Land-Use and Land-Cover Change Simulation and Its Driving Forces in Fuyuan, Sanjiang Plain, 2000-2020

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Abstract. As one of the most intact areas in the downstream of the Sanjiang Plain, Fuyuan is a key development area relying on the policy of "one island and two countries". Since 2000, the land use structure of Fuyuan has changed significantly due to natural and human factors. In this paper, we used MARKOV to simulate LUCC (Land-Use and Land-Cover Change) in Fuyuan from 2000 to 2020, calculating land use dynamic index, doing some correspondence analysis, and exploring its driving force factors. The results show that some land types are changed more violently. We analyzed the difficulty degree of land type mutual transformation, and the result is that the conversion of residential and other construction land is high, and the ecological reversibility is poor. Forest swamps and woodlands are most easily converted into cultivated land, and the competition is strong. Wetland is easy to convert into transport land; Fallow is the easiest way to restore wetlands. On this basis, we analyzed the natural factors and policy changes in the past 20 years, and concluded that human factors are the main driving forces for LUCC (Land-Use and Land-Cover Change), such as the urbanization process in Fuyuan and the implementation of policies about ecologically desertification and development of foreign trade, etc.

1 Research Overview
The analysis of land use/land cover change patterns and driving forces is an important approach to mitigate the conflicts between urbanization processes and ecological restoration. Scholars both domestically and internationally have explored the driving forces of land conversion in various regions, such as the Tamiraparani Basin in southern India [1], the Lake Erhai wetland in China [2], rural areas in Lovenia [3], and the Liaohe River Estuary wetland [4], using methods including matrices, qualitative research, and Logistic regression models. The Sanjiang Plain wetlands, located in the northeastern part of the Northeast China Plain, have been recognized by the United Nations under the Ramsar Convention and listed in the Ramsar List of Wetlands of International Importance. They are also included in the National Important Wetland List in China. Fuyuan City, situated as the downstream key area of the Sanjiang wetlands, serves as an important grain supply base for Heilongjiang Province. It is also a significant ecological conservation area, a tourist destination, a hub for trade and commerce, and a gateway port, contributing to the development of the strategic partnership between China and Russia. Four large-scale agricultural developments from 1949 to 1983 resulted in a significant reduction in wetland area [5]. Through a comprehensive comparison of domestic and international research, it is evident that most studies on land use/land cover change and its driving factors focus on the increase or decrease relationships of individual land types, while lacking exploration of the competition, co-growth, and conversion preferences among multiple land types. In this study, we introduce the theory of correspondence analysis to analyze the competition and interdependence among different land types in the Sanjiang Plain. Furthermore, we examine the natural and anthropogenic factors and explore the driving forces behind land use/land cover changes in Fuyuan County.

2 Data Sources and Research Methods

2.1 Study Area
The study area covers Fuyuan City, located in the Sanjiang Plain in Northeast China.

2.2 Data Sources and Processing
The basic data used in this study include land use vector data for the years 2000, 2010, and 2020, provided by the Data Center for Resources and Environment of the Chinese Academy of Sciences. Additionally, the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data was downloaded from the Geospatial Data Cloud. Administrative boundary maps and road data were obtained from the Institute of Landscape and Planning. The land use types are classified into 11

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categories, including herbaceous swamp, shrub swamp, industrial and mining storage land, dryland, transportation and logistics land, woodland, bare land, forested wetland, paddy field, water body, and residential land.

2.3 Technical Approach

Based on the land use conditions during the three periods, a transition matrix of land types is constructed. SPSS software is then used to analyze the preferences for land use conversions and the similarities between land use types. Finally, the driving factors behind land transitions in Fuyuan County are analyzed based on the natural, social, and policy factors (Figure 1).

\[ LC = \left( \frac{\sum_{i,j} LU_{i,j}}{2 \sum_{i} LU_{i}} \right) \times \frac{1}{T} \times 100\% \]  

where \( LU_{i} \) represents the area of land use type \( i \) at the beginning of the monitoring period, \( \Delta LU_{i,j} \) represents the absolute value of the area converted from land use type \( i \) to non-type \( i \) during the monitoring period, and \( T \) represents the duration of the monitoring period. When the monitoring period is set to one year, \( LC \) represents the annual land use change rate in the study area.

