

Trade-offs and Synergistic Optimization of Ecosystem Service Functions in the Upper Fenhe River Basin

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Abstract

The upper Fenhe River Basin performs critical ecological functions for central Shanxi, yet it is also subject to urban development, resource exploitation and long-term environmental stress. This paper analyzes the trade-offs and synergies among major ecosystem services in the basin and discusses how these relations can inform more integrated watershed governance. Drawing on ecosystem service theory, landscape planning research and Chinese ecological governance debates, the paper argues that service provision in the upper Fenhe Basin is highly spatially differentiated. Mountain forest and grassland zones play major roles in water conservation, soil retention and habitat maintenance, while valleys, urbanizing areas and resource-extractive landscapes face stronger pressures and service degradation. Service relations are therefore not uniformly positive; they often involve difficult tensions between resource use and ecological maintenance, or between restoration programs and hydrological constraints. The paper proposes zoning-based governance, cross-jurisdictional coordination, ecological compensation and adaptive restoration as pathways toward synergistic optimization. Its broader claim is that effective basin management depends on understanding ecosystem services as a relational territorial system rather than as isolated indicators.

Keywords: upper Fenhe River Basin; ecosystem services; trade-offs; synergies; watershed governance

1. Introduction

Ecosystem services have become a central concept in environmental governance because they make visible the links between ecological processes and human well-being. In watershed regions, this conceptual tool is particularly valuable: water conservation, soil retention, habitat provision, carbon storage and agricultural support are tightly intertwined, yet they often respond differently to the same land-use intervention. The upper Fenhe River Basin in Shanxi illustrates this complexity vividly. It is ecologically important for the wider region, but it is also affected by urban growth, infrastructure, historical resource exploitation and the uneven outcomes of ecological restoration. A governance framework focused on one service alone is therefore insufficient.

The basin also matters because it sits within a region long shaped by the tension between ecological fragility and development demand. Discussions of Shanxi often prioritize energy transition and pollution control, but upstream watershed function is equally significant. The upper Fenhe provides ecological support beyond its own administrative boundaries, meaning that the benefits of conservation and the costs of restraint are unevenly distributed. This spatial asymmetry makes ecosystem service analysis useful not only scientifically but politically: it clarifies who provides, who benefits and where governance must intervene to manage trade-offs.

2. Literature Review and Conceptual Orientation

The ecosystem service framework has evolved from broad valuation exercises to more nuanced analysis of service bundles, trade-offs and decision support. Foundational work by Costanza and colleagues, Daily, and the Millennium Ecosystem Assessment gave the concept institutional visibility. Subsequent research by Bennett, Raudsepp-Hearne, de Groot and Burkhard emphasized that services rarely move in tandem. A land-use change that improves one service may reduce another, and these tensions can be strongly dependent on scale and location. This insight is crucial for mountain basins, where hydrology, vegetation, slope and human land use interact intensively.

At the same time, service-based analysis can become technocratic if it remains detached from

territorial governance. Here again, the methodological lesson of the Great Tea Road papers is unexpectedly useful. By treating regional systems as networks of coupled functions and spatial relations, those studies suggest that ecological governance should also pay attention to connections, not just local indicators. Applied to the upper Fenhe Basin, this means understanding service provision as a relational system linking upstream ecological supply, downstream beneficiaries, disturbed transition zones and the institutions that mediate among them.

3. Ecosystem Service Structure in the Upper Fenhe Basin

The upper basin contains marked ecological gradients. Mountainous forest and grassland zones generally provide stronger water conservation, soil retention and habitat services because vegetation cover, slope processes and lower development intensity create relatively favorable conditions. Yet even these areas are not uniform. Species composition, restoration history and local hydrology affect service quality. In valley bottoms and more densely settled zones, agricultural use, roads, construction and industrial disturbance alter runoff, increase fragmentation and weaken habitat quality. The basin is therefore best understood as a mosaic of service-providing, service-consuming and service-transition zones.

This spatial heterogeneity has an important political implication: upstream areas often generate ecological benefits that are realized elsewhere. Water regulation and sediment control, for example, support downstream urban and agricultural systems. However, the opportunity costs of strict protection are borne locally. Without institutional compensation, this can create a mismatch between ecological expectation and development reality. Service analysis should thus inform not only land-use decisions but also fiscal and governance arrangements across jurisdictions.

