Research Paper

Coordinating Urban-Rural Development through Scenario-Driven Land Use and Ecological Network Planning: A Case Study of the Dawen River Basin

Xingyu Wu, Shandong Jianzhu University, China
Feng Song,Shandong Jianzhu University, China
Guangjin Zhou,Satellite Application Center for Ecology and Environment,
Ministry of Ecology and Environment,China

Abstract

Global urbanisation, compounded by climate and resource crises, is inducing LUCC that degrades ecosystem quality, decreases biodiversity, and exacerbates urban-rural imbalances, particularly in fragile river basins. Further in the lower Yellow River, uncontrolled urbanization, population concentration on limited land, elevated riverbeds, and fragmented governance undercut the ecological security and development quality. But LUCC as a vector for the integration of social, economic and ecological systems is still poorly estimated at the basin level. Here we consider the Dawen River Basin, an ecotone associated with ecological–development of the lower Yellow River region, to study how alternative LUCC pathways might alter ecosystem networks while influencing urban-rural coordination. Based on land use data for 2000, 2010 and 2020, we synthesize CA-Markov, multi-objective programming and the PLUS model to build potential land uses in 2030 for an inertial current trajectory (CS), Ecological–Economic Development Priority (EED) and Balanced Urban-Rural Development (BURD). We also use MSPA, Conefor, and MCR to describe ecological sources and corridors and to assess network connectivity and redundancy at the spatial level by scenario. Results are that EED can increase ecological land by 11.6%, economic output efficiency by 8.2%, and in-line with the concentration of the mountain–river ecological spine. BURD, on the other hand, increases rural public service and multifunctional land by 15.4%, produces a more compact and more balanced landscape, generates new diverse ecological sources (47.1% of new sources) derived from rural multifunctional land, and denser short-range corridors in urban-rural transition zones. Combined, these results reveal a basin-scale LUCC-ecological network infrastructure that clarifies the trade-offs among ecological connectivity and spatial equity, and presents an easily-transferable frame of reference for designing sustainable growth paths within areas characterized by intense human–land conflict.

Keywords

Urban-Rural Development, *Scenario Simulation*, *Ecological Network*, *Sustainable Governance*, *Dawen River Basin*

1. Introduction

Global urbanization is unfolding alongside escalating climate, biodiversity, and socio-economic challenges. In this context, land-use and land cover change (LUCC) is increasingly understood not as a passive outcome of development, but as a critical nexus linking global environmental change with regional pathways of sustainable transformation (Li *et al.*, 2024). Over the past 50 years, the expansion of cropland, rangeland, and built-up land has altered carbon cycles, hydrological regimes, and surface energy balances, and is now recognized as a major driver of biodiversity loss and ecosystem service degradation (Hasan *et al.*, 2020). More importantly, LUCC is not merely a redistribution of land uses. It reorganizes production-living-ecological spaces, reshapes the relationships among these functions, and reconfigures the ecological and service networks that support regional sustainability (Felipe-Lucia *et al.*, 2020). These tensions are particularly pronounced in the Yellow River Basin. As one of China ' s key ecological barriers and a strategic base for energy production and grain security, the basin also represents a hotspot of human-environment conflict under rapid global change (Chen *et al.*, 2020). A growing body of empirical and policy research shows that long-term water scarcity, intensive land development, and imbalanced industrial structures have jointly contributed to ecosystem degradation, wetland contraction, and rising ecological risks. These pressures are especially acute in the lower basin, where dense urbanization and energy-intensive industries intensify the trade-offs between ecological protection and development quality (Liu *et al.*, 2022). Although national strategies have increasingly emphasized ecological priority, sustainable development, and urban-rural integration, basin-scale scenario-based planning frameworks that can simultaneously address ecological integrity and spatial accessibility remain limited, especially beyond pilot projects (Xu, Renaud and Barrett, 2022).

At the same time, land-use transition has become a key mechanism through which urban-rural relations are reordered and urban-rural integration is advanced (Chen *et al.*, 2020). In China, flows of people and capital, industrial restructuring, and land institutional reforms have profoundly reshaped land-use intensity and spatial configuration, thereby influencing urban-rural integration and regional inequality (Liu, Li and Yang, 2018). Yet most studies of the coupled urban-rural-land system still rely on composite indicators and temporal diagnostics. Such approaches often privilege statistical associations over spatial processes and rarely combine scenario-based LUCC simulation with ecological network reconstruction to reveal the spatial mechanisms of urban-rural coordination. As a result, their capacity to support territorial spatial optimisation and concrete planning decisions remains limited.

Scenario-based land-use simulation and optimisation provide an important bridge between theory and planning practice. Spatially explicit models such as CA-Markov, CLUE-S, FLUS, and PLUS can reconstruct land expansion and transition under alternative policy constraints, offering a quantitative basis for evaluating the long-term consequences of development strategies for ecosystem services and carbon emissions (Liang *et al.*, 2021). Meanwhile, multi-objective programming (MOP) has been widely used to identify Pareto-optimal land-use structures balancing economic development, ecological protection, and carbon mitigation, thereby moving land-use optimisation beyond narrow economic objectives toward more integrated production-living-ecological solutions (Voskamp *et al.*, 2023). However, most existing applications remain confined to administrative units, making it difficult to integrate urban-rural coordination and ecological network reconstruction within a single basin-scale decision framework.