2.3.2 Correspondence Analysis

Correspondence analysis is primarily used to study the relationship between two or more qualitative variables. It relies on dimension reduction techniques, such as principal component analysis, to visually and comprehensively observe and analyze the interrelationships among multiple states of qualitative variables [6]. In this study, SPSS models were employed to investigate the preferences of land conversion. Firstly, scatter plots were generated using correspondence analysis to depict the relationships between different land types. A specific land use was selected as the reference vector, and its reverse extension line was used as the baseline. Perpendicular lines were drawn from other land use types to this baseline, and the lengths of these lines were used to estimate the ease or difficulty of land conversion between different types. Secondly, lines were drawn connecting the vectors with the origin, and the larger the cosine value of the angle between the lines, the more significant the similarity between the two land use types.

3 Analysis of Land Transfer Patterns

3.1 Analysis of Land Transfer Results

Through the statistical analysis of the areas of various types of land collected from GIS information (Figure 2), it is shown that the areas of forestland, paddy fields, waters, residential land, industrial and mining warehouse land, and transportation land have increased. The areas of dryland, bare land, forest swamps, and herbaceous swamps have decreased. Among them, the area with the largest increase is the land used for transportation, while the area with the largest decrease is forest swamps.
From 2000 to 2010, the land use structure in Fuyuan City remained relatively stable. By 2020, there had been significant changes in the usage of certain lands in Fuyuan City. In Fuyuan City, cultivated land held an absolute majority of the total land use area, accounting for 69.81%, 69.17%, and 67.63% respectively, all reaching around 70%. However, there was a slight reduction in 2020, suggesting that in Fuyuan City, with the continuous improvement of urbanization level, progress has been made in the conversion of croplands back to grasslands and forests. The area of wetlands was 17.30%, 17.29%, and 15.06% respectively, and there was a significant reduction in 2020. This reduction deserves sufficient attention from the government and relevant personnel (Table 1).

**Table 1. Land Area in 2000, 2010, and 2020**

<table>
<thead>
<tr>
<th></th>
<th>Area in 2000</th>
<th>Area in 2010</th>
<th>Area in 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forestland</td>
<td>54490.18612</td>
<td>56590.40826</td>
<td>58235.3481</td>
</tr>
<tr>
<td>Paddy Fields</td>
<td>139362.5527</td>
<td>168175.1375</td>
<td>181758.5214</td>
</tr>
<tr>
<td>Dryland</td>
<td>265806.9042</td>
<td>231887.4317</td>
<td>210782.3701</td>
</tr>
<tr>
<td>Bare Land</td>
<td>14.692738</td>
<td>4.440274</td>
<td>3.205064342</td>
</tr>
<tr>
<td>Waters</td>
<td>11395.6176</td>
<td>12198.31761</td>
<td>12517.92459</td>
</tr>
<tr>
<td>Residential Land</td>
<td>5028.797753</td>
<td>5976.694721</td>
<td>7783.178253</td>
</tr>
<tr>
<td>Industrial and Mining Warehouse Land</td>
<td>32.799125</td>
<td>46.117998</td>
<td>76.8808925</td>
</tr>
<tr>
<td>Transportation Land</td>
<td>1828.350244</td>
<td>3515.442425</td>
<td>19829.80362</td>
</tr>
<tr>
<td>Forest Swamps</td>
<td>303.645052</td>
<td>18.053682</td>
<td>3.882694616</td>
</tr>
<tr>
<td>Shrub Swamps</td>
<td>10341.68532</td>
<td>12807.02328</td>
<td>14345.60997</td>
</tr>
<tr>
<td>Herbaceous Swamps</td>
<td>89777.17066</td>
<td>87163.3156</td>
<td>73045.68759</td>
</tr>
</tbody>
</table>

**3.2 Land Transfer Dynamics**

Based on the calculation principle and formula in 2.2.2, the land use dynamics and comprehensive land use dynamics of Fuyuan City from 2000-2010 and 2010-2020 can be calculated (Table 2).

