Land Use Changes on Both Sides of the Tumen River Basin (China and North Korea) over the Past 20 Years

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Abstract

This study selects the Tumen River Basin as the research area. By downloading Global30 land use data for 2000, 2010, and 2020, we utilized ArcGIS for mask extraction, raster reclassification, and data integration to standardize land categories and facilitate comparative analysis. Subsequently, we systematically analyzed the area, change magnitude, and dynamic degree of land use on both sides of the Tumen River Basin over the past two decades. Through spatial operations such as overlay analysis in ArcGIS, we further employed land use transfer matrices and transition probability matrices to examine the characteristics of land use type conversions. Key findings include:

1.Forest reduction: Forest areas on both sides of the basin decreased, primarily due to insufficient environmental awareness and overexploitation of resources in the early 2000s.

2.Water body expansion: China's water conservancy projects increased total water area by approximately 66.39 km², while North Korea's water bodies remained stable.

3.Policy-driven shifts: Land use changes were closely linked to national policies and human activities, with recent improvements attributed to sustainable development initiatives

Keywords: Tumen River Basin; Cross-border comparison (China-North Korea); Land use change; Dynamic degree; Transfer matrix

Introduction

Since the 1980s, global environmental change research has rapidly developed under the promotion of international organizations such as the International Council for Science (ICSU) and the International Social Science Council (ISSCU). Land use change (LUC), defined as human-induced alterations to land cover and management practices, transforms natural ecosystems into anthropogenic systems. This study investigates LUC in the Tumen River Basin—a transboundary region spanning China, North Korea, and Russia—to analyze driving factors, ecological impacts, and implications for sustainable development.

1.1 Research Background and Significance

Land, as the fundamental ecological element for human survival and development, has progressively transitioned from a basic environmental component to an essential object and means of labor. Serving as the material foundation for human production and livelihood, the investigation of land use changes and the optimization of land utilization patterns have become crucial research priorities. In this context, ArcGIS technology plays a pivotal role in land use change studies, significantly enhancing the efficiency of remote sensing data processing and analytical workflows. The rapid advancement of remote sensing technology in recent years has not only diversified the acquisition channels for land use information but also substantially reduced the temporal and economic costs associated with data collection. These technological breakthroughs have greatly facilitated the advancement of land use change research.

The Tumen River Basin presents a unique geographical case as an international boundary river traversing three nations. From its headwaters to Fangchuan Village in Hunchun City, the Tumen River serves as the Sino-North Korean boundary, while its final 15-kilometer stretch to the estuary forms the Russia-North Korean border. This distinctive tri-national boundary configuration is exceptionally rare in global hydrological geography. Such complex geopolitical circumstances necessitate international collaborative governance in resource development and utilization within the basin. Rational planning and management of the Tumen River Basin can not only stimulate economic growth in riparian regions but also foster international cooperation among bordering nations.

China's 11th Five-Year Plan explicitly emphasizes the establishment of a resource-efficient and environmentally sustainable society. In this context, conducting systematic research on land use changes in the Tumen River region holds significant implications for implementing national strategic plans. This study leverages the unique advantages of remote sensing technology, including its extensive coverage capacity, rapid data acquisition capabilities, and cyclical monitoring features, to extract and analyze land use variations across both spatial and temporal dimensions. The research outcomes are expected to provide critical decision-making support for rational water resource management and offer substantial theoretical and practical contributions to regional sustainable development.

1.2Study purpose

With the rapid economic development in recent years, human activities related to natural resources have become increasingly active, leading to various positive and negative issues in land use. Therefore, this study focuses on the Tumen River Basin as the research area. By analyzing the dynamic changes and transfer characteristics of land use on both the Chinese and North Korean sides of the Tumen River Basin over the past 20 years, the study aims to identify the reasons for land use changes and the driving forces behind these changes. The goal is to comprehensively understand the land use changes in the Tumen River Basin from both temporal and spatial perspectives, thereby achieving rational allocation and scientific management of land resources. This will help maximize social and environmental benefits, ensure the sustainable development of land resources in the Tumen River Basin, and provide valuable insights for future research on land use changes in the Tumen River Basin and the broader Northeast Asia region.

1.3 Research Status at Domestic and International Levels

In recent years, heightened global awareness of environmental conservation and rapid advancements in scientific technology have catalyzed the emergence of sustainable development paradigms. As land use change constitutes an indispensable component of global anthropogenic activities, its investigation inherently aligns with the principles of sustainable development.

The Tumen River Basin, the focal area of this study, has garnered significant attention in Northeast Asia due to its transboundary water resource dynamics. The evolution of remote sensing technology, particularly improvements in spatial resolution, has revolutionized the monitoring and analysis of surface water resource variations within the basin. Given the temporally sensitive nature of land use patterns, continuous theoretical updates are imperative to provide researchers with actionable insights and methodological references.

Since the inception of the Land-Use and Land-Cover Change (LUCC) core project jointly launched by the International Council for Science (ICSU) and the International Social Science Council (ISSU) in 1993, global change research has entered a phase of accelerated development. International organizations and national entities have subsequently initiated related programs. Notably, the International Institute for Applied Systems Analysis (IIASA) launched a triennial project in 1995 titled "Modeling Land Use/Cover Change in Europe and Northern Asia," which systematically analyzed the spatial characteristics, temporal dynamics, and environmental impacts of land use/cover changes from 1900 to 1990. The project further simulated potential land use trajectories over the subsequent 50 years under evolving global environmental, demographic, and economic conditions, thereby informing policy formulation.

Contemporary research on land use change primarily addresses five conceptual frameworks, two focal themes, and several critical domains. Representative studies include Wang Jiawei et al.'s investigation of land use dynamics in Huangling County [1], and Liu Chen's analysis of spatiotemporal patterns and driving forces in Urumqi [2]. Methodologically, the land use transfer matrix and dynamic degree analysis—employed in this study—remain cornerstone approaches in the field.

1.4 Research Content and Technical Framework

This study employs mask extraction and raster reclassification techniques to quantify land use type transitions within the Chinese and North Korean sections of the Tumen River Basin across three temporal nodes (2000, 2010, 2020). Through this spatiotemporal analysis, the research aims to elucidate the evolutionary characteristics of land use patterns over two decades, while evaluating the impacts of anthropogenic activities and natural disasters. The technical framework encompasses the following components:

(1)Dynamic Degree Analysis: Conduct spatiotemporal quantification of land use changes across the basin, including calculation of dynamic degree indices and characterization of transitional patterns. Cross-temporal comparisons of land class areas will be performed to derive comprehensive dynamic assessments.