Parallel to this, research on ecological security patterns and ecological networks has largely converged on a “source-corridor-network” framework aimed at enhancing ecological security and habitat connectivity (Yu, 1995). MSPA provides an effective way to identify core patches and potential corridor backbones in complex landscapes (Zhang *et al.*, 2025), while the MCR approach supports the construction of resistance

surfaces and least-cost pathways for ecological security pattern design and corridor identification (Ding *et al.*, 2022). At the network level, Conefor and related indices such as the Probability of Connectivity (PC) and Integral Index of Connectivity (IIC) have shifted evaluation beyond patch area and number toward functional connectivity. Yet this body of research still has clear limitations. Most studies implicitly assume that an ecology-first model is always optimal, while seldom examining how alternative LUCC trajectories reconfigure source-corridor systems, interact with urban-rural spatial structures, or shape the distribution of socially desirable land uses. This weakens their relevance for integrated governance in regions such as the Yellow River Basin, where ecological protection and urban-rural integration must be pursued simultaneously.

Against this background, this study takes the Dawen River Basin in the lower Yellow River as a representative case and develops a basin-scale framework integrating LUCC scenario simulation, land-use structure optimisation, and ecological network reconstruction. It addresses three questions: (1) how alternative LUCC trajectories reshape source-corridor-network structures; (2) whether ecological network optimisation can enhance ecological security and urban-rural coordination simultaneously rather than trading one against the other; and (3) to what extent a scenario-driven, integrated land-use–ecological network planning approach can offer transferable theoretical insights and actionable decision support for the lower Yellow River and other regions characterised by acute human–land conflicts.

2. Materials and methods

2.1. Study area

The Dawen River Basin is in the southwestern region of Shandong Province in the lower reaches of the Yellow River (116°15′–117°55′E, 35°50′–36°40′N). Its main stem is about 239 km long and drains around 8,840 km². Low mountains and hills dominate the headwater reaches, while the middle and lower reaches grade into a plain–lake–wetland complex, forming a characteristic mountain-to-plain transition basin. The basin climatically has a warm temperate monsoon climate with a mean annual temperature of 12–14 °C and mean annual precipitation of 640–760 mm, most of which falls during the June–September flood season. It has a resident population of around 5.09 million. Land use is primarily cropland (approximately 60%), with forest and grassland as secondary types; together, agricultural landscapes cover more than 80% of the basin. Built-up areas are mainly spread over belt-like zones along river valleys and plain corridors, so the Dawen River Basin serves as a major grain-producing area and core belt for energy and building-materials industries in Shandong Province.

2.2. Data sources

This study employs biophysical and socio-economic factors to choose driving factors as per the sources and definitions provided in Table 1. After harmonized preprocessing, land-use data for the Dawen River Basin were classified into eight categories—cropland, forest, grassland, shrubland, wetland, water, bare land, and built-up land—which act as inputs for subsequent scenario simulations and ecological network analyses.

Table 1. Sources of driving factors

Category	Driver	Source	Year	Spatial resolution
Natural attributes	Land use	Data Sharing and Service Portal, Big Earth Data Center, CAS (https://data.casearth.cn/)	2020	30m

	Soil	Tibetan Plateau Data Center (http://westdc.westgis.ac.cn)	2003	1km
	Mean annual precipitation		2019	1km
	Mean annual temperature		2020	1km
	Elevation	Geospatial Data Cloud (https://www.gscloud.cn/search)	\	30m
	GDP	Resource and Environmental Science Data Platform (https://www.resdc.cn/data.aspx?DATAID=360)	2015	1km
Social attributes	Secondary and tertiary industrial value added	Shandong Statistical Yearbook (http://tjj.shandong.gov.cn/tjnj/nj2020/zk/indexch.htm)	2020	\
	Fixed-asset investment		2020	\
	Population density	WorldPop (https://hub.worldpop.org/)	2020	100m
	Roads	OpenStreetMap (https://www. openstree tmap.org/)	\	\
	Expressways		\	\
	Railways		\	\
	Village, town, county and city centres		\	\