**Table 2. Land Dynamics from 2000-2020**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Forestland</td>
<td>54490.18612</td>
<td>56590.40826</td>
<td>58235.3481</td>
<td>2100</td>
<td>1645</td>
<td>0.39%</td>
<td>0.29%</td>
<td>0.64%</td>
<td>0.61%</td>
</tr>
<tr>
<td>Paddy Fields</td>
<td>139362.5527</td>
<td>168175.1375</td>
<td>181758.5214</td>
<td>28813</td>
<td>13583</td>
<td>2.07%</td>
<td>0.81%</td>
<td>0.64%</td>
<td>0.61%</td>
</tr>
<tr>
<td>Dryland</td>
<td>265806.9042</td>
<td>231887.4317</td>
<td>210782.3701</td>
<td>-33919</td>
<td>-21105</td>
<td>1.28%</td>
<td>0.91%</td>
<td>0.64%</td>
<td>0.61%</td>
</tr>
<tr>
<td>Bare Land</td>
<td>14.692738</td>
<td>4.440274</td>
<td>3.205064342</td>
<td>-10</td>
<td>-1</td>
<td>6.98%</td>
<td>2.78%</td>
<td>0.64%</td>
<td>0.61%</td>
</tr>
<tr>
<td>Waters</td>
<td>11395.6176</td>
<td>12198.31761</td>
<td>12517.92459</td>
<td>803</td>
<td>320</td>
<td>0.70%</td>
<td>0.26%</td>
<td>0.64%</td>
<td>0.61%</td>
</tr>
<tr>
<td>Residential Land</td>
<td>5028.797753</td>
<td>5976.694721</td>
<td>7783.178253</td>
<td>948</td>
<td>1806</td>
<td>1.88%</td>
<td>3.02%</td>
<td>0.64%</td>
<td>0.61%</td>
</tr>
<tr>
<td>Industrial and Mining Warehouse Land</td>
<td>32.799125</td>
<td>46.117998</td>
<td>76.8808925</td>
<td>31</td>
<td>14</td>
<td>4.06%</td>
<td>6.67%</td>
<td>0.64%</td>
<td>0.61%</td>
</tr>
<tr>
<td>Transportation Land</td>
<td>1828.350244</td>
<td>3515.442425</td>
<td>19829.80362</td>
<td>1687</td>
<td>16314</td>
<td>9.23%</td>
<td>46.41%</td>
<td>0.64%</td>
<td>0.61%</td>
</tr>
<tr>
<td>Forest Swamps</td>
<td>303.645052</td>
<td>18.053682</td>
<td>3.882694616</td>
<td>10341.68532</td>
<td>12807.02328</td>
<td>14345.60997</td>
<td>0.64%</td>
<td>0.61%</td>
<td></td>
</tr>
<tr>
<td>Shrub Swamps</td>
<td>89777.17066</td>
<td>87163.3156</td>
<td>73045.68759</td>
<td>304</td>
<td>18</td>
<td>4.06%</td>
<td>6.67%</td>
<td>0.64%</td>
<td>0.61%</td>
</tr>
<tr>
<td>Herbaceous Swamps</td>
<td>25489.18612</td>
<td>56590.40826</td>
<td>58235.3481</td>
<td>139362.5527</td>
<td>168175.1375</td>
<td>181758.5214</td>
<td>0.64%</td>
<td>0.61%</td>
<td>0.64%</td>
</tr>
</tbody>
</table>
3.2.1 Overall Land Use/Cover Change in Fuyuan City is Not Significant

From the table, it is clear that the change values for various types of land use in Fuyuan City from 2000 to 2020 are relatively small, with LC being 0.64% and 0.61% in the two decades respectively. Although the dynamism of land used for transportation is slightly higher, the dynamism of residential land and industrial and mining warehouse land is not high. This suggests that although the process of urbanization in Fuyuan City is developing rapidly, the overall level of urbanization is still not high, the population situation is relatively stable, and it is in the initial stage of urban development.

