Land Use/Land Cover Evaluation Using Trajectory Maps Based on Landsat TM/OLI in Southwest China

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ABSTRACT

This study mainly aims to detect the county-level spatio-temporal variability of LULCC (Land Use and Land Cover Change) spatial patterns in Southwest China. Multi-temporal Remote Sensing (RS) images (Landsat TM/OLI in 2000, 2005, 2010, and 2015) were applied to extract land use/cover types at each of the four-time nodes using the Support Vector Machine (SVM) method. Then, the trajectory map methodology was adopted to identify the spatio-temporal distribution characteristics of LULCC patterns throughout the given time series. According to the results, the area of unused land decreased continuously, 0.094% total. An evident decline of grassland by 2.17% was documented, and a notable increase was observed in forestland by 63.94 km^2 during the period from 2000 to 2015. Water bodies, built-up land, and unused land showed no significant change throughout the study period. The conversion from grassland to forestland and vice-versa (code 13 or 31) was prominent due to an adjustment made to local forestry policy during the first two periods (2000-2005 and 2005-2010), accounting for 17.55% and 17.56% of the study region, respectively. The anaphase trajectory transition type occupied the smallest area of all the trajectory maps. By contrast, the repetitive trajectory was the leading land-use transition type and covered the largest area. Trajectory analysis provides an effective approach for detecting the spatio-temporal changes in LULCC patterns.

INTRODUCTION

Human activities contribute to LULCC through their impact on the regional ecological environment, changes in climate, hydrology, vegetation, biogeochemical cycles, and biodiversity across a range of temporal and spatial scales (Collier et al. 2013). LULCC has become the core research focus in global change studies and also a significant facet of sustainable land use around the world. Over the last decade, as local socio-economic development has accelerated, as has regional industrialization and urbanization, a growing number of LULCC scholars have reduced their focus from the macro to the regional and micro scales. Furthermore, for LULC globally, understanding the temporal and spatial evolution process of regional LULCC has become critical, and several methodologies have been used to discover regional LULCC (Hao et al. 2009). These researches try to detect changes in the biological environment that drive human activities (Petrosillo et al. 2013), simulate and investigate the LULCC process (Hao et al. 2009), and anticipate future land use dynamics (Verburg et al. 2004). However, land-use change models have uncertainties due to the use of different sources for initialization, such as land use maps (Zomlot et

al. 2017, Verburg et al. 2013). Moreover, the general approach to analysis with land-use change models cannot fully reveal the complex and dynamic process of local, regional and global land uses. Thus, there is a need to develop a new methodology to better express the complex characteristics of spatial patterns and the various temporal processes in land-use change at various spatial and temporal scales.

Liu and Zhou (2004) provided a supplementary methodology for evaluating the accuracy of land cover change trajectories, in which a set of reasonable principles for evaluating the land cover change can be defined. By generating the 'curves' or 'profiles' of multi-temporal remotely sensed imagery, Zhou et al. (2008a, 2000b) developed and interpreted the spatial pattern metrics of multi-epoch trajectories of land cover change. The main benefit of trajectory analysis over other LULCC research methods is that it has been integrated into LULCC to assure data series continuity by interpolating or extending the temporal scale of the study (prospectively and retrospectively) beyond the period during which data is accessible (Wang et al. 2012, Zhou et al. 2008a, 2000b). The changing trajectory of LULCC has gained growing attention in studies of economically developed regions, basins,

and other areas over the last two decades. Using different temporal and spatial scales of RS image data and GIS, many studies on landscape pattern changes and the spatio-temporal process evolution of LULCC have used trajectory map methodology (Herold et al. 2003, Liu & Zhou 2004, Musa et al. 2020, Narasimhan & Stow 2010, Tang et al. 2005, Zhou et al. 2008a). However, to our knowledge, no studies have carried out the spatio-temporal trajectory analysis of LULCC at the county level for Youyang City in Southwest China.