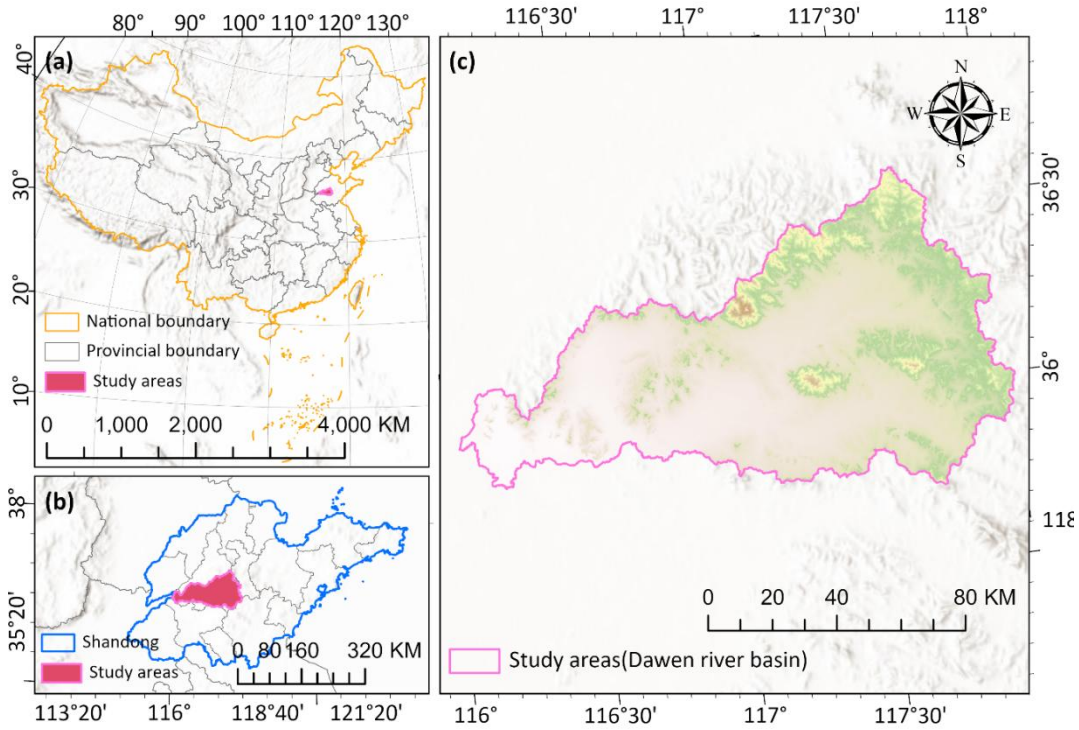


Figure 1. The location of the study area (a.China, b.Shandong, c.Dawen river basin). Source: author's own drawing.

2.3. Methods

The overall research framework, integrating LUCC scenario simulation, land-use optimisation, and ecological network analysis, is presented in Figure 2. To examine how alternative development pathways reshape LUCC, ecological networks, and urban-rural spatial patterns, three scenarios were defined: (1) Current Scenario (CS), which extends the observed 2000–2010 land-use trajectory without additional policy constraints; (2) Ecological–Economic Development Priority (EED), which strengthens cultivated land and ecological redline protection while promoting ecological land expansion and economic efficiency; and (3) Balanced Urban-Rural Development (BURD), which controls overall development intensity while increasing rural public-service and multifunctional land to reduce urban-rural disparities in both scale and spatial configuration.

Methodologically, a CA–Markov model was first calibrated using LUCC data from 2000 and 2010 to derive transition probabilities and spatial autocorrelation parameters, and then validated by simulating the 2020 land-use pattern against the observed map. Based on this, a multi-objective programming (MOP) model was used to optimise the 2030 land-use structure under the EED and BURD scenarios. These optimised land-use demands were then incorporated into the PLUS model to generate spatially explicit 2030 patterns for all scenarios. Finally, MSPA and Conefor were applied to identify ecological sources and evaluate network structure, while an integrated resistance surface and the Minimum Cumulative Resistance (MCR) model were used to extract key ecological corridors, enabling comparison of ecological connectivity and urban-rural coordination across scenarios (Figure 2).

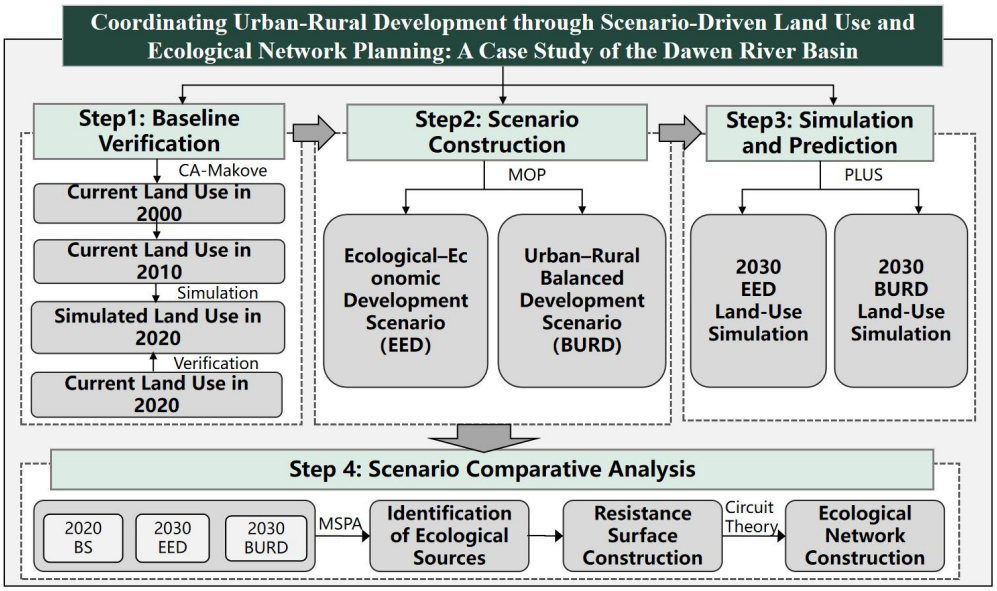


Figure 2. Research framework. Source:author's own drawing.