3.2.2 Significant Reduction in the Area of Forest Swamps

From 2000 to 2020, the area of forest swamps significantly reduced. Combined with the transition matrix, it was found that a large amount of forest swamps were converted into forestland and herbaceous swamps, indicating that the vegetation system of forest swamps is degrading. The comprehensive land use dynamism of Fuyuan City from 2000 to 2010 was 0.64%, and from 2010 to 2020 was 0.61%. This shows that the overall deterioration of the ecological environment in Fuyuan City is not significant, and the improvement of its urbanization scale and socio-economic development has not been at the expense of the ecological environment. Therefore, in-depth investigation of the development situation of Fuyuan City has important implications for its future development and the development of other similar cities nationwide.

3.2.3 Significant Increase in the Land Used for Transportation

Among all types of land use in the past 20 years, the dynamism of land used for transportation is higher. In this decade, part of the area of herbaceous swamps, shrub swamps, dryland, forestland, paddy fields, and waters was converted into land for transportation, with 7754 ha of herbaceous swamps and 1035 ha of dryland developed into transportation land. In the dynamics of the land use structure from 2010-2020, the K value of the land used for transportation reached 46.41%, and the area of industrial and mining warehouse land also expanded significantly, indicating that the density of road network in Fuyuan City increased significantly, and hence the degree of urbanization in Fuyuan City is very large.

Secondly, the area of forest swamps still significantly reduced. This urgently requires identifying the corresponding reasons according to the local natural, economic and policy conditions, in order to formulate countermeasures.

3.3 Analysis of Land Use Type Transfer Difficulty

Based on the land transfer matrix from 2000 to 2020, the corresponding analysis diagrams of land transfer from 2000 to 2020 were calculated using SPSS software (Figures 3 to 6).
3.3.1 Each type of land use does not change much based on its original scale

Each type of land use on the scatter plot is closest to its previous value, indicating that each type of land use played the most significant role in the formation of the total land use scale in 2020. At the same time, it shows that the land use in Fuyuan County has changed on its original scale, but the changes are not drastic.

3.3.2 The conversion of residential and other construction lands is highly specific, with poor ecological reversibility

From the figure, we can see that the positions of residential land in 2000 and 2020 are not in the same quadrant as other land use types. This implies that residential land has a low correlation with other types of land use and has unique conversion laws. However, other types of land use are all in the same quadrant, indicating that the overall conversion of land use types in Fuyuan City is relatively stable, and there are fewer land use types with unique conversion modes. In combination with the transfer matrix, it was found that the land use types converted to urban construction-related land use are difficult to be converted to other uses, indicating the poor ecological reversibility in Fuyuan City.

3.3.3 Forest swamps and forest land are most likely to be converted into cultivated land

The diagram shows a line drawn from the origin to the point of cultivated land in 2020 and extended in the opposite direction. Then, perpendicular lines are drawn from the scatter points of each land use type in 2000 to this line, resulting in the above analysis diagram.

According to the theory of correspondence analysis, points closer to the line have a stronger conversion preference, so forest swamps and forest land are most likely to be converted into cultivated land, and residential land is the least likely to be converted into cultivated land. As cultivated land is composed of dry land and paddy fields, it implies that deforestation and transformation into cultivated land is the easiest way to reclaim land. The above analysis mentioned that the area of forest swamps has been significantly reduced. From the land use type transfer matrix from 2000 to 2010, it can be seen that the areas of forest swamps and forest land converted into cultivated land were 13.72ha and 8991.12ha, respectively, accounting for 4.5% and 16.5% of the forest swamp and forest land area in 2000, respectively. This indicates that this blind reclamation is an important cause of wetland degradation in the Sanjiang Plain.

3.3.4 Returning to cultivation is the easiest way to restore wetlands

Since wetland restoration starts from herbaceous wetlands, connecting herbaceous wetlands to the origin and extending in the opposite direction, it can be concluded that bare land and water areas are the land use types that are most easily reconverted into cultivated land, followed by dry land and paddy fields. This indicates that the natural ecological status of bare land and water areas in Fuyuan City is well protected. However, the total area of bare land has been reduced to 3ha, and water areas are also types of land that should be protected, so it also implies that returning to farming is the easiest way to restore wetlands.

