13 M. Luo, Y. Zhou, Z. Ju, H. Wei, and S. Zhang: Acta Ecol. Sin. **39** (2019) 8911 (in Chinese). https://doi.org/10.5846/stxb201905291118
14 J. Wang: Innovative Research on Performance Evaluation of Beijing-Hebei Cooperative Afforestation Project (Beijing Forestry Univ., Beijing, 2016) PhD Thesis (in Chinese). https://kjc.csuft.edu.cn/info/1091/1971.htm
15 S. Wang: Benefit Analysis and Evaluation of Vegetation Restoration Project in Huguan County, Shanxi Province (Shanxi Agric. Univ., Jinzhong, 2016) Master's Thesis (in Chinese). http://www.51papers.com/lw/69/7/wz3026565.htm
16 Y. Ding: Risk Management and Performance Evaluation of Black and Odorous Water Body Treatment Projects under PPP Model (Beijing Jiaotong Univ., Beijing, 2019) Master's Thesis (in Chinese). https://doi.org/10.26944/d.cnki.gbfju.2019.000286
17 J. Zhu, Y. Yu, and S. Wang: Resour. Environ. Yangtze Basin **29** (2020) 1995 (in Chinese). https://yangtzebasin.whlib.ac.cn/CN/10.11870/cjlyzyyhj202009010
18 S. Fan and H. Wang: Areal Res. Dev. **38** (2019) 132 (in Chinese). https://doi.org/10.3969/j.issn.1003-2363.2019.04.022
19 Y. Cui, K. Zhao, S. Zhou, and J. He: Chin. J. Eco-Agric. **28** (2020) 147 (in Chinese). https://doi.org/10.13930/j.cnki.cjea.190788
20 W. Yu: Monitoring and Benefit Evaluation of Desertified Grassland Management in Minqin County (Lanzhou Univ., Lanzhou, 2016) Master's Thesis (in Chinese). https://doi.org/10.7666/d.D01033856
21 Y. Meng, Z. He, B. Liu, L. Chen, and B. Liu: Resour. Sci. **42** (2020) 2022 (in Chinese). https://doi.org/10.18402/resci.2020.10.18
22 J. Zhang: Health Assessment and Service Function Evaluation of East Juyan Lake Wetland Ecosystem (Lanzhou Univ., Lanzhou, 2018) PhD Thesis (in Chinese). https://doi.org/10.7666/d.D01448890
23 S. Wang: J. Chin. Public Adm. (2014) 62 (in Chinese). https://doi.org/10.3782/i.issn.1006-0863.2014.11.13
24 W.-L. Hsu, L. Mou, Z. Dong, Y. Zhong, H.-L. Liu, F. Cai, and S. Deng: Sens. Mater. **8** (2025) 37. https:/doi.org/10.18494/SAM5662
25 S. C. Yu, D. B. Shin, and J. W. Ahn: Sens. Mater. **31** (2019) 3215. https://doi.org/10.18494/SAM.2019.2340
26 M. Wang, X. Yang, Y. Huang, S. Wu, and J. Chen: Sens. Mater. **35** (2023) 669. https://doi.org/10.18494/SAM4231
27 T. D. Acharya and D. H. Lee: Sens. Mater. **31** (2019) 3931. https://doi.org/10.18494/SAM.2019.2706
28 L. Wang, N. Huang, Z. Niu, M. Luo, Y. Chen, Y. Guo, Y. Lei, Q. Fu, and L. Ying: J. Remote Sens. **26** (2022) 1547 (in Chinese). https://doi.org/10.11834/jrs.20220002