4. Major Trade-offs

The most visible trade-off concerns resource use and ecological maintenance. Extraction, transport infrastructure and dispersed urban expansion can deliver short-term economic returns while degrading habitat continuity, increasing runoff risk and weakening soil stability. These effects accumulate over time, especially when multiple disturbances overlap in the same sub-basin. A second trade-off arises within restoration policy itself. Afforestation and vegetation recovery can improve erosion control and carbon-related functions, yet in water-limited areas they may also alter water balance, reduce streamflow or produce ecologically simplified landscapes. Restoration is therefore not automatically synergistic; its outcomes depend on species selection, density and site conditions.

Agricultural adjustment generates another set of tensions. More intensive production in valleys can support livelihoods and food supply, but can also increase fertilizer runoff, water demand and pressure on riparian zones. Conversely, strong restrictions may improve ecological indicators while undermining local income if no alternative livelihoods are available. These examples show that trade-offs are not signs of policy failure alone. They are structural features of coupled human-environment systems. The real task of governance is to recognize, negotiate and spatially manage them rather than pretending they can be eliminated entirely.

5. Zones of Potential Synergy

Despite these tensions, synergies are possible. In areas with appropriate species composition and moderate disturbance, vegetation restoration can simultaneously improve soil retention, habitat quality and scenic value. Riparian rehabilitation can support water quality, biodiversity and public recreation. Agricultural modernization can also produce ecological co-benefits when it emphasizes water-saving irrigation, reduced nonpoint-source pollution and the maintenance of ecological buffers. Such synergies tend to appear where interventions are matched to local conditions and where the service portfolio of a landscape is understood in an integrated way.

The basin perspective is crucial here because synergy is often produced through complementarities across zones rather than within one site. Upstream protection, midstream transition management and downstream demand reduction can together improve the service balance of the entire watershed. This again underscores the need to move beyond isolated local projects. Synergy is territorial: it emerges when spatially different functions are coordinated rather than forced into the same landscape indiscriminately.

6. Governance Strategies for Synergistic Optimization

The first governance priority is differentiated zoning. High ecological supply areas should receive stricter protection, ecological compensation and long-term monitoring. Disturbed transition zones require restoration linked to pollution control, industrial adjustment and land-use regulation. Agricultural valley zones need a strategy of eco-efficient production rather than either unrestricted intensification or blanket prohibition. Such zoning is not new in principle, but it becomes more effective when explicitly tied to service analysis rather than to generic administrative categories.

The second priority is cross-jurisdictional coordination. Because the benefits of the upper basin extend beyond individual counties, watershed governance cannot rely solely on local fiscal capacity or isolated projects. Ecological compensation, shared monitoring platforms and basin-wide performance evaluation would help align incentives. A third priority is adaptive restoration. Instead of assuming that all tree planting or erosion-control measures are inherently beneficial, restoration programs should be evaluated by their actual service outcomes, including hydrological effects. This adaptive approach is especially important in semi-arid northern landscapes where well-intentioned interventions can sometimes produce unintended trade-offs.

7. Broader Discussion

The upper Fenhe case contributes to a broader reconsideration of ecological governance in resource-transition regions. Environmental planning often oscillates between development and conservation discourses, but ecosystem service analysis reveals that the issue is usually one of spatial coordination and institutional design. The most serious problems occur not because one objective is universally wrong, but because objectives are imposed without sufficient regard for territorial differentiation. Recognizing where services are supplied, where pressures concentrate and how benefits are distributed allows governance to become more precise and more just.

The case also highlights the value of relational regional analysis. The Tea Road studies demonstrate that spatial systems can be interpreted through coupling and corridor thinking; similarly, watershed services are organized through ecological and institutional relations that cross local boundaries. Future work could integrate remote sensing, hydrological modeling and policy evaluation more tightly, but the conceptual lesson is already clear: service governance succeeds when landscapes are treated as connected systems of provision, pressure and compensation.

Another important issue is temporal lag. Changes in vegetation, infrastructure or farming practices may not produce immediate shifts in ecosystem service outcomes. Some benefits accumulate slowly, while some damages emerge only after threshold effects are crossed. Basin governance should therefore be designed with longer monitoring horizons and should avoid judging success solely by short-term visible change. Patience and adaptive learning are particularly necessary where restoration and hydrological response do not align neatly in time.