(2)Land Use Transfer Matrix Analysis: Utilize GIS-based spatial analysis methodologies to construct transfer matrices for the three study periods, systematically mapping inter-class conversion pathways over the 20-year span.

By synthesizing the driving mechanisms of land use change and conducting comparative analyses between the Chinese and North Korean riparian zones, this research seeks to identify universal patterns and developmental trends in transboundary land use evolution within the Tumen River Basin.

2 Materials and Methods

2.1Overview of the Tumen River Basin

The study area of this research is the Tumen River Basin, which originates from the eastern foothills of the main peak of the Changbai Mountain Range on the China-North Korea border. It is located between 128°17' to 131°18'E and 41°59' to 44°1'N. The Tumen River (also known as the Duman River or Tumannaya River) originates from Changbai Mountain and has a total length of 505.4 km. Its upper and middle reaches form the boundary between China and North Korea, stretching approximately 490.4 km. The lower reaches, from the tri-border point of China, North Korea, and Russia on the Tumen River to its estuary, serve as the boundary between North Korea and Russia, extending about 15 km, before finally flowing into the Sea of Japan. The total basin area of the Tumen River is 33,168 square kilometers. The basin predominantly traverses mountainous terrain, with a total elevation drop of 1,297 meters, resulting in significant hydropower potential and a well-preserved ecological environment.

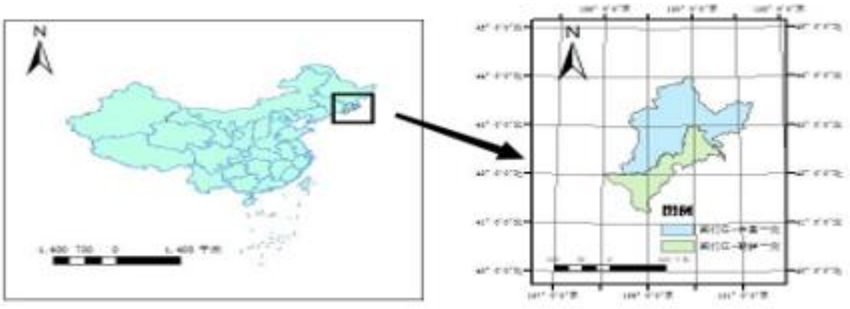

Figure 2-1: Schematic Diagram of the Geographical Location of the Study Area

The Tumen River was referred to as "Tuomen" during the Liao Dynasty. During the Jin and Yuan Dynasties, it was called the "Aiyeku River," with its lower reaches known as the "Tongmen River." In the Ming Dynasty, it was called the "Aye Ku River," with its lower reaches referred to as the "Tumen River." During the Qing Dynasty, the upstream section was named the "Dalang River," while the section below Tumen City was called the "Tongmen Water" or "Tumen River." During the Kangxi era, it was referred to as "Tumen," and Emperor Gaozong (Qianlong) of the Qing Dynasty officially designated it as "Tumen" in the Jinshi Yujie (Interpretation of Jin Dynasty Terms). In 1962, an agreement between China and North Korea established that the section downstream of the "Hongtushui" and "Niliushui" would be called the Tumen River. During the Qing Dynasty, the Tumen River was translated from Manchu as the "Tumen River."

As the only route for China to access the Sea of Japan, the Tumen River's coastal access rights were lost due to unequal treaties in modern history. It was not until 1992 that China regained its access rights to the Tumen River.

The Tumen River Basin is located in the main area of the Changbai Mountains, where the elevation difference is the greatest. Due to the influence of terrain height, various climatic factors exhibit vertical variations. The common characteristics of this climatic zone are humidity and abundant rainfall. On a broader scale, cold, wet, and alpine conditions remain its fundamental features. Only in the southern slopes of the Ji'an Lingnan region, which has a relatively low latitude and faces south, does the area experience the highest temperatures and abundant precipitation in Jilin Province, making it a place rich in both water and thermal resources.

The left bank of the Tumen River belongs to the Yanbian Korean Autonomous Prefecture in Jilin Province, China. It is the only Korean autonomous prefecture in China and the largest Korean ethnic enclave in the country. The prefecture covers an area of 42,700 square kilometers and has a total population of 2.146 million, including 778,000 ethnic Koreans, accounting for 36.3% of the prefecture's population and 43% of the total Korean population in China. The region boasts 5 national-level nature reserves and 8 provincial-level nature reserves, with a forest coverage rate of 80.8%. It is home to 367 species of wild animals, including the wild Siberian tiger, known as the "king of beasts," and 3,890 species of wild plants, including over 850 medicinal plants. The area is renowned for producing ginseng, deer antlers, and mink fur, collectively known as the "Three Treasures of Northeast China." Among these, the production of ginseng and antlers ranks first in the world. As the main production area of ginseng, often referred to as the "king of herbs," Yanbian currently has 3,627 hectares of cultivated ginseng (garden ginseng), with an annual production of 9,300 tons of fresh ginseng, accounting for more than half of Jilin Province's total output. Yanbian is also famous for its specialty products such as Yanbian rice, cattle, edible fungi, tobacco leaves, honey, Schisandra chinensis, and apple pears. The apple pear cultivation area spans 5,492 hectares, making it the largest apple pear production base in Asia. Additionally, the region's mineral water resources are among the few concentrated distribution areas of natural drinking mineral water in China. The quality of this mineral water has been recognized by international authorities as world-class, placing Changbai Mountain alongside the European Alps and the Russian Caucasus as one of the world's three major mineral water production areas. The daily water output in the Erdaobaihe area alone reaches 120,000 cubic meters, indicating significant development potential. Yanbian is China's only region that combines border openness to Northeast Asia with the development of the Tumen River Basin. The prefecture currently has 2 national-level development zones, 3 provincial-level economic development zones, and 5 industrial concentration zones.

The right bank of the Tumen River belongs to North Korea's Ryanggang Province and North Hamgyong Province. Ryanggang Province is located in the northern inland region, bordered to the north by the Yalu River and the Tumen River, which serve as the boundary with China, to the south by the Pujonryong Mountains, which separate it from South Hamgyong Province, to the east by North Hamgyong Province, and to the west by Chagang Province. Established in 1954, the province covers an area of 14,000 square kilometers and encompasses most of the Kaema Plateau and the Paektu Plateau, known as the "roof of Korea." North Hamgyong Province is located in the northeastern part of North Korea, bordered by the Sea of Japan to the east and the Tumen River to the north.

