WEP Warwick Evans Publishing

International Journal of Global Economics and Management
ISSN: 3005-9690 (Print), ISSN: 3005-8090 (Online) | Volume 10, Number 4, Year 2026
DOI: https://doi.org/10.62051/ijgem.v10n4.04
Journal homepage: https://ijgem.org

# Analysis of Land Use Change in Sichuan Province from 2000 to 2020

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## ABSTRACT

Against the background of accelerated urbanization and increasing demand for ecological protection, land use change has significant impacts on regional ecological security and sustainable development. Based on land use data of Sichuan Province for the years 2000, 2010, and 2020, this study systematically analyzes the characteristics of land use change from the perspectives of temporal variation, type conversion, and spatial patterns by integrating the land use transition matrix and the standard deviational ellipse method. The results show that from 2000 to 2020, the land use structure in Sichuan Province underwent significant adjustments, with forest and built-up land continuously increasing, while cropland and grassland showed a declining trend. Land use conversion was mainly characterized by mutual transformations among cropland, grassland, and forest, accompanied by the conversion of cropland to built-up land, presenting an overall pattern of “cropland shifting toward ecological land and built-up land.” The spatial distribution pattern was strongly constrained by topographic conditions, forming a basic pattern of “plateau forest-grassland, basin agriculture, and urban agglomeration,” with the overall structure remaining relatively stable over the 20-year period. The spatial distribution directions of different land use types were generally stable, and the migration of the centers of gravity was limited. Among them, cropland exhibited relatively significant changes, while built-up land showed a continuous expansion trend. The findings of this study can provide a scientific reference for optimizing regional land use allocation and ecological protection.

## KEYWORDS

Land use change; Transition matrix; Standard deviational ellipse; Center of gravity migration; Sichuan Province

## 1. INTRODUCTION

Land use change is a direct manifestation of the evolution of the Earth’s surface system under the combined influence of human activities and natural processes, and serves as a critical link between ecological environmental change and regional development patterns [1]. With the intensification of global climate change and the continuous increase in human development activities, land use/land cover change has become one of the key driving forces affecting ecosystem structure and function [2], exerting profound impacts on carbon cycling, hydrological processes, biodiversity, and ecological security patterns [3]. At the regional scale, land use change not only reflects shifts in resource utilization patterns but is also closely related to the supply capacity of ecosystem services and the level of sustainable development [4]. Therefore, systematically analyzing the temporal characteristics, conversion processes, and spatial pattern evolution of land use change is of great significance for understanding the dynamics of human–land relationships and optimizing territorial spatial structures.

Existing studies have mainly focused on quantitative changes in land use or the evolution of individual land use types, providing systematic insights into the changing trends of different categories. Some studies have also introduced methods such as transition matrices to examine the conversion relationships among land use types [5]. However, in general, previous research has emphasized the description of change outcomes, while paying relatively less attention to the transformation pathways among multiple land use types and their spatial evolution characteristics. This limitation is particularly evident in regions with complex terrain, where the conversion processes and spatial response mechanisms among different land use types require further investigation. In this context, Sichuan Province, as a typical region in southwestern China characterized by pronounced topographic differentiation, spans the eastern margin of the Qinghai-Tibet Plateau and the Sichuan Basin, featuring diverse landforms and significant internal heterogeneity in natural conditions. In recent years, driven by the combined effects of ecological restoration projects and rapid urbanization, the land use structure and spatial patterns in the region have undergone noticeable adjustments, demonstrating strong representativeness [6].

Accordingly, this study takes Sichuan Province as the study area and utilizes land use data for 2000, 2010, and 2020. Based on the analysis of area changes for different land use types, a land use transition matrix is constructed to reveal the conversion relationships among cropland, forest, grassland, water, unused land, and built-up land. Furthermore, focusing on the more significantly changing types-cropland, forest, grassland, and built-up land-the standard deviational ellipse method is employed to characterize their spatial distribution evolution and center-of-gravity migration. The aim is to systematically identify the main characteristics of land use change in Sichuan Province from both temporal and spatial perspectives, thereby providing a reference for regional land spatial optimization and ecological conservation.