Youyang, the largest county in Chongqing City, is situated in southwest China. Furthermore, it is not only a National Key Poverty Alleviation County but is also part of the important ecological zones along the Yangtze River Basin and in the Three Gorges Reservoir Area (Hua et al. 2014). It has played a significant role in ecological protection for the upper reaches of the Yangtze River. However, Youyang county is geographically dominated by mountainous areas. Further, the caster landform dominates, with an area of 0.31×10^4 km^2, and accounts for nearly 60% of the total coverage. The usual erosion type is rocky desertification, which is widespread (0.15104 km^2) and poses a threat to both local socio-economic growth and regional ecological security. Furthermore, 40.28% of the municipality's agricultural areas have varying degrees of soil erosion (Yan et al. 2016), and this number is anticipated to rise in the future. The current state of the environment has been a key source of concern for the local administration, particularly when it comes to afforestation and the Green for Grain Project (GGP). The population density is about 170 km^2, which is about 1.14 times higher than the national average, and 82.8% of the population is farmers. Additionally, the arable land per capita is less than 0.18 ha (Shi et al. 2018). Under the strong support of the central government, the Youyang government has implemented a series of policies and measures to encourage more young agricultural laborers to forgo agricultural activities. Though this increases the household income for residents and accelerates urbanization, this will also lead to a shortage in the traditional farming sector and increase the probability of cropland abandonment (Yan et al. 2016), thus affecting the local land-use change models. Hence, it is essential to gain an in-depth understanding of the status of spatial and temporal LULC dynamics in the study region to provide valuable guidance for future smart land-use management and planning, and to balance out the micro-rationality of farmers in decisions on farming intensity and the macro-rationality for the development of national food security policy (Yan et al. 2016).

In this paper, a study was conducted to 1) develop a methodology combining GIS and RS to identify spatio-temporal LULC change trajectories by overlaying the four stages of binary images in 2000, 2005, 2010, and 2015) to investigate the spatio-temporal characteristics of LULCC evolution by analyzing the metrics of the spatio-temporal patterns of those change trajectories at 5-year intervals, and 3) to investigate the potential environmental impacts on the metrics for characterizing those.

MATERIALS AND METHODS

Study Area and Data

Located in the southeast part of Chongqing City at 28°19'28"-29°24'18" N and 108°18'25 " -109°19'02" E, Youyang County, covers an area of about 5150 km^2 (Fig. 1), with forests accounting for about 52.2% of its territory. It is situated in the Wuling mountain region and dominated by mountains, covering the Yuanjiang River basin and the Wujiang River basin in the upper reaches of the Yangtze River. The local altitude ranges from 263 m to 1895 m. Meanwhile, the region's climate is subtropical humid monsoon, and the annual precipitation varies from 1000 mm to 1500 mm on average. The average annual temperature is 14.4 °C (Shi et al. 2018).

Data Processing

Landsat data pre-processing: We downloaded all Landsat TM pictures (2000, 2005, and 2010) and Landsat OLI imagery (2015) from the USGS using a cloud threshold of 10%. At a spatial resolution of 30 m, all the images were geo-referenced to the same Universal Transverse Mercator (UTM, 49 N) map projection using a second-order polynomial transformation using a bilinear interpolation algorithm. The graphics were then created using a red-green-blue (RGB) color scheme using bands 543 (TM) and 654. (OLI). All the images were
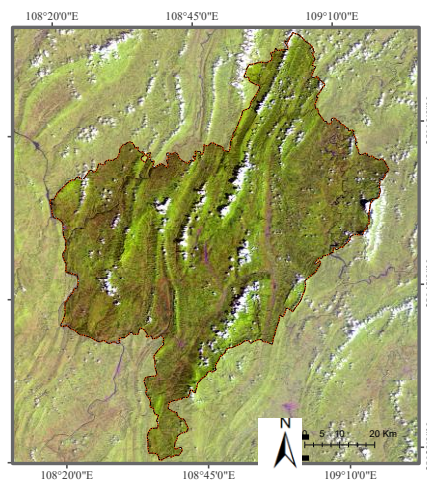

Fig. 1: Geographic location of Youyang County.