On the left bank of the Tumen River estuary lies the Khasan District of Russia's Primorsky Krai. The northern part of Khasan District borders Ussuriysk and the Nadezhdinsky District of Primorsky Krai; to the west, it shares a border with China; to the south, it runs along the Tumen River basin, adjacent to the Democratic People's Republic of Korea; and to the east, it is bounded by the natural coastline of Peter the Great Bay.

2.2 Data Sources and Processing

The data used in this study were obtained from the Globalland30 website, consisting of remote sensing raster data for land use in the Tumen River Basin for the years 2000, 2010, and 2020, with a resolution of 30 meters.

First, the downloaded raster data were subjected to mask extraction to obtain three periods of raster data for the Chinese and North Korean sides over the past two decades. Subsequently, the extracted raster data were reclassified to preliminarily process the data, unifying land use categories and facilitating comparison.

2.3 Research Methods

2.3.1 Raster Reclassification

Raster reclassification refers to the process of reassigning the original pixel values of a raster to a new set of values and outputting the results. This involves grouping specific values from the original data, reclassifying a set of raster data according to the same classification levels, and setting null values. Since the initial data obtained varies across different time periods and locations, and the classification standards differ over time, raster reclassification helps unify land use categories, making it easier to compare changes in land use types.

2.3.2Land Use Change Dynamics

We typically use the land use dynamics degree to describe the rate of land use change, which can be divided into single land use dynamics degree and comprehensive land use dynamics degree. Among these, the single land use dynamics degree can scientifically and intuitively reflect the spatiotemporal evolution pattern of a specific land use type. The expression for the single land use dynamics degree is as follows:

$$K=(Ub-U\alpha)U\alpha\times 1T\times 100\% K=U\alpha(Ub-U\alpha)\times T1\times 100\%$$

Where:

- KK represents the degree of dynamic change of the land use type,
- Uα$U\alpha$ is the percentage of the land use type relative to the total study area at the beginning of the study period,
- UbUb is the percentage of the land use type relative to the total study area at the end of the study period,
- TT is the time interval of the study period.

By applying the land use dynamics degree to analyze the dynamic changes in land use types, we can accurately reflect the intensity of changes in land use/cover within a region. This allows us to derive a more precise result of land use changes and identify the reasons behind land use transitions.

2.3.3 Land Use Transition Matrix

The land use transition matrix is a two-dimensional matrix derived from the change relationships in land cover status between different time periods within the same region. By analyzing the transition matrix, it is possible to determine the mutual transformations between different land use types across two time periods. It describes the land use categories that have changed, their locations, and the extent of change between different years. The matrix not only reflects static data on the area of each land use type within a fixed region and time but also provides more detailed information on the area transferred out of each land use type at the beginning of the period and the area transferred in at the end of the period. Starting from area changes, it reflects regional land use changes. Changes in area are first reflected in the total changes of different land use types. By analyzing the total changes in land use types, we can understand the overall trends in land use change and the structural shifts in land use.

3 Results and Analysis

3.1 Tumen River Basin Land Use Reclassification Results

Through processing three phases of remote - sensing images, the raster reclassification method in ArcGIS 10.8 was used to obtain the land - use classification results for the Tumen River Basin in 2000, 2010, and 2020. For easier viewing, the results are presented in the figure below：