## 2. MATERIALS AND METHODS

### 2.1. Study Area

Sichuan Province is located in southwestern China (approximately 97°21′-108°33′E, 26°03′-34°19′N), at the transitional zone between the eastern margin of the Qinghai-Tibet Plateau and the upper reaches of the Yangtze River, with a total area of about 486,000 km². It borders Chongqing Municipality to the east, Yunnan and Guizhou Provinces to the south, the Xizang (Tibet) Autonomous Region to the west, and Qinghai, Gansu, and Shaanxi Provinces to the north (Fig. 1). The region is characterized by significant topographic variation, exhibiting an overall pattern of higher elevations in the west and lower elevations in the east. The western part consists of the high-altitude and cold Sichuan Plateau, while the central part is occupied by the Sichuan Basin, surrounded by mountainous and hilly terrains, resulting in complex geomorphological conditions. Influenced by both topography and climate, the region shows pronounced spatial heterogeneity in natural geographic conditions [7]. The climate is dominated by a subtropical humid monsoon regime, with relatively abundant but unevenly distributed precipitation, forming three major climatic zones: the mid-subtropical humid climate zone of the Sichuan Basin, the subtropical semi-humid climate zone of the southwestern mountainous region, and the cold alpine climate zone of the northwestern plateau. In terms of geomorphological composition, plateaus and mountains dominate, accounting for approximately 74.2% and 10.3% of the total area, respectively, while hills and plains account for relatively smaller proportions, at 8.2% and 7.3% [8].

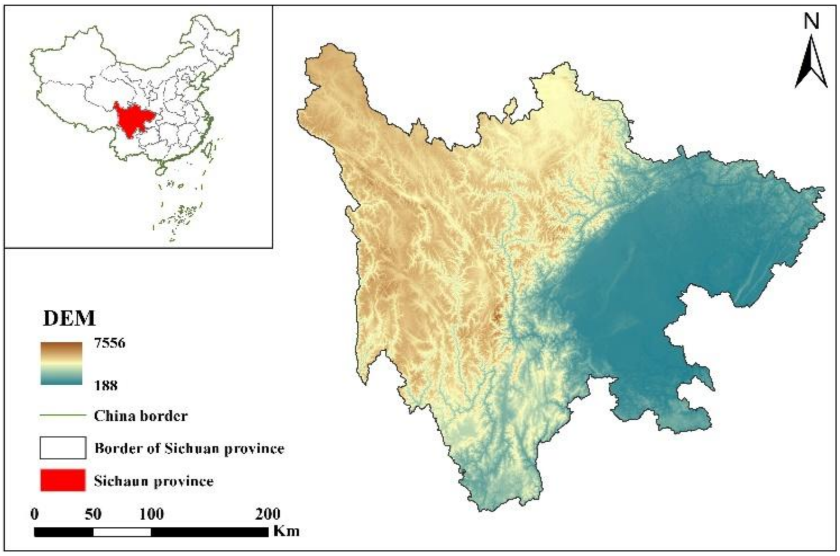



**Figure 1.** Overview of the study area

## 2.2. Methods

### 2.2.1. Land use transition matrix

The land use transition matrix is a commonly used method for characterizing the conversion relationships among different land use types over time. It enables the quantitative analysis of the transfer-in and transfer-out processes of each land use type, as well as their structural characteristics. By overlaying land use data from different time periods, the transition matrix is constructed to reflect the dynamic changes among land use types during the study period [9].

In this study, based on land use raster data for 2000, 2010, and 2020, GIS-based spatial overlay analysis was employed to construct land use transition matrices for three periods: 2000-2010, 2010-2020, and 2000-2020. Through statistical analysis and comparison of matrix elements, the main conversion directions and key transition pathways were identified, thereby revealing the underlying characteristics of land use structural changes in Sichuan Province [10].