converted to surface reflectance using the sensor calibration algorithm, and the atmospheric correction was done with ENVI 5.3 software. Based on the national standard of land use classification system (GB/T 21010-2017), as developed by the Ministry of Land and Resources of China, the status of local land use and the field survey data was collected by a simple GPS instrument. This study involved six land-use types, cropland, forest, grassland, bodies of water, built-up land, and unused land. ENVI 5.3 software was used to classify all images via the SVM method. The overall accuracy of the land use data for the four periods was determined as 85.2%, 85.7%, 86.8%, and 88.9%, respectively, and the Kappa coefficient exceeded 72% for all types of land use. Then, the land cover classes were classified into one of six classes and denoted as 1, 2, 3, 4, 5, or 6 (1-forestland; 2-cropland; 3-grassland; 4-waterbody; 5-built-upland; 6-unused land). Finally, the land-use and land-cover maps for all the study periods were generated in Grid format using ArcGIS10.6 to facilitate further study in the subsequent change trajectory analysis.

Change trajectory analysis: Six land-use types from the four stages were included in the trajectory analysis mapping of the research region to investigate overall gains and losses of area for different temporal slices of land cover type. The land cover codes 1 through 6 were shown first. Second, using the raster calculation module in ArcGIS10.6, as well as the equation below, the trajectory codes for each raster pixel were calculated.

$$Z_{ij} = M_{ij} \times 10 + N_{ij} \qquad \ldots(1)$$

Where, Z_{ij} represents the trajectory layer with the trajectory code of the pixel at row i and column j, with no mathematical sense, while M_{ij} and N_{ij} refer to the code of LULC types from the beginning to the end of the study period.

In this study, to build a time series trajectory map, the ArcGIS spatial analysis module was used, and trajectory codes were formed using the following method.

$$T_{ij} = (G1)_{ij} \times 10^{n-1} + (G2)_{ij} \times 10^{n-2} + \cdots + (Gn)_{ij} \times 10^{n-n} \qquad \ldots(2)$$

Where, T_{ij} has no mathematical sense and represents the trajectory code of the pixel at row i and column j in the trajectory layer, n refers to the number of time codes, while $(G1)_{ij}$, $(G2)_{ij}$ and $(Gn)_{ij}$ represents the LULC map code values in different periods. A numeric trajectory code in the form of *xxxx* was treated as stable, *xyyy* as prophasic, *xxxy* as an aphasic, *xxyy* as middle, *xyzx* as repetitive, and *xyxz* or others as continual.

Change trajectories and mapping: To gain a deeper understanding of LULCC processes and to depict the spatial pattern of change dynamics, we analyzed the spatio-temporal dynamics of LULCC during different periods in the GIS environment. To begin, the LULCC transfer matrix model was used to calculate the area of various land-use transitions from 2000 to 2005, 2005 to 2010, and 2010 to 2015. Second, the spatial analysis tool "Overlay" in ArcMap 10.6 was used to determine the spatio-temporal trajectory map of LULCC for each of the three periods. The following is how the transfer matrix was calculated:

$$P_{ij} = \begin{vmatrix} P_{11} & P_{12} & \cdots & P_{1m} \\ P_{21} & P_{22} & \cdots & P_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ P_{m1} & P_{m2} & \cdots & P_{mm} \end{vmatrix} \qquad \ldots(3)$$

Where, P_{ij}, with non-negative value, indicates the land area in transition from type i to j, and $\sum_{i=1}^{m} P_{ij} = 1, 0 < P_{ij} \leq 1$.