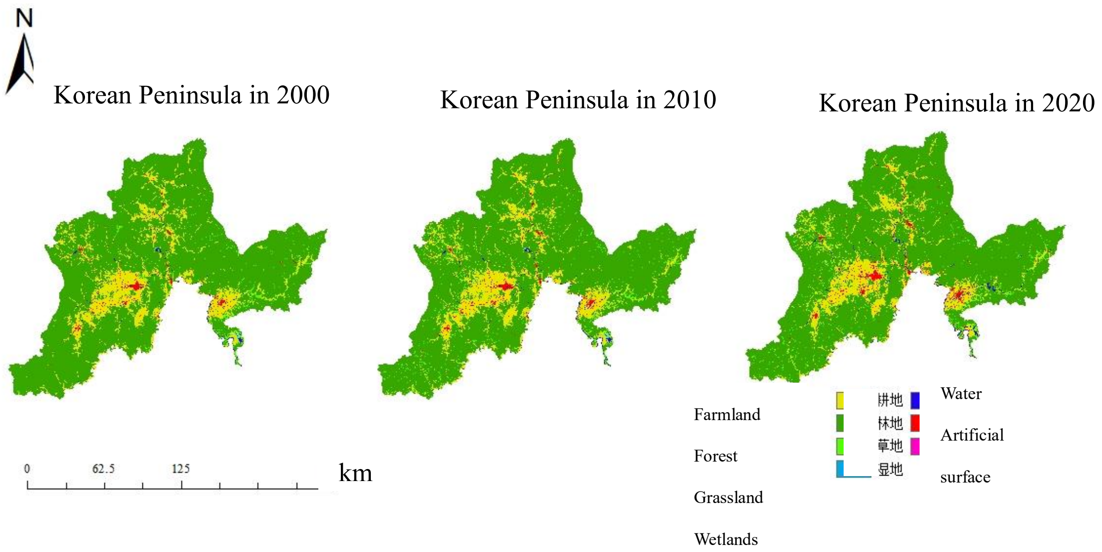

Figure 3.1 (a) Raster Reclassification on the Chinese Side

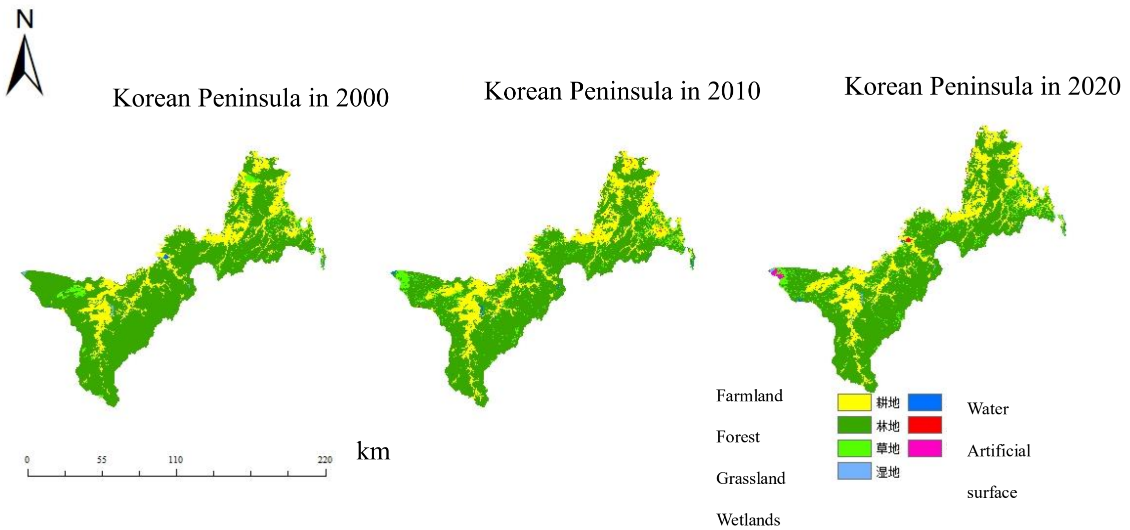

Figure 3.1 (b) Raster Reclassification on the North Korean Side

3.2 Analysis on the Characteristics of Land Use Dynamic Changes in the Tumen River Basin over the Past 20 Years

In this study, the analysis of land - use dynamic changes in the Tumen River Basin over the past 20 years is conducted from temporal and spatial perspectives. First, we collate the overall land - use area on both sides of the basin for different years and the changes between two years. Then, we calculate the single - land - use change rate using formulas. Finally, we compare and analyze the land - use changes on both sides over the past 20 years using the obtained data.

3.2.1 Analysis on the Characteristics of Land - Use Dynamic Changes in the Chinese Part of the Tumen River Basin over the Past 20 Years

The analysis of land - use dynamic changes on the Chinese side is done by collating the total area, land - use change volume, and change rate over 20 years. Details are in Table 3.2.1(a) and 3.2.1(b).

Table 3.1 (a) Area of the Chinese Part of the Tumen River Basin over the Past 20 Years (Unit: km²)

Land Type Year	2000	2010	2020
Grassland	316.2	576.3	568.4
Farmland	3448.7	3509.1	3239.7
Forest	19,086.3	18725.0	18790.5
Artificial surface	261.7	280.9	425.0
Wetland	9.9	10.1	2.5
Water	98.9	120.4	165.3

Table 3.2.1 (b) Changes and Change Rates of Land Use Types on the Chinese Side of the Tumen River Basin over the Past 20 Years (km², %)

Year / Land Type	2000-2010		2010-2020		2000-2010	
	Change	Rate	Change	Rate	Change	Rate
Grassland	260.081	0.082	-7.829	-0.014	252.252	0.798
Farmland	60.4	0.002	-269.388	-0.077	-208.988	-0.061
Forest	-361.316	-0.002	65.546	0.004	-295.77	-0.015
Artificial surface	19.197	0.007	144.037	0.513	163.234	0.624
Wetland	0.163	0.002	-7.605	-0.754	-7.442	-0.75
Water	21.462	0.022	44.973	0.374	66.435	0.672

From the table, between 2000 and 2010, grassland and cultivated land increased, while forest, artificial surfaces, wetlands, and water bodies decreased. This might be due to rapid economic development and intensified human exploitation.

Between 2010 and 2020, there was a significant reduction in cultivated land, along with minor decreases in wetlands and grasslands. Forest, artificial surfaces, and water bodies all expanded. This likely reflects the implementation of sustainable development concepts, the grain for green program, and enhanced environmental awareness. The growth in artificial surfaces also indicates ongoing economic development.

In conclusion, over the past 20 years, land use on the Chinese side of the Tumen River Basin has been relatively extensive and problematic, but it is moving in a positive direction.

3.2.2 Analysis on the Characteristics of Land - Use Dynamic Changes in the North Korean Part of the Tumen River Basin over the Past 20 Years

The analysis of land - use dynamic changes on the North Korean side is done by collating the total area, land - use change volume, and change rate over 20 years. Details are in Table 3.2.2(a) and 3.2.2(b).

Table 3.2.2 (a) Area of the North Korean Part of the Tumen River Basin over the Past 20 Years (Unit: km²)

Year / Land Type	2000	2010	2020
Farmland	2,146.3	2,546.6	2,503.2
Forest	8,338.0	7,615.9	7,667.0
Grassland	276.1	601.5	551.6
Water	49.5	55.8	62.2
Artificial surface	62.2	52.3	61.5
Wetland	0.0	0.0	0.0

Table 3.2.2 (b) Changes and Change Rates of Land Use Types on the North Korean Side of the Tumen River Basin over the Past 20 Years (km², %)

Year / Land Type	2000-2010		2010-2020		2000-2010	
	Change	Rate	Change	Rate	Change	Rate
Farmland	400.307	0.019	-43.425	-0.002	356.882	0.017
Forest	-722.033	-0.009	51.101	0.001	-670.932	-0.008
Grassland	325.325	0.118	-49.883	-0.008	275.442	0.1
Water	6.337	0.013	6.4113	0.011	12.748	0.026
Artificial surface	-9.892	-0.016	9.1874	0.018	-0.705	-0.001
Wetland	0.019	0	-0.019	-0.1	0	0

From the table, between 2000 and 2010, in the North Korean part of the Tumen River Basin, there was a substantial increase in cultivated and grassland areas, alongside a significant decrease in forest area. This may have resulted from excessive deforestation and land - clearance during that decade.

Between 2010 and 2020, cultivated and grassland areas slightly decreased, while forest area showed some signs of recovery.

This could be attributed to policy implementation and enhanced public environmental awareness, which facilitated partial ecological restoration. However, the significant increase in bare - land area indicates some land abandonment.

From this, it is evident that the North Korean side urgently needs to strengthen ecological protection, with substantial room for improvement in the management of bare land and forest restoration. This also reflects the extensive nature of land - use methods, leading to the inefficient use of some land.

Overall, the Chinese side has utilized the land in the Tumen River Basin more effectively than the North Korean side. In recent years, the positive results of ecological restoration efforts on the Chinese side have been evident, while North Korea's land - use methods have also shifted towards sustainable development. Both sides have experienced fluctuations in land - use methods, but in recent years, the situation has been relatively stable, with positive trends. The results show that recently, thanks to policies such as the ban on indiscriminate logging, reforestation, the effective implementation of sustainable development concepts, and increased public awareness of nature protection, soil and water conservation in the basin has improved. This is closely linked to national water conservancy projects, with reservoir construction in the basin playing a role in water source conservation and the protection of the ecological environment in the Tumen River Basin.