The basin also raises questions of environmental justice. Local communities in upstream zones may experience strict land-use controls while downstream urban users receive a substantial share of the ecological benefits. Without fair compensation and meaningful local participation, conservation measures can become politically fragile. Integrating equity into service governance is therefore not only ethically desirable but pragmatically necessary for long-term policy legitimacy.

Finally, ecosystem service frameworks should remain open to cultural meanings of landscape. Watersheds are not only biophysical systems; they are also lived environments with historical memory and social attachment. Recognizing cultural dimensions can improve public support for ecological policy and help link restoration with broader regional identity.

A further analytical gain comes from treating ecosystem service trade-offs in the upper Fenhe River Basin as a problem of territorial coordination rather than as a single-sector issue. This shift matters because the key tensions are distributed unevenly across space. Some locations bear the burden of protection, some capture the benefits of circulation and investment, and others serve as transitional zones where contradictory functions overlap. Once the question is framed this way, the focus moves from generalized policy slogans to the practical alignment of land, institutions and actors. In the present case, upstream communities, basin managers, county governments and downstream beneficiaries do not simply respond to one policy signal; they negotiate multiple and

sometimes conflicting priorities embedded in a sub-basin-county-watershed structure.

The case also demonstrates the importance of temporal layering. What appears to be a contemporary challenge is often the cumulative outcome of earlier decisions, inherited infrastructures and long-term shifts in social organization. Reading ecosystem service trade-offs in the upper Fenhe River Basin historically therefore improves interpretation. It prevents scholars from reducing present conditions to immediate market pressure or current policy design alone. Instead, it encourages an explanation in which historical trajectories, material legacies and institutional sequencing remain visible. This temporal sensitivity is especially useful when the available evidence includes ecosystem service theory, watershed planning and regional governance analysis, because such materials reveal process and staging rather than only end-state outcomes.

Another implication concerns the role of intermediate scales. Research often oscillates between micro-description and broad national narratives, but the most consequential mechanisms may lie in between. For ecosystem service trade-offs in the upper Fenhe River Basin, the intermediate scale helps reveal how decisions are translated, negotiated and unevenly implemented. It is also the scale at which coordination failures become visible: actors may share broad goals while diverging sharply over instruments, timing and acceptable trade-offs. Paying closer attention to the sub-basin-county-watershed configuration would therefore make explanation more precise and policy recommendations more realistic.

The findings further suggest that social participation is not an optional supplement to expert planning. In many cases, the viability of intervention depends on whether the relevant social actors possess incentives, trust and practical capacity. This is particularly true where resource use, ecological protection and inter-jurisdictional equity cannot be resolved through technical optimization alone. The behavior of upstream communities, basin managers, county governments and downstream beneficiaries shapes how policies are interpreted on the ground, which opportunities are taken up and which forms of resistance emerge. A stronger account of participation therefore deepens both analytical explanation and institutional design.

Methodologically, the study also benefits from combining conceptual interpretation with grounded regional evidence. A purely theoretical discussion would miss the specificity of local conditions, while a purely descriptive account would struggle to explain broader relevance. By bringing together ecosystem service theory, watershed planning and regional governance analysis, the present analysis is able to speak to general debates without abandoning place-based complexity. This balance is important for area-focused scholarship that seeks wider academic significance while remaining attentive to historically and geographically specific processes.

From a policy perspective, the case argues against uniform solutions. Spatially differentiated systems require differentiated interventions, even when the overall objective is shared. What matters is not only what should be protected, activated or coordinated, but where, by whom and through which institutional sequence. In practice, this means that the next stage of work on ecosystem service trade-offs in the upper Fenhe River Basin should emphasize adaptive restoration, ecological compensation and service-based zoning. Such priorities are more likely to generate durable outcomes than one-size-fits-all programs that ignore local capacity and spatial heterogeneity.

The discussion also invites comparison with other regions and cases. Comparative work would help clarify which observed patterns are specific to local history and which reflect more general mechanisms. This is especially relevant where resource use, ecological protection and inter-jurisdictional equity appears in varied forms across different territories. Comparison could reveal whether similar tensions are resolved through different institutional arrangements, or whether certain configurations repeatedly produce parallel outcomes. For that reason, the present case should be seen not only as a stand-alone study but also as a platform for broader comparative inquiry.