RESULTS AND DISCUSSION

LULC Status and Change

The LULC types extracted from 2000, 2005, 2010, and 2015 images were forestland, grassland, cropland, water bodies, built-up land, and unused land (Fig. 2). Forestland and grassland were the main land use types across the study region, with a combined proportion of 86.79%, 88.54%, 86.13%, and 85.86% of land area in the four years, respectively (Table 1). This is consistent with the characteristics of regional socio-economic development. Forestland accounted for the largest proportion in the study area, comprising 52.95%, 66.64%, 54.27%, and 54.19% of total land cover, respectively. During the study period, the net area of forestland increased by 63.94 km^2, with an overall annual change ratio of 0.47%, which was largely attributed to the implementation of the GGP which was launched by the government in 1999. The grassland was the second most prominent and comprised 33.84%, 21.83%, 31.86%, and 31.67% of the study region, respectively. Overall, grassland declined, with an overall annual change ratio of -1.28% throughout the study period. This indicates that overgrazing and encroachment are still major stressors on grasslands. Over the past 15 years, the cropland covered an area of 630.64 km^2, 557.8 km^2, 660.77 km^2, and 660.10 km^2 in the four study periods, respectively, with the net increase area of 12.12 km^2. Cropland has faced renewed pressure in recent years due to urban expansion of the built-up area. Built-up land was the smallest man-made land use type, accounting for 0.38%, 0.14%, 0.43%, and 0.62% of total land cover, respectively. The smallest proportion of land was covered by unused land, with areas reaching only
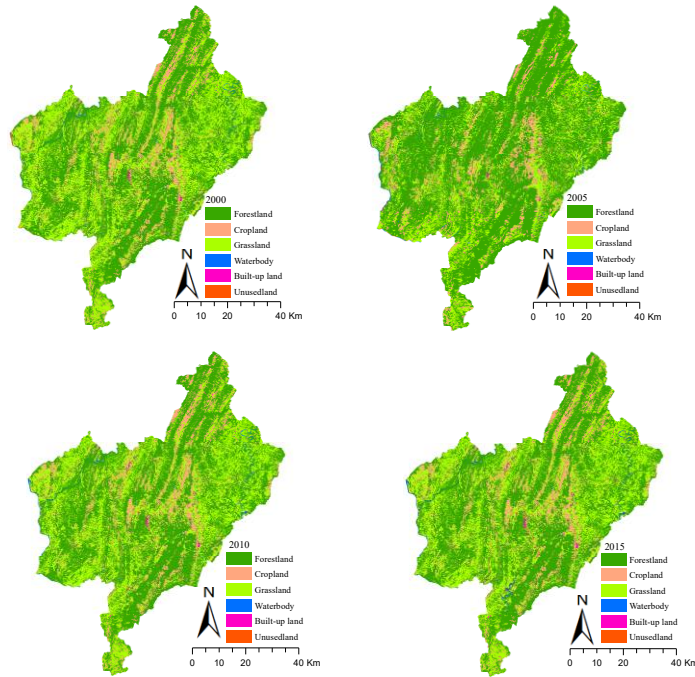
Fig. 2: Land-use maps of the study region in 2000, 2005, 2010 and 2015.

5.26 km², 2.04 km², 0.43 km² and 0.42 km², respectively. It seemed that water bodies, built-up land, and unused land showed no significant change throughout the study period.

Land Trajectory Analysis

The LULCC maps for each of the four years were obtained from RS satellites and analyzed using ArcGIS software to generate the spatio-temporal trajectory map. Here we characterize region-wide spatio-temporal trajectory maps for each of the three-time frames (Table 2).

Land trajectory analysis map for 2000-2005: We identified 34 trajectories of total land cover (Fig. 3-a), with 28 different land-use changes accounting for 35.56% of the total land area. As shown in Table 2, the conversion from grassland

to forestland (code 31) makes up the largest area at 695.21 km². This conversion accounted for 38.09% of the total area of land-use changes and was mainly scattered across the slopes. This highly significant change in the trajectory map is attributed to the implementation of various forestry policies and the adjustment made to agricultural policies during this period, especially regarding the ecological protection of ecological zones. Through these measures, the government encouraged local households to develop local forest industries of characteristic species. The cropland was abandoned and gradually transformed into grassland. However, the proportion of transition (code 13) reached 7.64%, indicating that a large amount of former forestland was occupied by grassland. Cropland→forestland (code 21) comprised

Table 1: Land use changes from 2000 to 2015 in Youyang County.

Land cover class	2000		2005		2010		2015	
	Area in km²	In %	Area in km²	In %	Area in km²	In %	Area in km²	In %
Forestland	2725.70	52.95	3430.59	66.64	2793.72	54.27	2789.64	54.19
Grassland	1742.22	33.84	1127.13	21.90	1640.07	31.86	1630.36	31.67
Cropland	630.64	12.25	557.81	10.84	660.77	12.84	660.10	12.82
Water body	24.22	0.47	22.87	0.44	30.81	0.60	35.40	0.69
Built-up land	19.71	0.38	7.29	0.14	21.94	0.43	31.83	0.62
Unused land	5.26	0.10	2.04	0.04	0.43	0.01	0.42	0.01
Sum	5147.75	100	5147.75	100	5147.75	100	5147.75	100