3.3 Analysis on the Land - Use Transfer Characteristics of the Tumen River Basin over the Past 20 Years

In this study, ArcMap 10.8 was used to analyze land - use data from 2000, 2010, and 2020 on both sides of the Tumen River Basin. Data integration and intersection were applied to overlay the three phases of data for each side, obtaining land - use information for two years. Area was calculated geometrically, and land - use transfer matrices were generated for 2000 - 2010, 2010 - 2020, and 2000 - 2020 (see Tables 3.3.1(a)-(b), 3.3.2(a)-(b), 3.3.3(a)-(b)). These matrices help analyze land - use changes over the past 20 years.

Based on the land - use area transfer matrices, land - use transfer - in and transfer - out matrices were developed (see Tables 3.3.1(c)-(f), 3.3.2(b)-(f), 3.3.3(c)-(f)). They show the transfer - in and transfer - out of land - use objects on both sides of the basin at different times, aiding in understanding the dynamics of land - use changes.

3.3.1 Characteristics of Land Use Type Transfer on the Chinese and North Korean Sides of the Tumen River Basin from 2000 to 2010

Table 3.3.1 (a) Land - use area transfer matrix of the Chinese part of the Tumen River Basin from 2000 to 2010 (Unit: km²)

2000/2010	Grassland	Farmland	Forest	Artificial surface	Wetland	Water	Total
Grassland	197.4	29.6	85.7	0.5	0.1	2.6	316.0
Farmland	21.7	3,251.2	136.8	29.4	0.2	8.8	3,448.1
Forest	351.1	202.0	18,491.7	13.5	0.2	24.4	19,082.9
Artificial surface	3.9	18.0	2.4	236.8	0.0	0.7	261.7
Wetland	0.1	0.3	0.0	0.0	9.0	0.5	9.9
Water	1.8	7.3	5.2	0.8	0.6	83.0	98.6
Total	576.0	3,508.5	18,721.8	280.9	10.1	120.1	23,217.3

Table 3.3.1（b）Land Use Area Transfer Matrix on the North Korean Side of the Tumen River Basin from 2000 to 2010 (Unit: km²)

2000/2010	Grassland	Farmland	Forest	Artificial surface	Wetland	Water	Total
Grassland	99.67	109.43	66.29	0.25	0.1	0.32	275.95
Farmland	13.83	2082.77	40.37	4.67	0.2	4.09	2145.73
Forest	486.81	331.9	7504.78	3.53	0.2	8.68	8335.7
Artificial surface	0.21	17.83	0.28	43.78	0.0	0.07	62.16
Wetland	0.1	0.3	0.0	0.0	9.0	0.5	9.9
Water	0.47	3.99	2.29	0.04	0.6	42.37	49.16

As per the table, from 2000 to 2010, land use types on both sides of the Tumen River Basin changed.

On the Chinese side, grassland grew from 315.96 km² to 575.97 km², arable land slightly increased from 3,448.13 km² to 3,508.45 km², forest land declined from 19,082.93 km² to 18,721.80 km², artificial surfaces rose from 261.74 km² to 280.92 km², wetlands expanded from 9.93 km² to 10.09 km², and water bodies jumped from 98.60 km² to 120.05 km².

On the North Korean side, grassland surged from 275.95 km² to 600.98 km², arable land increased from 2,145.73 km² to 2,545.91 km², forest land fell from 8,335.70 km² to 7,614.01 km², artificial surfaces dropped from 62.16 km² to 52.26 km², and water bodies grew from 49.16 km² to 55.52 km².

In summary, between 2000 and 2010, both sides of the Tumen River Basin saw a reduction in forest land and an increase in grassland and arable land, with similar patterns of land use change.

Table 3.3.1 (c) shows the land use type transfer - out probability matrix of the Chinese part of the Tumen River Basin from 2010 to 2020.

Land Use Type	Grassland	Farmland	Forest	Artificial surface	Wetland	Water	Total
Grassland	62.47%	9.38%	27.14%	0.14%	0.04%	0.83%	100.00%
Farmland	0.63%	94.29%	3.97%	0.85%	0.01%	0.26%	100.00%
Forest	1.84%	1.06%	96.90%	0.07%	0.00%	0.13%	100.00%
Artificial surface	1.50%	6.86%	0.90%	90.48%	0.00%	0.27%	100.00%
Wetland	1.09%	3.11%	0.24%	0.00%	90.60%	4.96%	100.00%
Water	1.77%	7.45%	5.24%	0.77%	0.61%	84.17%	100.00%

Table 3.3.1 (d) presents the land use type transfer - out probability matrix of the North Korean part of the Tumen River Basin from 2010 to 2020.

Land Use Type	Grassland	Farmland	Forest	Artificial surface	Water	Total
Grassland	36.12%	39.65%	24.02%	0.09%	0.12%	100.00%
Farmland	0.64%	97.07%	1.88%	0.22%	0.19%	100.00%
Forest	5.84%	3.98%	90.03%	0.04%	0.10%	100.00%
Artificial surface	0.34%	28.68%	0.45%	70.43%	0.11%	100.00%
Water	0.95%	8.11%	4.65%	0.08%	86.21%	100.00%

From the table, between 2000 and 2010 on the Chinese side of the Tumen River Basin, 9.38% of grassland became cultivated land, 27.14% became arable land, 0.14% became artificial surfaces, 0.04% became wetlands, and 0.83% became water bodies. For cultivated land, 0.63% became grassland, 3.97% became forest, 0.85% became artificial surfaces, and 0.26% became water bodies. Forest land saw 1.84% become grassland, 1.06% become cultivated land, 0.07% become artificial surfaces, and 0.13% become water bodies. Artificial surfaces had 1.5% become grassland, 6.86% become cultivated land, 0.90% become forest, and 0.27% become water bodies. Wetlands saw 1.09% become grassland, 3.11% become cultivated land, 0.24% become forest, and 4.96% become water bodies. Water bodies had 1.77% become grassland, 7.45% become cultivated land, 5.24% become forest, 0.77% become artificial surfaces, and 0.61% become wetlands.