3.3.5 Wetlands are relatively easy to convert into transportation land

Using the same method to analyze the transformation difficulty preference for converting into transportation land, it was found that the types of land with closer vertical distances are bare land, water areas, herbaceous swamps, forest swamps, and shrub swamps. This indicates that sacrificing the area of wetlands for urbanization is a very simple and easy shortcut, which is an important reason for wetland degradation. It also serves as a warning that it is urgent and necessary to properly constrain these actions through laws and policies.

3.4 Analysis of Similarity in Land Use Types

Since the total area within the study region is relatively constant, apart from the transformations of various land types from 2000 to 2020, the land structure in 2020 can also reflect the similarities between land types. The similarity between various land use types in Fuyuan City can objectively reflect the competition or dependence between different land use types in this region. According to the relevant theory of correspondence analysis, the larger the cosine of the angle between the vectors from two points to the origin in the figure, the greater the similarity between the two land use types. Based on this, we can proceed with the following analysis:

3.4.1 Transportation land and wetlands have a strong competition

The types of land that are highly similar to wetlands are bare land, transportation land, water areas, cultivated land,
and forest land. In contrast, industrial and mining warehouse land and residential land have lower similarity. This confirms that returning to farming is an effective method for wetland protection and also proves a strong competitive relationship between transportation land and wetlands. This competitive relationship essentially leads to the intensification of conflicts between human activities and natural resource protection.

3.4.2 There is competition between cultivated land and forest land

The land use type most similar to cultivated land is forest land, followed by wetlands and industrial and mining warehouse land. This demonstrates the competitive relationship between cultivated land and forest land and validates that the illegal activity of deforestation for farming is likely to occur. In combination with the transfer matrix, it was found that 8990ha of forest land was converted into cultivated land from 2000 to 2010. This urgently requires the improvement of relevant laws and regulations to prevent this phenomenon.

4 Land Transfer Drivers in Fuyuan County

4.1 Natural Factors

Fuyuan City has four types of landforms: low mountains, alluvial plains, low plains, and floodplains, making the land adaptable to various uses. It is located in the eastern part of the subsiding Sanjiang alluvial plain, with low-lying terrain. The western part is slightly higher than the eastern part, and occasional floods occur. The Sanjiang Plain belongs to a continental monsoon climate. The summer is short and hot, and the winter is long and cold, the spring is windy, and the summer is rainy. The average annual sunshine duration is 2,304 hours [7]. The elevation in the plain area ranges from approximately 37 to 60 meters, while the highest elevation in the mountains is 279.1 meters. Rivers, lakes, ponds, and swamps are scattered throughout the region. The city experiences a long freezing period, with stable freezing starting in early November and thawing beginning in late March of the following year. The frozen soil layer can reach a depth of 212 centimeters.

Table 3. Average temperature, rainfall and runoff in Fuyuan City in 2000, 2010 and 2017

<table>
<thead>
<tr>
<th>years</th>
<th>Annual average temperature/℃</th>
<th>Rainfall/mm</th>
<th>Heilongjiang runoff/100 million m³</th>
<th>Runoff of Wusuli River/100 million m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>4.6</td>
<td>452.1</td>
<td>3386</td>
<td>624.5</td>
</tr>
<tr>
<td>2010</td>
<td>3.2</td>
<td>741.9</td>
<td>3405</td>
<td>630.4</td>
</tr>
<tr>
<td>2017</td>
<td>5.1</td>
<td>529.7</td>
<td>3465</td>
<td>625.7</td>
</tr>
</tbody>
</table>

The temperature and precipitation in Jiamusi City changed significantly (Table 3). The temperature gradually increased, and the precipitation first increased and then decreased. There was no significant change in the river runoff, resulting in a gradual decrease in the area of wetlands, grasslands and woodlands. At the same time, the increase in temperature has created favorable conditions for the development of paddy fields, which has greatly increased the area of paddy fields in the Sanjiang Plain.

In addition, in the mid-1990s, the grain planting structure of the Sanjiang Plain underwent major changes, gradually shifting from soybean and wheat-based crops to soybean, corn and rice, which also led to the rapid development of paddy fields.