the second-largest area on the trajectory maps, covering an area of 343.02 km^2 and accounting for 18.80% of the total area of land-use changes. This change was also attributable to the implementation of GGP. As a result of GGP, a large amount of cropland was abandoned (or unoccupied) and then converted into forestland. The study region has drawn a lot of attention from the local government as a major forestry county in Chongqing and a candidate county for China's National Afforestation Model City. Forestry has become the region's main industry. Cropland to forest conversion occurred in mountainous areas with steep slopes (>25°) and high elevations (over 800 m). In the flatter mountain region, where a local minority population lives, forestland (123.91 km^2) changed to farmland (code 12). In this stage, it appeared that there was a substantial imbalance in the creation and destruction of forestland. Cropland is the most essential natural asset for a household's subsistence in the study region's poor mountainous terrain (Hua et al. 2016). Furthermore, Youyang County's population increased dramatically from 5.94105 in 2000 to 8.56105 in 2019. Mountain dwellers in this area must deal with the problem of more people sharing less land. Forestland was cleared for agricultural expansion by humans to make a living. Local villagers' livelihoods were harmed, and regional soil erosion was increased. A total of 279.73 km^2 (16.06%) of grassland was converted to cropland (code 32), indicating that grassland was the primary source of new cropland. The lack of high-quality land resources and crops in Youyang county has hampered local economic development to some extent. Grasslands distributed in the central region along the river valley are often converted to

obtain more agricultural products. Comparatively, the conversion from cropland to grassland (code 23) accounts for 137.26 km^2 (21.76%), indicating that the implementation of forestry ecological policies by the local government has made an impact.

Land trajectory analysis map for 2005-2010: Using the ArcGIS 10.6 spatial analysis module, we obtained the spatio-temporal trajectory map for the period from 2005-2010 (Fig.3-b). Major mutual conversions between forestland and grassland continued to occur, making this stage's most critical trajectory. The conversion of 658.38 km^2 of forestland to grassland (code 13) accounted for 35.61% of all land-use conversions. In deforested places, this process is linked to forestland degradation and grassland restoration. The shift from grassland to forestland (code 31) covered 245.66 km^2 (21.84%), owing to natural vegetation succession in the mountainous region and the local Forestry Bureau's implementation of environmental protection policies. "Forestland-cropland" (Code 12) was another important trajectory, accounting for 19.15% of the total area of land-use change. Despite the GGP and the associated subsidy starting in 1999, deforestation still occurred in some areas. To meet the demands of both agriculture production and livestock, a typical farming household, particularly of the Tujia ethnic group, appeared to prefer foraging in forestland near cropland. Smallholders cultivate the majority of forestland plots of high or middling quality with a modest or abrupt slope (Hua et al. 2016). Furthermore, the codes 23 and 21 in the trajectory map, which account for regions of 267.62 km^2 and 128.79 km^2, respectively, represent a considerable change.

Table 2: Trajectory map order of LULCC from 2000 to 2015 in study region.

2000-2005			2005-2010			2010-2015		
Code	Area (km^2)	Change ratio / %	Code	Area (km^2)	Change ratio / %	Code	Area (km^2)	Change ratio %
31	695.21	38.09	13	658.38	35.61	35	8.15	54.58
21	343.02	18.80	12	353.99	19.15	14	2.46	16.49
32	279.73	15.33	23	267.62	14.48	15	1.60	10.70
13	208.29	11.41	31	245.66	13.29	34	1.53	10.28
23	137.26	7.52	32	149.31	8.08	25	0.40	2.67
12	123.91	6.79	21	128.79	6.97	54	0.31	2.09
53	10.64	0.58	35	12.33	0.67	45	0.05	0.36
41	6.96	0.38	14	7.39	0.40	12	0.04	0.26
43	4.86	0.27	34	7.03	0.38	32	0.02	0.14
51	3.82	0.21	15	3.97	0.21	31	0.01	0.09
14	3.73	0.20	41	3.90	0.21	65	0.01	0.05
34	3.70	0.20	43	2.48	0.13	-	-	-
63	2.47	0.14	64	1.79	0.10	-	-	-
52	1.40	0.08	54	1.61	0.09	-	-	-