The transition matrix is generally expressed as:

$$S_{ij} = \begin{pmatrix} S_{11} & \cdots & S_{1n} \\ \vdots & \ddots & \vdots \\ S_{n1} & \cdots & S_{nn} \end{pmatrix}$$

Where $S_{ij}$ represents the area of land use type $i$ at the initial time that is converted to type $j$ at the final time, and $n$ is the number of land use types. The diagonal elements of the matrix indicate unchanged areas, while the off-diagonal elements represent conversions between different land use types.

### 2.2.2. Standard deviational ellipse and center of gravity migration analysis

The standard deviational ellipse, proposed by Lefever, is a statistical method used to characterize the directional distribution and dispersion of spatial features, and it can comprehensively reflect the central tendency, spatial extent, and clustering characteristics of geographic elements [11]. This method describes spatial distribution patterns by constructing ellipse parameters, where the ellipse center represents the mean center, the major and minor axes indicate the dispersion along the principal and secondary directions, respectively, and the azimuth reflects the dominant orientation of the spatial distribution.

The center of gravity is an important indicator for measuring changes in spatial location, and it is calculated as follows:

$$\bar{x} = \frac{\sum_{i=1}^{n} \omega_i\, x_i}{\sum_{i=1}^{n} \omega_i}, \qquad \bar{y} = \frac{\sum_{i=1}^{n} \omega_i\, y_i}{\sum_{i=1}^{n} \omega_i}$$

Where $(x_i, y_i)$ denotes the coordinates of the $i$-th spatial unit, $\omega_i$ is the corresponding weight (in this study, the area of each land use type), and $n$ is the number of units.

To further quantify the dynamic changes in spatial location between different years, the migration distance of the center of gravity is introduced to measure the displacement between adjacent periods [12]. The calculation is expressed as:

$$D_{(j+1)-j} = R \times \sqrt{(y_{j+1} - y_j)^2 + (x_{j+1} - x_j)^2}$$

Where $(x_i, y_i)$ and $(x_{j+1}, y_{j+1})$ represent the coordinates of the center of gravity in two consecutive years, $D$ is the migration distance, and $R$ is the conversion coefficient, taken as 111.11 km.

In this study, farmland, forest, grassland and impervious land with significant changes are selected. Based on the land use data in 2000, 2010 and 2020, the spatial distribution information of various types is extracted and the standard deviation ellipse parameters are calculated. On this basis, the changes of ellipse shape and its center of gravity position in different periods are compared and analyzed, thus revealing the evolution characteristics and migration trajectory of spatial pattern of different land use types.

### 2.3. Data Sources and Processing

The land use data used in this study were obtained from the China Land Use Remote Sensing Monitoring Dataset released by the research team of Yang Jie and Huang Xin from Wuhan University (https://zenodo.org/records). The dataset has a spatial resolution of 30 m × 30 m, providing relatively high spatial accuracy and effectively reflecting regional land use patterns [13]. Land use data for the years 2000, 2010, and 2020 were selected as the basis of this study. According to the research objectives, land use types were reclassified into six categories: cropland, forest, grassland, water, unused land, and built-up land. To ensure consistency in spatial analysis, all datasets were preprocessed in ArcGIS 10.8. A unified coordinate system (WGS_1984_UTM_Zone_48N) was adopted for all spatial data, providing a consistent basis for subsequent analyses.

## 3. RESULTS AND ANALYSIS

### 3.1. Temporal Variation and Structural Transformation of Land Use

#### 3.1.1. Temporal characteristics of land use change

From 2000 to 2020, land use in Sichuan Province underwent notable structural adjustments (Table 1). Forest and built-up land showed continuous increases, while cropland and grassland exhibited declining trends. Water and unused land fluctuated during different periods.

Specifically, forest area increased by 10,825.17 km² over the study period, representing a growth rate of approximately 5.68% and indicating a steady upward trend. Built-up land expanded from 1,895.15 km² to 4,499.52 km², with a remarkable increase of 137.43%, showing the most significant expansion among all types. The area of water experienced relatively minor overall change, characterized by an initial increase followed by a decrease, with a cumulative growth rate of 6.59%. In contrast, cropland decreased from 120,312.34 km² to 111,006.17 km², with a reduction of approximately 7.73%. Grassland also showed a gradual decline, though at a relatively moderate rate of about 3.38%. Unused land decreased slightly during 2000-2010 but then increased markedly to 4,555.94 km², exhibiting an overall fluctuating upward trend with a cumulative increase of 36.42%.