On the North Korean side, 39.68% of grassland became cultivated land, 24.02% became forest, 0.09% became artificial surfaces, and 0.12% became water bodies. For cultivated land, 0.64% became grassland, 1.88% became forest, 0.22% became artificial surfaces, and 0.19% became water bodies. Forest land saw 5.84% become grassland, 3.98% become cultivated land, 0.04% become artificial surfaces, and 0.10% become water bodies. Artificial surfaces had 0.34% become grassland, 28.68% become cultivated land, 0.45% become forest, and 0.11% become water bodies. Water bodies saw 0.95% become grassland, 8.11% become cultivated land, 4.65% become forest, and 0.08% become artificial surfaces.

The comparison shows that on both sides of the Tumen River Basin from 2000 to 2010, most forest land was converted to grassland and cultivated land, mainly due to excessive natural resource exploitation for economic development.

Table 3.3.1 (e) presents the land use type transfer - in probability matrix of the Chinese part of the Tumen River Basin from 2010 to 2020.

Land Use Type	Grassland	Farmland	Forest	Artificial surface	Wetland	Water
Grassland	34.27%	0.84%	0.46%	0.16%	1.19%	2.20%
Farmland	3.76%	92.67%	0.73%	10.47%	2.06%	7.36%
Forest	60.97%	5.76%	98.77%	4.80%	1.64%	20.33%
Artificial surface	0.68%	0.51%	0.01%	84.30%	0.00%	0.58%

Wetland	0.02%	0.01%	0.00%	0.00%	89.14%	0.41%
Water	0.30%	0.21%	0.03%	0.27%	5.97%	69.12%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table 3.3.1 (f) Land Use Type Transfer-in Probability Matrix of the North Korean Side of the Tumen River Basin from 2010 to 2020

Land Use Type	Grassland	Farmland	Forest	Artificial surface	Water
Grassland	16.58%	4.30%	0.87%	0.47%	0.58%
Farmland	2.30%	81.81%	0.53%	8.93%	7.37%
Forest	81.00%	13.04%	98.57%	6.75%	15.63%
Artificial surface	0.04%	0.70%	0.00%	83.77%	0.12%
Water	0.08%	0.16%	0.03%	0.07%	76.31%
Total	100.00%	100.00%	100.00%	100.00%	100.00%

From the table, on the Chinese side in 2010, 3.76% of grassland came from cropland, 60.97% from forest, 0.68% from artificial surfaces, 0.02% from wetlands, and 0.30% from water bodies. For cropland, 0.84% came from grassland, 5.76% from forest, 0.51% from artificial surfaces, 0.01% from wetlands, and 0.21% from water bodies. For forest, 0.46% came from grassland, 0.73% from cropland, 0.01% from artificial surfaces, and 0.03% from water bodies. For artificial surfaces, 0.16% came from grassland, 10.47% from cropland, 4.80% from forest, and 0.27% from water bodies. For wetlands, 1.19% came from grassland, 2.06% from cropland, 1.64% from forest, and 5.97% from water bodies. For water bodies, 2.20% came from grassland, 7.36% from cropland, 20.33% from forest, 0.58% from artificial surfaces, and 0.41% from wetlands. On the North Korean side, 2.30% of grassland came from cropland, 81.00% from forest, 0.04% from artificial surfaces, and 0.08% from water bodies. For cropland, 4.30% came from grassland, 13.04% from forest, 0.70% from artificial surfaces, and 0.16% from water bodies. For forest, 0.87% came from grassland, 0.53% from cropland, and 0.03% from water bodies. For artificial surfaces, 0.47% came from grassland, 8.93% from cropland, 6.75% from forest, and 0.07% from water bodies. For water bodies, 0.58% came from grassland, 7.37% from cropland, 15.63% from forest, and 0.12% from artificial surfaces.

In summary, from 2000 to 2010, most grassland and cropland on both sides of the Tumen River Basin were converted from forest, highlighting the need for stronger environmental protection awareness and sustainable resource management at that time.

3.3.2 Characteristics of Land Use Type Transfer between China and North Korea in the Tumen River Basin from 2010 to 2020

Table 3.3.2 (a) Transfer Matrix of Land Use Area on the Chinese Side in the Tumen River Basin from 2010 to 2020 (Unit:) km²)

2010/2020	Grassland	Farmland	Forest	Artificial surface	Wetland	Water	Total
Grassland	304.0	28.8	220.9	5.8	0.0	16.1	576.1
Farmland	41.9	2,932.8	313.1	172.1	0.0	37.7	3,508.6
Forest	214.7	236.2	18,227.7	15.2	0.6	20.0	18,722.8
Artificial surface	0.9	29.7	17.5	230.3	0.4	2.0	280.9
Wetland	2.1	2.3	0.1	0.0	1.1	4.4	10.1
Water	4.7	9.5	9.1	1.6	0.3	85.0	120.2
Total	568.3	3,239.3	18,788.4	425.0	2.5	165.1	23,218.7

Table 3.3.2 (b) Transfer Matrix of Land Use Area on the North Korean Side in the Tumen River Basin from 2010 to 2020 (Unit:) km²)

2010/2020	Grassland	Farmland	Forest	Artificial surface	Water	Total
Grassland	336.7	37.4	222.6	3.5	0.8	601.1
Farmland	21.1	2,278.6	194.0	18.6	13.8	2,546.1
Seawater	0.0	0.0	0.0	0.0	0.0	0.0
Forest	192.3	168.2	7,243.9	2.5	4.2	7,614.6
Artificial surface	0.7	13.4	1.0	36.8	0.0	52.3
Water	0.5	5.3	4.4	0.1	43.2	55.6
Total	551.3	2,502.8	7,665.8	61.4	62.0	10,869.8

From the table, it can be seen that in the past decade, the restoration of forest land on one side of China has been relatively good, with an increasing trend in arable land, a significant increase in artificial surface area, a significant increase in wetland area, and a decreasing trend in water bodies. Through analysis, it can be concluded that environmental protection work has been progressing smoothly in recent years. While forest land has been restored, various land types have shown a growth trend, indicating that undeveloped wasteland has been treated. At the same time, the increase in artificial surface area also shows a good economic development trend. Overall, the efficiency of land use has been strengthened. The area of grassland and cultivated land on the North Korean side has increased. Forests, artificial surfaces, and water bodies are showing a decreasing trend.