2.4. Optimising land-use structure and scenario-based simulation

2.4.1 2030 land-use structure under the EED and BURD scenarios

We first applied a CA–Markov model to derive transition matrices and simulate the spatial diffusion of land-use change between the 2000 and 2010 patterns, and then validated the simulations against the observed 2020 landscape using the Kappa statistic. Once the model met the accuracy requirement, it was used to generate the 2030 land-use pattern for the inertial Current Scenario (CS). CA–Markov combines

Markov chain–based estimates of class transition probabilities with cellular automata neighbourhood rules, allowing it to represent both changes in class totals and the spatial aggregation of land-use patches. Building on the total change trends projected by CA–Markov, we introduced a multi-objective programming (MOP) model to optimise the 2030 land-use structure under different scenarios. The decision variables were the areas of cropland, forest, grassland, water, built-up land, rural multifunctional land and unused land. For the EED scenario, the objective function was specified to maximise both the total area of ecological land (forest, grassland and water) and economic output per unit land area, subject to constraints on total land balance, a minimum cropland area, ecological redlines, and upper and lower bounds for each land-use category. For the BURD scenario, the same ecological and cropland constraints were retained, but additional indicators were introduced to capture the scale gap between urban and rural built-up land and the proportion of rural public-service land; the optimisation sought to minimise deviations of the urban-rural built-up land ratio from a target value while increasing the area of rural multifunctional land. The optimised 2030 land-use structures for the EED and BURD scenarios were then used as quantity-control constraints in the PLUS model.

2.4.2 Scenario-based LUCC simulations

Building on the optimised land-use structures, we then used the Patch-generating Land Use Simulation (PLUS) model to generate spatially explicit LUCC patterns for 2030 under the EED and BURD scenarios. PLUS uses the Land Expansion Analysis Strategy (LEAS), coupled with a random forest algorithm, to identify the dominant drivers of expansion for each land-use type (including elevation, slope, distance to major roads, towns and water, and population density), and combines multi-type random patch seeds (CARS) with an improved CA rule set to produce evolution patterns whose patch morphology more closely resembles real landscapes. Using the MOP-optimised class totals as hard constraints on area, the PLUS model generated spatially explicit land-use/land-cover maps for 2030 under the CS, EED, and BURD scenarios. These maps provide the spatial basis for subsequent ecological network construction and analysis of urban-rural coordination.

2.5. Ecological source identification

Using the baseline (2020) as well as the simulation of land-use maps in 2030 for both EED and BURD scenarios, forest, grassland, and water bodies were treated as foreground classes; all other land-use types were treated as background. Morphological Spatial Pattern Analysis (MSPA) (implemented in the GUIDOS Toolbox) was then performed to dissect the foreground into morphological categories like core, bridge, edge, and branch patches.

2.6. Resistance surface construction

We designed resistance surfaces to capture the landscape resistance across multiple development pathways for three temporal time slices: 2020 baseline and simulated 2030 EED and BURD scenarios. Each time slice was fitted with baseline resistance values for land-use classes based on their hypothesized hindrance to species movement and ecological processes. These values were then refined by a suite of natural factors, such as topography, slope aspect, proximity to water bodies, soil properties and meteorological conditions, and socio-economic variables such as GDP, population density, distance to transport infrastructure (ordinary roads, expressways and railways), distance to settlements and distance to surface water. All parameters were normalized and integrated to generate composite resistance surfaces for the three time slices.

2.7. Ecological network construction

Using the composite resistance surfaces, we treated ecological source patches as origin–destination pairs. Under a Minimum Cumulative Resistance (MCR) model, we calculated the least-cost paths available in each case and then delineated ecological corridor networks under each scenario. Redundant or unrealistically short corridors were screened and merged to obtain a structurally coherent "source–corridor–node" backbone. Corridor accessibility and flow-carrying capacity were then evaluated using indicators such as corridor length, mean resistance, and cumulative current, the latter derived by coupling the network with circuit theory (Gao *et al.*, 2024).

$$MCR = \int \min \sum_{j=m}^{i=n} (D_{ij} \times R_i) \quad (1)$$

Where D_{ij} denotes the spatial distance travelled from landscape unit j to unit i and $R_i$is the resistance value that ecological flows must overcome when passing through cell i.