Overall, land use change in Sichuan Province during the study period was characterized by the simultaneous expansion of ecological land and rapid growth of built-up land, alongside a continuous reduction in agricultural land, reflecting the combined effects of ecological restoration and urbanization processes.

**Table 1.** Area statistics of land use types in Sichuan province from 2000 to 2020 ($km^2$)

| Land use type | 2000 | 2010 | 2020 |
|---|---|---|---|
| Cropland | 120312.34 | 117259.47 | 111006.17 |
| Forest | 190433.66 | 194851.88 | 201258.83 |
| Grassland | 166491.79 | 163548.09 | 160855.85 |
| Water | 4492.70 | 5174.18 | 4788.96 |
| Unused | 3339.63 | 3177.89 | 4555.94 |
| Built-up | 1895.15 | 2953.76 | 4499.52 |

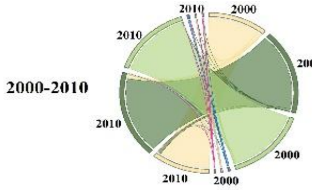
### 3.1.2. Land use transition matrix analysis

Based on the land use transition matrix, land use change in Sichuan Province during the study period was mainly characterized by mutual conversions among cropland, grassland, and forest, accompanied by a small proportion of conversion to built-up land (Fig. 2).

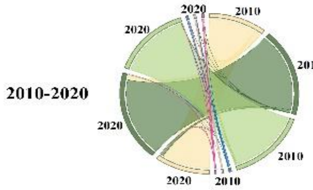
During 2000-2010, cropland showed significant outflow, primarily converting to forest (8,260.74 km²) and grassland (974.85 km²), while a considerable portion was also converted to built-up land (1,171.13 km²). Forest remained relatively stable, with only limited conversion to cropland (6,518.43 km²) and grassland (799.15 km²). Grassland, while maintaining high stability, also exhibited conversion to forest (3,459.04 km²) and cropland (1,082.23 km²). Overall, this period was dominated by the conversion of cropland to ecological land.

During 2010-2020, the overall conversion pattern persisted, although the intensity changed. Cropland continued to convert to forest (10,991.25 km²), and the conversion to built-up land further increased (1,576.55 km²). Grassland showed notable transitions to unused land (1,514.31 km²) and forest (2,630.44 km²), indicating some fluctuations in ecosystem stability in certain areas. The expansion of built-up land was mainly derived from cropland, accounting for the largest proportion, reflecting the continuous encroachment of urban development on agricultural land.

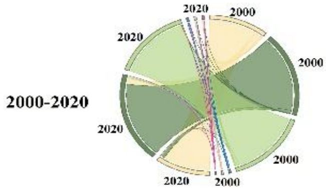
Over the entire period from 2000 to 2020, cropland exhibited a clear net loss, mainly converting to forest (14,397.40 km²) and built-up land (2,758.37 km²). Grassland was primarily transformed into forest (5,471.31 km²) and unused land (1,684.76 km²). Forest maintained a high degree of internal stability and was one of the most stable land use types in the study area. Overall, land use transitions in Sichuan Province can be summarized as a pattern of “cropland shifting toward ecological land and built-up land, and grassland differentiating into forest and unused land.”