By comparing the two sides, it can be clearly seen that there is an improvement in land use change on the Chinese side, while there are still phenomena such as overdevelopment on the North Korean side.

Table 3.3.2 (c) Probability Matrix of Land Use Type Transfer in the Chinese Side of the Tumen River Basin from 2010 to 2020

Land Use Type	Grassland	Farmland	Forest	Artificial surface	Wetland	Water	Total
Grassland	52.8%	5.0%	38.4%	1.0%	0.0%	2.8%	100.0%
Farmland	1.2%	83.6%	8.9%	4.9%	0.0%	1.1%	100.0%
Forest	1.2%	1.3%	97.4%	0.1%	0.0%	0.1%	100.0%
Artificial surface	0.3%	10.6%	6.2%	82.0%	0.2%	0.7%	100.0%
Wetland	21.3%	23.1%	1.0%	0.1%	10.8%	43.8%	100.0%
Water	3.9%	7.9%	7.6%	1.3%	0.2%	70.7%	100.0%

Table 3.3.2 (d) Probability Matrix of Land Use Type Transfer on the North Korean Side in the Tumen River Basin from 2010 to 2020

Land Use Type	Grassland	Farmland	Forest	Artificial surface	Water	Total
Grassland	56.0%	6.2%	37.0%	0.6%	0.1%	100.0%
Farmland	0.8%	89.5%	7.6%	0.7%	0.5%	100.0%
Forest	2.5%	2.2%	95.1%	0.0%	0.1%	100.0%
Artificial surface	1.3%	25.6%	1.8%	70.4%	0.1%	100.0%
Water	0.8%	9.5%	7.8%	0.2%	77.6%	100.0%

From the table above, it can be seen that between 2010 and 2020, 38.35% of grasslands in China were converted to forests, 8.92% of cultivated land was converted to forests, and 6.22% of man-made buildings were converted to forests. This indicates that the sustainable development concept of returning farmland to forests has deeply penetrated people's hearts. The transformation from grasslands to forests shows that a large part of grasslands have been planted as trees, which not only maintains soil and water, but also absorbs carbon dioxide from the atmosphere to a certain extent, alleviating the greenhouse effect. On the North Korean side, 37.02% of grasslands have been converted to forests, 7.62% of cultivated land has been converted to forests, and 7.83% of water bodies have been converted to forests, indicating that the land use pattern on the North Korean side is also undergoing a good transformation, which is in line with the world's environmental protection concept.

Table 3.3.2 (e) Probability Matrix of Land Use Type Transition in the Chinese Side of the Tumen River Basin from 2010 to 2020

Land Use Type	Grassland	Farmland	Forest	Bare land	Artificial surface	Wetland	Water
Grassland	53.5%	0.9%	1.2%	1.5%	1.4%	0.8%	9.7%
Farmland	7.4%	90.5%	1.7%	36.9%	40.5%	1.6%	22.8%
Forest	37.8%	7.3%	97.0%	27.9%	3.6%	25.6%	12.1%
Artificial surface	0.2%	0.9%	0.1%	0.3%	54.2%	17.8%	1.2%
Wetland	0.4%	0.1%	0.0%	0.0%	0.0%	44.0%	2.7%
Water	0.8%	0.3%	0.1%	33.4%	0.4%	10.3%	51.5%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 3.3.2 (f) Probability Matrix of Land Use Type Transition on the North Korean Side in the Tumen River Basin from 2010 to 2020

Land Use Type	Grassland	Farmland	Forest	Bare land	Artificial surface	Water
Grassland	61.1%	1.5%	2.9%	0.9%	5.6%	1.3%
Farmland	3.8%	91.0%	2.5%	75.8%	30.3%	22.2%
Forest	34.9%	6.7%	94.5%	13.0%	4.1%	6.8%
Artificial surface	0.1%	0.5%	0.0%	1.6%	59.9%	0.1%
Water	0.1%	0.2%	0.1%	8.6%	0.1%	69.6%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

As shown in the table above, in 2020, 33.77% of the grasslands on the Chinese side were converted from forest land, and 7.29% of the cultivated land was converted from forest land. It is worth mentioning that 40.49% of the artificial land surface was converted from cultivated land, indicating that some land use has been converted into artificial buildings. On the North Korean side, 34.89% of grassland is converted from forest land, 6.72% of arable land is converted from forest land, and 30.32% of arable land is converted into artificial surface. During this period, the land use types on the Chinese side and the North Korean side were roughly similar.

3.3.3 Characteristics of Land Use Type Transfer between China and North Korea in the Tumen River Basin from 2000 to 2020

Table 3.3.3 (a) Transfer Matrix of Land Use Area on the Chinese Side in the Tumen River Basin from 2000 to 2020 (Unit:) km²)

2000/2020	Grassland	Farmland	Forest	Artificial surface	Wetland	Water	Total
Grassland	108.4	37.8	148.1	2.8	0.0	18.5	316.1

Farmland	50.4	2,810.8	362.2	183.2	0.0	32.9	3,448.5
Forest	400.4	348.7	18,259.0	28.3	0.8	33.0	19,084.9
Artificial surface	3.8	31.9	14.3	209.2	0.4	2.0	261.7
Wetland	2.0	2.4	0.1	0.0	1.1	4.4	9.9
Water	3.4	7.8	5.6	1.5	0.2	74.4	98.8
Total	568.3	3,239.5	18,789.2	425.0	2.5	165.2	23,219.9

Table 3.3.3 (b) Transfer Matrix of Land Use Area on the North Korean Side in the Tumen River Basin from 2000 to 2020 (Unit:) km²)

2000/2020	Grassland	Farmland	Forest	Artificial surface	Water	Total
Grassland	59.6	117.3	97.7	0.6	0.7	276.1
Farmland	23.6	1,938.8	142.6	18.3	12.3	2,146.1
Forest	467.2	426.5	7,422.7	8.2	8.0	8,337.0
Artificial surface	0.6	16.8	0.9	34.3	0.0	62.2
Water	0.4	3.6	2.3	0.1	41.1	49.3
Total	551.4	2,502.9	7,666.2	61.5	62.1	10,870.6

From the above table, it can be seen that from 2000 to 2020, the grasslands, cultivated land, artificial surfaces, and water bodies on the Chinese side have all increased to varying degrees, but the overall trend of forest land and wetlands is still decreasing. On the North Korean side, grasslands, cultivated land, and water bodies are all showing an increasing trend, while forest land is decreasing significantly, and the overall trend of artificial surface changes is not significant.