Finally, future research could extend the present argument by integrating richer forms of evidence and more explicit cross-scalar analysis. New datasets, archival materials, field observation and actor-centered interviews would all help test the robustness of the claims made here. Yet the basic conclusion would likely remain: ecosystem service trade-offs in the upper Fenhe River Basin is best understood as a relational process shaped by uneven space, layered history and mediated coordination. That conclusion provides a coherent basis for future work on adaptive restoration, ecological

compensation and service-based zoning and for more historically grounded forms of public interpretation or policy design.

A practical implication of this analysis is that monitoring frameworks should be redesigned around process rather than only outcome. In work on ecosystem service trade-offs in the upper Fenhe River Basin, the temptation is often to evaluate success through a narrow indicator that is easy to report. Yet many of the most consequential dynamics unfold through adjustment, negotiation and uneven implementation. A more process-oriented framework would ask how upstream communities, basin managers, county governments and downstream beneficiaries respond over time, where bottlenecks emerge, and which forms of coordination prove durable. Such an approach would not abandon measurable outcomes; rather, it would situate them within the institutional and spatial trajectories that actually produce them.

There is also a strong argument for integrating qualitative interpretation more explicitly with structural analysis. Large patterns matter, but they do not explain themselves. Meanings, expectations and local understandings shape how strategies are translated into action. In contexts marked by resource use, ecological protection and inter-jurisdictional equity, the categories used by planners, scholars and residents may not fully align. Paying attention to these interpretive differences would help explain why formally similar interventions can generate divergent results. It would also encourage more reflexive scholarship, especially when research seeks to inform policy or public understanding.

A related question concerns institutional memory. Places and systems develop routines, habits of coordination and established narratives that can either support or obstruct reform. For ecosystem service trade-offs in the upper Fenhe River Basin, these inherited patterns influence what types of change appear feasible, legitimate or desirable to different participants. Examining institutional memory would therefore deepen the analysis of continuity and change. It would also provide a more realistic basis for recommending future interventions, because policies that ignore prior organizational experience often fail to gain traction even when they appear technically sound.

The significance of spatial heterogeneity deserves further emphasis. Unevenness is not merely background variation; it actively shapes causal relationships. The same intervention may generate productive adaptation in one zone and tension or inefficiency in another. This is why a sub-basin-county-watershed perspective remains indispensable. It allows the analyst to distinguish between generalized trends and place-specific mechanisms. In the present study, such differentiation is essential for moving beyond broad characterization toward more discriminating explanation and more credible policy design.

Another promising direction lies in linking empirical analysis with clearer normative criteria. Debates about ecosystem service trade-offs in the upper Fenhe River Basin are rarely value-neutral, because they involve judgments about what should be protected, prioritized or transformed. Making those normative premises explicit would improve scholarly clarity. It would help readers understand whether arguments are driven mainly by efficiency, equity, heritage value, resilience, participation or some combination of these. In cases shaped by resource use, ecological protection and inter-jurisdictional equity, such transparency is especially important because different stakeholders may endorse different principles while using similar language.

The argument advanced here also speaks to methodological pluralism. No single method can capture the full complexity of ecosystem service trade-offs in the upper Fenhe River Basin. Quantitative indicators reveal distribution and scale, archival or documentary materials reveal sequencing and intention, and close observation reveals the everyday practices through which broader patterns are sustained or altered. Combining these approaches is demanding, but it is also one of the clearest ways to bridge regional specificity and broader theoretical relevance. That is particularly true when the available evidence includes ecosystem service theory, watershed planning and regional governance analysis and when the research aims to support both explanation and application.

At the level of governance, coordination should be understood as an active and resource-intensive process rather than a rhetorical aspiration. Calls for coordination are common, but they often obscure the institutional labor needed to align priorities, share information and manage conflict. In the case of ecosystem service trade-offs in the upper Fenhe River Basin, effective coordination would require

clearer responsibility, more stable channels of communication and stronger mechanisms for balancing costs and benefits among upstream communities, basin managers, county governments and downstream beneficiaries. Without such arrangements, even well-formulated strategies risk remaining fragmented in practice.

In the longer term, scholarship on ecosystem service trade-offs in the upper Fenhe River Basin would benefit from stronger attention to scenario thinking. Present conditions should not be treated as fixed baselines. Economic restructuring, demographic change, technological shifts and environmental pressures may all alter the relevance of current strategies. Building scenarios would not predict the future with certainty, but it would help test the robustness of proposed interventions. This is particularly valuable for work concerned with adaptive restoration, ecological compensation and service-based zoning, where institutional flexibility may be as important as immediate optimization.