| 2000\2010 | Cropland | Forest | Grassland | Water | Unused |
|---|---|---|---|---|---|
| Cropland | 109589.61 | 8260.74 | 974.85 | 315.92 | 0.08 |
| Forest | 6518.42 | 183107.13 | 799.15 | 2.53 | 0.00 |
| Grassland | 1082.22 | 3459.04 | 160742.54 | 462.66 | 728.65 |
| Water | 65.52 | 24.60 | 340.16 | 3811.47 | 209.58 |
| Unused | 0.25 | 0.36 | 691.35 | 406.69 | 2239.57 |
| Built-up | 3.44 | 0.02 | 0.03 | 174.91 | 0.00 |
| Sum | 117259.47 | 194851.88 | 163548.09 | 5174.18 | 3177.89 |




| 2010\2020 | Cropland | Forest | Grassland | Water | Unused |
|---|---|---|---|---|---|
| Cropland | 103367.47 | 10991.25 | 1076.64 | 246.21 | 1.35 |
| Forest | 6089.85 | 187616.08 | 1128.63 | 2.41 | 0.01 |
| Grassland | 1324.07 | 2630.44 | 157613.33 | 441.50 | 1514.31 |
| Water | 219.69 | 18.13 | 471.48 | 3591.70 | 817.73 |
| Unused | 0.35 | 2.92 | 565.57 | 386.13 | 2222.53 |
| Built-up | 4.74 | 0.01 | 0.20 | 121.01 | 0.00 |
| Sum | 111006.17 | 201258.83 | 160855.85 | 4788.96 | 4555.94 |




| 2000\2020 | Cropland | Forest | Grassland | Water | Unused |
|---|---|---|---|---|---|
| Cropland | 101465.04 | 14397.40 | 1238.06 | 451.61 | 1.86 |
| Forest | 7603.11 | 181348.39 | 1441.85 | 16.57 | 0.03 |
| Grassland | 1753.27 | 5471.31 | 157082.55 | 479.65 | 1684.76 |
| Water | 162.58 | 40.73 | 389.37 | 3200.97 | 634.12 |
| Unused | 0.63 | 0.95 | 703.57 | 397.75 | 2235.16 |
| Built-up | 21.54 | 0.05 | 0.44 | 242.41 | 0.01 |
| Sum | 111006.17 | 201258.83 | 160855.85 | 4788.96 | 4555.94 |

**Figure 2.** Land use transfer matrix of Sichuan Province from 2000 to 2020

## 3.2. Spatial Characteristics of Land Use Change

### 3.2.1. Spatial distribution characteristics of land use

From 2000 to 2020, the overall spatial pattern of land use in Sichuan Province remained relatively stable (Fig. 3). Forest and grassland dominated the region, mainly distributed in the western plateau and the mountainous areas surrounding the Sichuan Basin, forming the core components of the regional ecosystem. Cropland was primarily concentrated in the Sichuan Basin and its surrounding hilly areas, exhibiting a contiguous distribution pattern. Built-up land was centered in the Chengdu Plain urban agglomeration and expanded outward along major transportation corridors, showing strong spatial clustering and continuous growth over time. Water was mainly distributed along the main stream of the Yangtze River and its tributaries in a belt-like pattern, while unused land was largely located in the high-altitude areas of western Sichuan, strongly constrained by natural conditions.

Overall, the spatial distribution of land use in Sichuan Province is closely associated with topographic gradients, forming a differentiated pattern of "plateau forest–grassland, basin agriculture, and urban agglomeration." Although the overall spatial structure remained largely unchanged over the 20-year period, significant local transformations were observed, particularly the conversion of cropland to built-up land and ecological land.