From this, it can be concluded that although the land use changes on both the Chinese and North Korean sides have improved to some extent in recent years, there are still some problems.

Table 3.3.3 (c) Probability Matrix of Land Use Type Transfer in the Chinese Side of the Tumen River Basin from 2000 to 2020

Land Use Type	Grassland	Farmland	Forest	Artificial surface	Wetland	Water	Total
Grassland	34.3%	12.0%	46.8%	0.9%	0.0%	5.8%	100.0%
Farmland	1.5%	81.5%	10.5%	5.3%	0.0%	1.0%	100.0%
Forest	2.1%	1.8%	95.7%	0.2%	0.0%	0.2%	100.0%
Artificial surface	1.5%	12.2%	5.5%	79.9%	0.2%	0.8%	100.0%
Wetland	19.8%	24.2%	1.0%	0.1%	10.9%	44.1%	100.0%

Water	3.5%	7.9%	5.6%	1.5%	0.2%	75.3%	100.0%

Table 3.3.3 (d) Probability Matrix of Land Use Type Transfer on the North Korean Side in the Tumen River Basin from 2000 to 2020

Land Use Type	Grassland	Farmland	Forest	Artificial surface	Water	Total
Grassland	21.6%	42.5%	35.4%	0.2%	0.2%	100.0%
Farmland	1.1%	90.3%	6.7%	0.9%	0.6%	100.0%
Forest	5.6%	5.1%	89.0%	0.1%	0.1%	100.0%
Artificial surface	0.9%	27.0%	1.5%	55.1%	0.0%	100.0%
Water	0.9%	7.2%	4.7%	0.2%	83.4%	100.0%

From the above table, it can be concluded that in the past 20 years, the conversion of grassland and cultivated land to forest land in China has been relatively large, wetlands have been relatively large in transferring water bodies, and the conversion of artificial land to grassland, cultivated land, and forest land has been relatively even. The grassland on the North Korean side has a relatively large transfer of cultivated land and forest land, while the forest land has a relatively even transfer of grassland and cultivated land, but the artificial surface has a larger transfer of cultivated land. From this, it can be concluded that in the past 20 years, the grassland on both sides of China and North Korea has had a relatively large transfer of forest land, but the conversion of cultivated land and artificial land in China is relatively even, while North Korea still occupies an important part of land use for cultivated land.

Table 3.3.3 (e) Probability Matrix of Land Use Type Transition in the Chinese Side of the Tumen River Basin from 2000 to 2020

Land Use Type	Grassland	Farmland	Forest	Artificial surface	Wetland	Water
Grassland	19.1%	1.2%	0.8%	0.7%	0.2%	11.2%
Farmland	8.9%	86.8%	1.9%	43.1%	0.6%	19.9%
Forest	70.5%	10.8%	97.2%	6.7%	33.5%	20.0%
Artificial surface	0.7%	1.0%	0.1%	49.2%	15.9%	1.2%
Wetland	0.4%	0.1%	0.0%	0.0%	43.6%	2.7%
Water	0.6%	0.2%	0.0%	0.4%	6.2%	45.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 3.3.3 (f) Probability Matrix of Land Use Type Transition on the North Korean Side in the Tumen River Basin from 2000 to 2020

Land Use Type	Grassland	Farmland	Forest	Artificial surface	Water
Grassland	10.8%	4.7%	1.3%	1.0%	1.1%
Farmland	4.3%	77.5%	1.9%	29.8%	19.8%
Forest	84.7%	17.0%	96.8%	13.3%	12.9%
Artificial surface	0.1%	0.7%	0.0%	55.7%	0.0%
Water	0.1%	0.1%	0.0%	0.1%	66.3%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

From the table, it can be seen that in the past 20 years, 70.45% of grassland on the Chinese side has been converted from forest land, 10.76% of arable land has been converted from forest land, 33.47% of wetlands have been converted from forest land, and 15.93% of wetlands have been converted from artificial surfaces. It can be inferred that there is a significant degree of exchange between forest land and other land types. On the North Korean side, 84.72% of the grassland is converted from forest land, and 17.04% of the cultivated land is converted from forest land. It can be said that in the past 20 years, the grassland on the North Korean side has mainly come from forest land. Overall, the land use types on both sides of China and North Korea are roughly similar, with similar development trends. By comparing the data from the first two periods, it can be concluded that in the first decade, excessive development and collection of forest land led to significant changes in land use. Although a gradual recovery trend can be seen in the second decade, overall there is still a downward trend in forest land use.

4 Conclusion

This paper takes the Tumen River Basin as the study area and uses remote sensing image data from three periods (2000, 2010, and 2020). ArcGIS is employed to perform mask extraction and raster reclassification on the obtained images, integrating and processing basic information while unifying land use categories for easier comparison. Subsequently, land use dynamic change analysis is applied to organize and analyze the land use area, change magnitude, and dynamics degree on both the Chinese and North Korean sides of the Tumen River Basin over the past 20 years. Finally, through a series of operations such as image fusion and intersection, the land use area transition matrix and the land use transfer probability matrix are used to analyze the characteristics of land use type transitions in the Tumen River Basin over the past 20 years. The following conclusions are drawn:

Between 2000 and 2020, the grassland and cultivated land areas on both the Chinese and North Korean sides generally increased to some extent, while the forest area decreased on both sides. The water body area on the Chinese side showed a noticeable increase, whereas the change on the North Korean side was minimal. Analysis reveals that the overall decline in forest area on both sides of the Tumen River Basin was primarily due to excessive human exploitation of natural resources in the first decade, leading to a significant reduction in forested land. In recent years, however, the introduction of national policies, promotion of sustainable development concepts, and increased awareness of environmental protection have contributed to some recovery of forested areas, although the overall trend remains downward. This highlights the significant impact of human activities on the natural environment.I believe that the increase in water body area on the Chinese side is related to the construction of water conservancy facilities, such as the Laolongkou Reservoir, which has helped to conserve water resources to some extent. Additionally, the development of secondary and tertiary industries has gradually reduced the role of farmland as a primary economic driver. Declining profits have led to the conversion of less fertile land into forested areas, which are closely linked to soil and water conservation. Finally, rapid advancements in agricultural technology have significantly increased crop yields per unit area, allowing some land with declining fertility or steep terrain to be repurposed for other uses.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, author-ship, and/or publication of this article.

Data Sharing Agreement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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