3. Result

3.1. Spatiotemporal evolution of LUCC patterns (2000–2020)

For the three observation years of 2000, 2010 and 2020, the land-use change in the Dawen River Basin was mainly marked by the outward expansion of the built-up land, coupled with a persistent loss in ecological land. Cropland, forest, and grassland area was 6,135.93 km^2, 1,120.37 km^2, and 1,121.98 km^2, respectively; typical cropland–forest–grassland mosaic (2000). Cropland size fell to only 5,889.02 km^2, forest and grassland to 1,045.38 km^2 and 880.69 km^2, while built-up land increased to 1,567.17 km^2 along the Tai'an–Feicheng–Laiwu–Xintai transport corridor and surrounding major urban nodes; surface water area increased by a small amount to 486.49 km^2. Over the next decade, this extension of built-up land extended along this axis reaching 1,740.40 km^2 (2020). By contrast, forest and grassland decreased to 640.73 km^2 and 464.88 km^2 respectively and water bodies decreased from 427.14 km^2 to 314.84 km^2, with different tributaries (e.g., Chaiwen River) showing flow interruption and channel narrowing. While cropland area returned to an estimated 6,729.49 km^2 by the end of the second decade, recovery resulted in only a handful of patches; this was far from sufficient to recapture the earlier, more continuous cropland–forest–grassland configuration (Figure 3).

3.2. Simulated land-use patterns in 2030 under the EED and BURD scenarios

Both the EED and BURD scenarios substantially reshape the projected land-use composition in 2030. Cropland continues to dominate the dominant class in both cases, compared to the 2020 baseline, but is limited to a narrow range of about 62% (61.65-63.23%) of the total; built-up land is capped at only about 22.79% of the total, clearly signalling a brake on further urban expansion (Figure 4a). Cropland makes up a slightly smaller share under EED, whereas grassland, like the grain-pasture-forest type, provides a relatively larger share under EED and under this scenario, it reinforces the ecological production space. By contrast, under BURD a larger cropland share (63.23%) combined with a compressed grassland fraction (4.18%) makes land space available for the rural multifunctional land and public-service areas (Figure 4b). The forest and water areas differ only marginally between the two scenarios, demonstrating a conditionally fixed total ecological land area under strict ecological management.

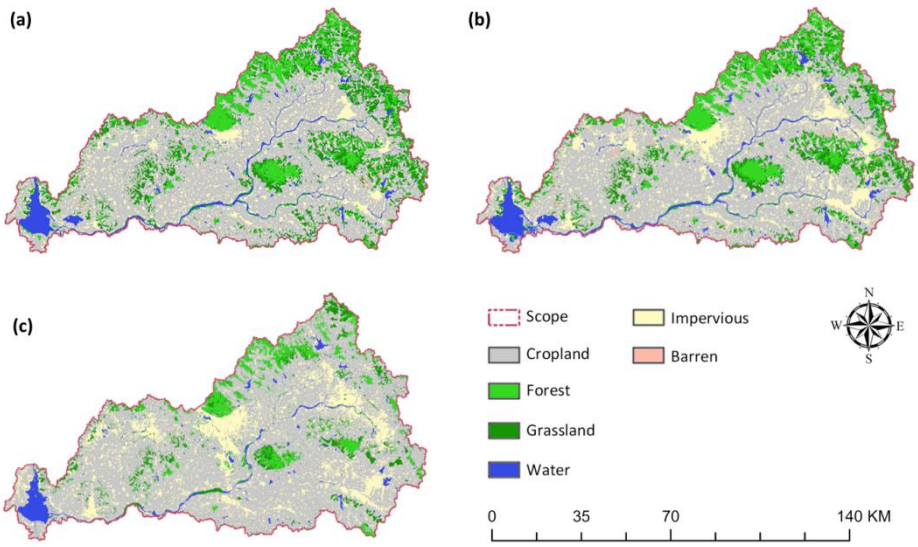


Figure 3. Land-use change in the Dawen River Basin from 2000 to 2020 (a.2000, b.2010, c.2020). Source: author's own drawing.

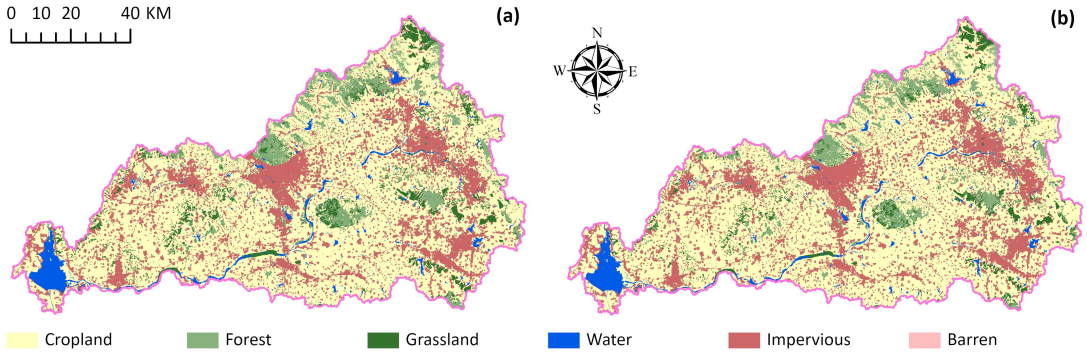


Figure 4. Simulated land use in 2030 (a. EED, b. BURD). Source: author's own drawing.