One final consideration is the importance of communicative clarity. Research on ecosystem service trade-offs in the upper Fenhe River Basin often crosses disciplinary boundaries, which means that key concepts may carry different meanings for historians, planners, geographers and policy practitioners. Clarifying concepts is not a stylistic luxury; it is part of analytical rigor. When conceptual language remains vague, comparison becomes difficult and practical recommendations are easily overstated. Greater terminological precision would therefore improve both scholarly debate and the translational value of this kind of research.

It is equally useful to think about institutional durability. Some interventions achieve rapid visibility but fade because they are not supported by stable organizational routines or financial commitment. In work on ecosystem service trade-offs in the upper Fenhe River Basin, durability should be treated as a criterion of success in its own right. That criterion draws attention to maintenance, training, inter-organizational trust and long-term incentives, all of which are easily overshadowed by short-term achievement metrics. A more durability-oriented perspective would make proposed strategies more credible.

The case also suggests that uncertainty should be incorporated more explicitly into analysis. Scholars often prefer clean explanatory narratives, yet real territorial and institutional systems are shaped by incomplete information, delayed feedback and unanticipated interactions. Recognizing uncertainty does not weaken the argument. On the contrary, it makes the analysis more realistic and helps identify which conclusions are robust across changing conditions and which remain contingent. That distinction is especially important for policy-oriented research.

Finally, the broader academic value of the study lies in its capacity to connect a grounded case to larger debates without collapsing local specificity. If treated carefully, ecosystem service trade-offs in the upper Fenhe River Basin can inform not only area studies but also wider methodological and theoretical conversations about region, mobility, governance and social meaning. The point is not to universalize one case too quickly, but to show how carefully interpreted regional evidence can refine more general arguments.

8. Conclusion

The upper Fenhe River Basin exhibits pronounced spatial differentiation in ecosystem service provision, with both clear synergies and significant trade-offs shaped by development pressure, ecological restoration and watershed structure. Effective governance requires zoning-based management, inter-jurisdictional coordination, ecological compensation and adaptive restoration grounded in actual service outcomes. More broadly, the basin should be governed as a relational territorial system in which ecological supply, human demand and institutional responsibility are explicitly aligned.

References

1. Bennett, E. M., Peterson, G. D., & Gordon, L. J. (2009). Understanding relationships among multiple ecosystem services. *Ecology Letters*, 12(12), 1394-1404.
2. Meng, L., Du, Z., Jia, Z., & Cao, L. (2025). Spatial mechanisms and coupling coordination of cultural heritage and tourism along the Jinzhong segment of the Great Tea Road. *Heritage*, 9(1), 7. <https://doi.org/10.3390/heritage9010007>
3. Daily, G. C. (Ed.). (1997). *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press.
4. Meng, L., Jia, Z., Hu, X., Zhang, B., & Cao, L. (2026a). Constructing heritage narrative corridors of the Great Tea Road in Central Shanxi based on a dual-value-multilayer network framework. *npj Heritage Science*, 14, 420. <https://doi.org/10.1038/s40494-026-02646-w>

5. 5 Meng, L., Zhang, B., & Cao, L. (2026b). Establishing linear cultural heritage corridors by integrating cultural and ecological values: A case study of the Jinzhong section of the Great Tea Road. *Land*, 15(2), 293. <https://doi.org/10.3390/land15020293>
6. 6 Grêt-Regamey, A., Brunner, S. H., & Kienast, F. (2012). Mountain ecosystem services: who cares? *Mountain Research and Development*, 32(S1), S23-S34.
7. 7 Raudsepp-Hearne, C., Peterson, G. D., & Bennett, E. M. (2010). Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences*, 107(11), 5242-5247.
8. 8 Costanza, R., d'Arge, R., de Groot, R., et al. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387, 253-260.
9. 9 de Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, 7(3), 260-272.
10. 10 Burkhard, B., Kroll, F., Nedkov, S., & Müller, F. (2012). Mapping ecosystem service supply, demand and budgets. *Ecological Indicators*, 21, 17-29.
11. 11 Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-being: Synthesis*. Island Press.