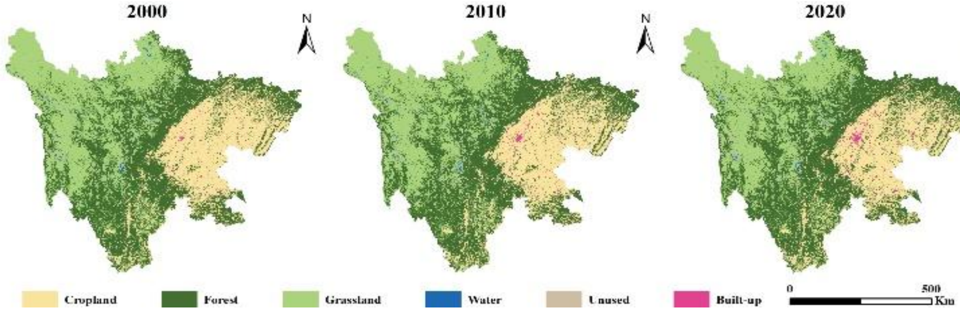



**Figure 3.** Temporal and spatial distribution of land use types in Sichuan Province from 2000 to 2020

### 3.2.2. Standard deviational ellipse and migration trajectory analysis of typical land use types

Cropland exhibited a stable northeast-southwest distribution pattern (Fig. 4a). From 2000 to 2020, the major axis of the standard deviational ellipse decreased from 377.22 km to 365.68 km, and the minor axis decreased from 175.78 km to 161.03 km, indicating a slight contraction in spatial extent and an increase in spatial concentration. The ellipse azimuth remained relatively stable at approximately 39°-40°, suggesting no significant change in the dominant distribution direction. In terms of center of gravity migration, the movement rate of cropland decreased from 4.14 km/a to 1.07 km/a, showing a trend of rapid change followed by stabilization. The cumulative migration distance was 36.82 km, indicating that the overall spatial pattern of cropland remained stable, with only localized adjustments (Tables 2 and 3).

Forest covered a wide spatial range, and its standard deviational ellipse was close to circular, indicating relatively weak directionality (Fig. 4b). During the study period, the major axis slightly decreased from 325.61 km to 319.57 km, while the minor axis increased from 270.11 km to 284.27 km, suggesting a more balanced spatial distribution and a slight increase in dispersion. The ellipse azimuth increased from 73.16° to 90.31°, indicating some adjustment in the dominant orientation. In terms of center of gravity migration, the movement of forest was relatively limited, although the migration rate increased over time, with a cumulative distance of 25.62 km. This reflects that the spatial pattern of forest remained generally stable, with some degree of dynamic adjustment (Tables 2 and 3).

**Table 2.** Migration distance (km) and speed (km/a) of land use center of gravity in Sichuan Province

| | Cropland | Forest | Grassland | Built-up |
|---|---|---|---|---|
| Year | Migration distance | Migration distance | Migration distance | Migration distance |
| 2000-2010 | 41.36 | 6.15 | 14.49 | 6.00 |
| 2010-2020 | 10.72 | 19.64 | 2.35 | 9.46 |
| 2000-2020 | 36.82 | 25.62 | 16.14 | 12.26 |

Grassland exhibited a pronounced north–south distribution pattern in its standard deviational ellipse (Fig. 4c), although the orientation showed some fluctuations. From 2000 to 2020, the major axis remained relatively stable (325.56 km to 321.36 km), while the minor axis decreased from 208.78 km to 190.48 km, indicating a slight increase in spatial concentration. The ellipse azimuth fluctuated among 4.24°, 179.83°, and 0.46°, which are all effectively aligned with the north–south direction, suggesting that the dominant distribution direction remained generally stable. In terms of center of gravity migration, grassland showed a migration distance of 14.49 km (1.45 km/a) during 2000-2010, which significantly decreased to 2.35 km (0.24 km/a) during 2010-2020. The overall migration magnitude was relatively small, indicating limited changes in the spatial pattern of grassland (Tables 2 and 3).

Built-up land displayed a clear northeast-southwest extension pattern with strong directionality (Fig. 4d). During the study period, the major axis of its standard deviational ellipse gradually decreased from 294.99 km to 268.76 km, while the minor axis remained relatively stable at around 130 km, suggesting a contraction along the principal direction with little change in the secondary direction. The ellipse azimuth consistently remained between approximately 38° and 39°, indicating a stable distribution orientation. In terms of center of gravity migration, the migration distances of built-up land were 6.00 km (0.60 km/a) for 2000-2010 and 9.46 km (0.95 km/a) for 2010-2020, showing a gradually increasing trend. The cumulative migration distance during the study period was 12.26 km, reflecting continuous spatial expansion while remaining concentrated within existing development areas (Tables 2 and 3).

Overall, significant differences were observed in the spatial distribution directions and evolution characteristics among different land use types. Cropland and built-up land shared a consistent and stable dominant orientation, forest exhibited a more balanced distribution, and grassland maintained a stable direction with relatively minor changes. None of the land use types experienced large-scale spatial reconfiguration during the study period; instead, changes were mainly characterized by localized adjustments based on the existing spatial pattern.