3.3. Scenario-driven restructuring of ecological sources

The 2020 baseline scenario (BS) allows MSPA to highlight 12 ecological source areas comprising a combined area of only about 316.6 km^2 (Figure 5a). Sources are few and spatially characterised by "fragmented edges and weakly connected central zones": the major ecological backbone displays a highly unbalanced structure with small patches in the east, tenuous linkages in the centre and isolated spots in the western segment.

Both EED and BURD raise the number and area of sources with respect to the CS, but to structurally different consequences, whereby in comparison to the CS scenario, the number of ecological sources doubles to 24 under the EED scenario and their total area expands to approximately 535.5 km² (Figure 5b). Large, contiguous core patches emerge along the central Shandong piedmont belt and on both sides of the main river valleys, yielding a pattern that is more clustered in the east and more river-aligned in the west. Under BURD, 22 sources are identified with a slightly larger total area of about 553.7 km², with most of the newly added sources forming mainly small to medium patches in the urban-rural transition

zones, which give a polycentric point-line structure. In such a structure, key ecological sources are no longer restricted to the mountains and major river valleys. Rather, several smaller patches extend into township hinterlands and urban-rural margins, broadening the coverage of population distributions and spaces of daily life, albeit with a small decrease in individual sources' size and integrity versus EED. Overall, the EED scenario strengthens a centralised, basin-scale ecological backbone because of an increased share of large core sources and high-grade corridors, whereas the BURD scenario favours the provision of medium and small sources and short-range corridors in urban-rural transition areas to provide a more polycentric, locally-focused ecological network.

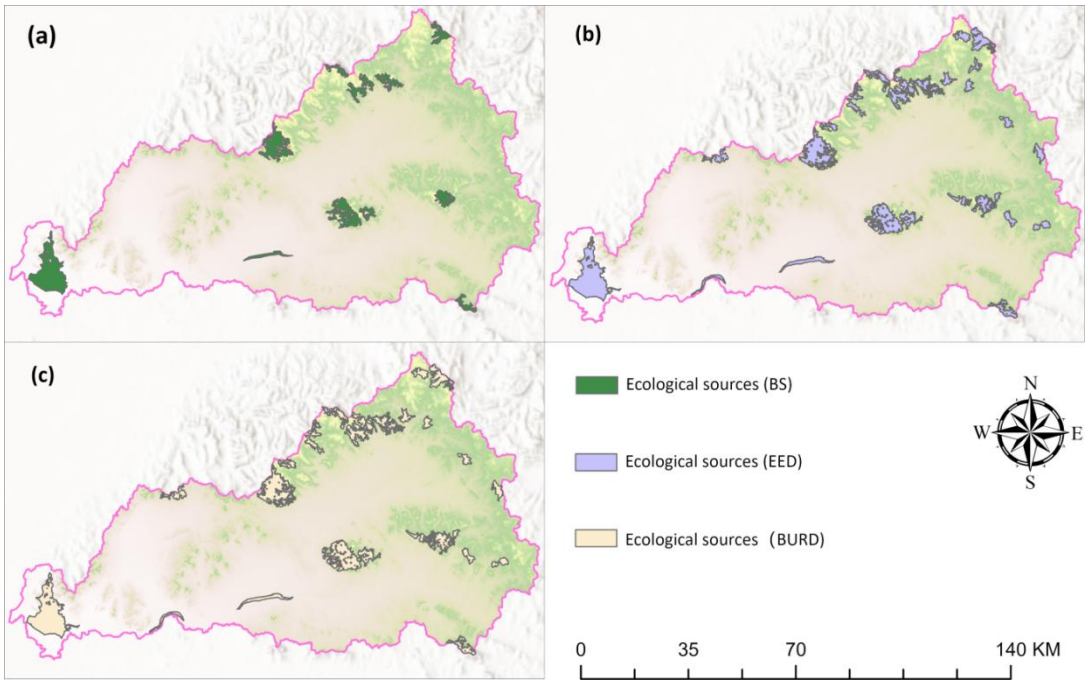


Figure 5. Spatial distribution of ecological sources under the three scenarios(a.BS, b.EED, c.BURD). Source: author's own drawing.

3.4. Ecological network configurations under different scenarios

As a 2020 baseline (BS), a mere 25 ecological corridors are found, with a total length of 1,676.35 km. The network shows a strongly skewed "multi-core east-hub-like centre-isolated west" pattern, highly dependent on a few long-distance corridors and mostly weak connectivity overall (Figure 6a). Under EED, however, the number of corridors of the network increases to 54 and the length is decreased to 1,135.39 km. The proportion of Class 4-5 (high-grade corridors) in total corridor length increases from 20% to 27.78%, and a more defined backbone is built, including a northern piedmont ring, a southern valley trunk, and a central radial hub. In other words, EED rearranges the network into a denser "north ring-south trunk-central hub" structure that improves redundancy and resistance to disturbance without expanding the total corridor mileage (Figure 6b).