4.2 Human Factors

After comparing the driving force of land use/cover change in the Sanjiang Plain in the 1990s studied by domestic experts, this paper finds that human factors have played an increasingly important role in the change of land pattern in Fuyuan City, instead of natural factors. There are mainly economic factors such as urbanization process, farm development, and establishment of protected areas, as well as policy factors such as laws and regulations, and strategic deployment.

In terms of cultivated land protection and development, the "Heilongjiang Province Land Utilization Master Plan (2006-2020)" clearly stated that in the eastern Sanjiang Plain land consolidation area combined with the construction of 14 large-scale irrigation projects, it is necessary to improve field facilities and increase the area of paddy fields. He also repeatedly emphasized the protection of basic farmland, prohibiting other land from occupying farmland, and stabilizing Heilongjiang Province's position in the country's commodity grain supply. This policy contributed to an increase of 42396 ha in the area of paddy fields in Fuyuan City from 2000 to 2020 [8].

In terms of ecological protection factors, the "Decision of the State Council on Implementing the Scientific Outlook on Development and Strengthening Environmental Protection" released in December 2005 put forward "environmental priority" for the first time in a document of the State Council. Therefore, the loss of forest land and wetland area slowed down [9]. At the same time, the "Heilongjiang Province Land Use Master Plan (1997-2010)" was implemented between 1997 and 2010, and large-scale development was prohibited in the whole province. In addition to the impact of the severe floods in the Songhua River and Nen River in 1998 and the ecological retreat of farmland, 1997-2005 In 2018, the province's cultivated land decreased by 165,000 hectares. Fuyuan City actively responded to the corresponding national and provincial policies, and also achieved the effect of ecological conversion of farmland, with 11,034ha of cultivated land converted to wetlands and 11,214ha of farmland converted to forests.

In terms of traffic policy factors, the province accelerated infrastructure construction from 1997 to 2005, and a total of 210 traffic land projects were arranged. The "Heilongjiang Provincial Land Use Master Plan (2006-2020)" and "Heilongjiang Provincial Transportation Development Plan" proposed to renovate Fuyuan and
other ports and wharves to improve the shipping capacity of Heilongjiang, Songhua River and Wusuli River. As a result, the transportation land in Fuyuan City has been greatly expanded in recent years.

In terms of tourism development factors, from 2010 to 2017, the state successively promulgated the "Songnen Plain Sanjiang Plain Agricultural Comprehensive Development Experimental Zone Construction Plan", "Northern Scenic and Characteristic Tourism Development Zone Planning". After the construction of the coal-electricity base in the east of Heilongjiang and the development plan of the open belt along the border, the process of urbanization has accelerated, and its economic strength has further strengthened. This makes the land related to urban construction continue to expand, but the increase in tourists inevitably brings some environmental problems, resulting in the degradation of some forest swamps into woodlands and herbaceous swamps[10].

5 Conclusion

(1) The more significant features of land use/cover change from 2000 to 2020 are: a large number of forest swamps degraded into woodlands and herbaceous swamps; land used for transportation increased significantly; paddy fields increased significantly; conversion of farmland to wetlands and woodlands was remarkable.

(2) The results of the mutual conversion preference of land types: construction land such as residential buildings has high specificity and poor ecological reversibility; forest, swamp and woodland are the easiest to convert into cultivated land; returning farmland is the easiest way to restore wetland area; woodland is easier to convert into traffic Land for transportation.

(3) The driving forces of land use/cover change from 2000 to 2020 are: changes in annual average temperature and rainfall; changes in grain planting structure; accelerated urbanization in Fuyuan City. Infrastructure, development of foreign trade, development of tourism and other policies.

The study conclusions allows relevant departments to formulate sustainable development policies that satisfy the needs of economic growth while also preserving wetland ecological resources.

Future research could consider predicting changes in land use in the Sanjiang Plain area of Heilongjiang Province under the context of climate change, based on different planning objectives. This would provide concrete and feasible suggestions and opinions for the long-term steady progress of the Sanjiang Plain wetlands.

References