**Table 3.** Parameters of the standard deviational ellipse for the spatial distribution of land use in Sichuan Province

| | Cropland | | | Forest | | |
|---|---|---|---|---|---|---|
| Year | long axis | minor axis | angle | long axis | minor axis | angle |
| 2000 | 377.22 | 175.78 | 39.32 | 325.61 | 270.11 | 73.16 |
| 2010 | 376.94 | 169.56 | 40.16 | 326.43 | 275.16 | 79.36 |
| 2020 | 365.68 | 161.03 | 39.31 | 319.57 | 284.27 | 90.31 |
| | Grassland | | | Built-up | | |
| Year | long axis | minor axis | angle | long axis | minor axis | angle |
| 2000 | 325.56 | 208.78 | 4.24 | 294.99 | 129.78 | 38.78 |
| 2010 | 319.09 | 196.99 | 179.83 | 282.34 | 130.78 | 38.35 |
| 2020 | 321.36 | 190.48 | 0.46 | 268.76 | 130.87 | 39.36 |

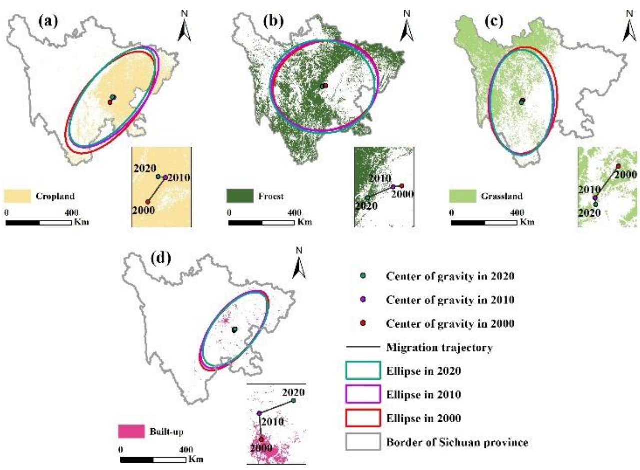



**Figure 4.** Ellipse of land use standard deviation and trajectory of center of gravity migration in Sichuan Province from 2000 to 2020

## 4. CONCLUSIONS

Based on land use data for 2000, 2010, and 2020, this study analyzed the characteristics of land use change in Sichuan Province from the perspectives of temporal variation, type conversion, and spatial patterns. The main conclusions are as follows:

(1) From 2000 to 2020, the land use structure of Sichuan Province underwent significant adjustments. Overall, forest and built-up land continuously increased, while cropland and grassland showed declining trends. Among them, built-up land exhibited the most significant growth, reflecting the impact of accelerated urbanization on land use structure. Cropland decreased continuously, while ecological land such as forest and grassland was restored to some extent.

(2) Land use conversion was mainly characterized by mutual transformations among cropland, grassland, and forest, accompanied by partial conversion of cropland to built-up land. Cropland showed a clear net loss, mainly converting to forest and built-up land, while grassland was primarily

transformed into forest and unused land. Overall, a general pattern of cropland shifting toward ecological land and built-up land was observed.

(3) The spatial distribution pattern was strongly controlled by topographic conditions, forming a basic pattern of “plateau forest–grassland, basin agriculture, and urban agglomeration.” Over the 20-year period, the overall spatial structure remained relatively stable; however, significant changes occurred in localized areas, particularly in the Sichuan Basin and surrounding urban agglomerations.

(4) The standard deviational ellipse analysis indicated clear differences in spatial distribution direction and dispersion among different land use types. Cropland and built-up land shared consistent and stable dominant orientations, forest exhibited a more balanced distribution, and grassland showed a north–south orientation. The results of center of gravity migration revealed that the overall migration distances were relatively small. Cropland exhibited relatively larger changes with a trend of gradual stabilization, while built-up land showed increasing migration, although all types generally remained within their original spatial frameworks.

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