Under BURD, 46 corridors are identified with a further shortened total length of 890.23 km(Figure 6c). The network contracts towards a polycentric, short-range configuration: numerous short corridors weave township nodes and rural multifunctional source areas into a dense local network, with high-grade corridors accounting for about 28.26% of total length. The resulting backbone aligns more closely with 15-30 minute commuting and service catchment scales, although around Dongping Lake, the system still

exhibits a weak point, with strong dependence on a few main corridors. Taken together, the baseline scenario is characterized by a small number of long-distance main corridors coexisting with multiple network bottlenecks; EED markedly enhances basin-scale backbone connectivity and redundancy, whereas BURD primarily strengthens local connectivity and spatial equity by increasing medium- and short-distance corridors in urban-rural transition zones.

3.5. Ecological network responses to urban–rural coordinated development

From the perspective of urban-rural coordination, EED and BURD represent two distinct yet complementary pathways of ecological network optimisation. EED primarily strengthens basin-scale connectivity by expanding large core sources along mountain-valley belts and increasing high-grade corridors, thereby enhancing the network's capacity to buffer regional ecological risks and resist large-scale fragmentation. However, its contribution to short- and medium-distance linkages and local accessibility in urban-rural transition zones remains limited.

By contrast, BURD maintains ecological redlines and the overall scale of core sources, while integrating rural multifunctional land and public-service spaces into medium- and small-scale nodes and secondary corridors. By preferentially allocating new sources and corridors to urban-rural fringe areas, BURD significantly improves near-distance accessibility for commuting, public services, and everyday ecological use, although at the cost of some reduction in the continuity and carrying capacity of long-distance, high-grade corridors.

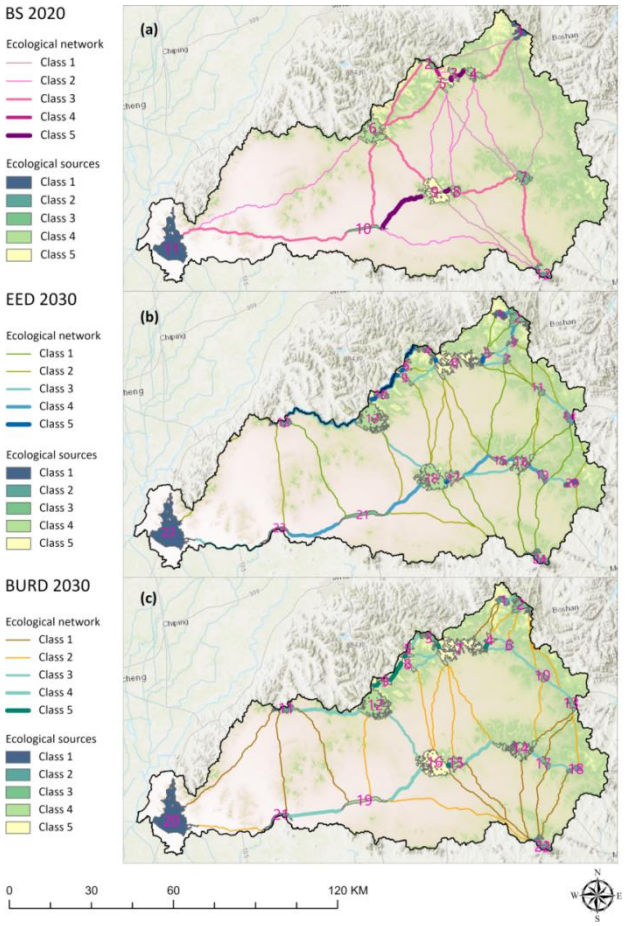


Figure 6. Ecological network structures under three scenarios (a.BS, b.EED, c.BURD). Source: author's own drawing.

4. Discussion

Methodologically, this study provides a transferable, scenario-driven framework linking land-use optimisation, ecological network construction, and urban-rural coordination analysis, and offers spatially explicit support for basin-scale territorial planning under different development priorities (Sun et al., 2022). The contrast between the EED and BURD scenarios further shows that ecological security and urban-rural coordination should be treated not as competing agendas, but as complementary planning tasks at different spatial scales: EED is more effective for safeguarding the basin-scale ecological backbone, whereas BURD is better suited to improving spatial equity in urban-rural transition zones through rural public services, multifunctional land, and local ecological linkages. Accordingly, effective

implementation requires cross-jurisdictional basin governance combined with county- and township-level planning, supported by differentiated zoning and scenario-based planning tools. At the same time, the ecological networks identified here are not only biophysical structures, but also spatial conditions that may shape community well-being, daily mobility, and access to ecological spaces. However, limitations remain, as resistance surfaces are still mainly derived from static macro-scale factors and the assessment does not yet fully incorporate ecosystem services, economic performance, or community-level social impacts such as livelihood change and unequal service accessibility (Zhang et al., 2024). Future research should therefore integrate ecosystem service assessment, carbon accounting, participatory planning, stakeholder preferences, socio-demographic indicators, and comparative applications across multiple basins to test and refine the framework (Iwaniec et al., 2020).

5. Conclusion

Based on the lower Dawen River Basin as a representative case, this study developed a basin-scale scenario framework that integrates CA-Markov-MOP-PLUS with MSPA-MCR and circuit theory (Wang *et al.*, 2024). By linking LUCC scenario simulation, land-use optimisation, and ecological network construction within a single analytical pathway (Xiao *et al.*, 2024), the framework reveals how alternative development trajectories reshape ecological networks and urban-rural spatial patterns.

From 2000 to 2020, built-up land expanded outward while ecological land contracted, driving ecological sources toward mountain areas and remnant wetlands. Although cropland partly recovered in the later period, its scattered pattern did not restore the continuity of ecological patches or corridor integrity, indicating that land-class recovery cannot substitute for network-level repair. Under strict ecological and cropland protection, the EED scenario expands piedmont-valley core sources and high-grade corridors, transforming a trunk-dominated network with bottlenecks into a more redundant ring-and-trunk structure. By contrast, BURD maintains overall source area while redistributing medium and small sources, together with mid- and short-distance corridors, into urban-rural transition zones, thereby strengthening local connectivity and spatial balance.

From the perspective of urban-rural coordination, EED and BURD should be understood as complementary, scale-differentiated pathways rather than competing options. EED is more effective in securing the basin-scale ecological backbone, whereas BURD is better suited to densifying short-range ecological links around settlements and supporting daily mobility, public services, and local ecological use. In highly contested human-environment regions of the lower Yellow River, neither a purely ecology-first strategy nor an exclusively equity-oriented strategy can simultaneously achieve ecological integrity and spatial balance. A combined approach, in which EED defines the backbone and BURD refines the local structure, therefore offers greater planning potential.

6. References

Chen, K. *et al.* (2020) 'Land use transitions and urban-rural integrated development: Theoretical framework and China's evidence', *Land Use Policy*, 92, p. 104465.

Chen, Y. *et al.* (2020) 'Sustainable development in the Yellow River Basin: Issues and strategies', *Journal of Cleaner Production*, 263, p. 121223.

Ding, M. *et al.* (2022) 'Construction and optimization strategy of ecological security pattern in a rapidly urbanizing region: A case study in central-south China', *Ecological Indicators*, 136, p. 108604.

Felipe-Lucia, M.R. *et al.* (2020) 'Land-use intensity alters networks between biodiversity, ecosystem functions, and services', *Proceedings of the National Academy of Sciences*, 117(45), pp. 28140–28149.

Gao, J. *et* al. (2024) 'Ecological network assessment in dynamic landscapes: Multi-scenario simulation and conservation priority analysis', *Land Use Policy*, 139, p. 107059.

Hasan, S.S. et *al.* (2020) 'Impact of land use change on ecosystem services: A review', *Environmental Development*, 34, p. 100527.

Iwaniec, D.M. *et al.* (2020) 'The co-production of sustainable future scenarios', *Landscape and Urban Planning*, 197, p. 103744.

Li, L. *et al.* (2024) 'Global Land Use Change and Its Impact on Greenhouse Gas Emissions', *Global Change Biology*, 30(12), p. e17604.

Liang, X. *et al.* (2021) 'Understanding the drivers of sustainable land expansion using a patch-generating land use simulation (PLUS) model: A case study in Wuhan, China', *Computers, Environment and Urban Systems*, 85, p. 101569.

Liu, P. *et al.* (2022) 'Comprehensive evaluation on water resources carrying capacity based on water-economy-ecology concept framework and EFAST-cloud model: A case study of Henan Province, China', *Ecological Indicators*, 143, p. 109392.

Liu, Y., Li, J. and Yang, Y. (2018) 'Strategic adjustment of land use policy under the economic transformation', *Land Use Policy*, 74, pp. 5–14.

Sun, X. *et al.* (2022) 'An urban hierarchy-based approach integrating ecosystem services into multiscale sustainable land use planning: The case of China', *Resources, Conservation and Recycling*, 178, p. 106097.

Voskamp, A. *et al.* (2023) 'Utilizing multi-objective decision support tools for protected area selection', *One Earth*, 6(9), pp. 1143–1156.

Wang, B. *et al.* (2024) 'Ecological security pattern based on remote sensing ecological index and circuit theory in the Shanxi section of the Yellow River Basin', *Ecological Indicators*, 166, p. 112382.

Xiao, S. *et al.* (2024) 'Constructing ecological network based on multi-objective genetic algorithms: a case study of Changsha City, China', *Landscape Ecology*, 39(12), p. 212.

Xu, J., Renaud, F.G. and Barrett, B. (2022) 'Modelling land system evolution and dynamics of terrestrial carbon stocks in the Luanhe River Basin, China: a scenario analysis of trade-offs and synergies between sustainable development goals', *Sustainability Science*, 17(4), pp. 1323–1345.

Yu, K. (1995) 'Ecological Security Patterns in Landscapes and GIS Application', *Annals of GIS*, 1(2), pp. 88–102.

Zhang, F. et *al.* (2024) 'Application of MSPA-MCR models to construct ecological security pattern in the basin: A case study of Dawen River basinMSPA-MCR', *Ecological Indicators*, 160, p. 111887.

Zhang, Song *et al.* (2025) 'Construction of forest ecological security patterns based on MSPA model and circuit theory in the Desertification Control forests in South China Karst', *npj Heritage Science*, 13(1), p. 432.