The local government implemented four strategic initiatives in 2009 for Industrial County, Forestry County, Tourism County, and Environmental County, which advanced local urbanization and industrialization while expanding rural people's economic prospects beyond farming. As a result, more workers were migrating into urban areas for non-farm employment opportunities. Further, the remaining farmers were primarily elderly people and women with relatively low labor capacity (Li et al. 2014). These new developments raised the opportunity cost for farming, thus reducing the relative profitability of traditional farming businesses (Yan et al. 2016). Consequently, a lot of cropland was abandoned or converted for other uses (Zhang et al. 2014). This indicates that the extent and dynamics of cropland abandonment may undermine national food security for China in the future.

Land trajectory analysis map for 2010-2015: With 17 different trajectories in this stage, the spatial distribution of trajectories throughout this time differed significantly from prior periods (Fig. 3-c). The most visible path was "grassland built-up land" (Code 35), which covered 8.15 km^2 and had a 54.58 per cent change ratio. Meanwhile, 2.00 km^2 of land was transformed from forestland or agriculture to built-up land (Codes 15 and 25), accounting for 13.3% of all converted land-use types. Due to rapid economic development and accelerated industrialization and urbanization, especially for the implementation policies of "one district and four parks", the expansion of constructed land caused some of the grassland, forestland, and cropland to be permanently converted. Meanwhile, Youyang county is well known for its karst. The lack of optimal land use will exacerbate rocky desertification and regional soil erosion, thus further deteriorating environmental quality and causing more environmental problems. Therefore, it will be important to prioritize reasonable utilization of land in the future. The conversion from forestland to water (code 14) accounted for 2.46 km^2, while the area of other trajectories was limited.

Land use Pattern for Trajectory Analysis

To determine the full spatio-temporal trajectory map for the study area, the trajectory map method was applied to identify a time series for spatio-temporal trajectory maps of four types in ArcGIS10.6, which are detailed as follows:

Prophase trajectory map analysis: The prophase transition trajectory map accounted for 37.02 km^2. The trajectory codes 3111 and 3222 were the major prophase transition types, accounting for 25.91 km^2 and 7.30 km^2, respectively. This indicates that conversions to forestland and cropland mostly occurred from grassland. The initial transition was influenced by local agricultural policies, whereas the latter transition showed that grassland was converted to cropland

at a consistent rate across the research period. The proportions of trajectory codes 3444 and 6333, which accounted for 1.08 km^2 and 0.99 km^2, respectively, were likewise major components of the prophase transition map.

Anaphase trajectory map analysis: The anaphase transition type only occurred during the period from 2010-2015
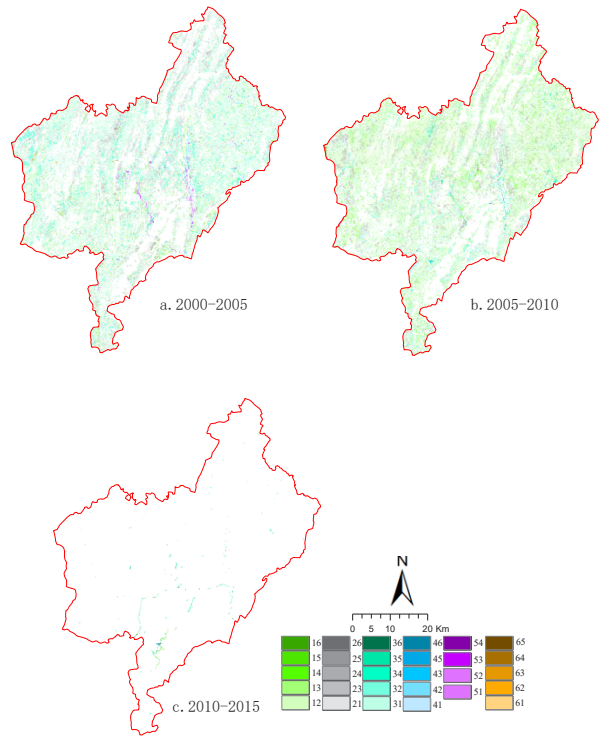

Fig. 3: Distribution map of LULCC trajectories from 2000 to 2015 of the study region.
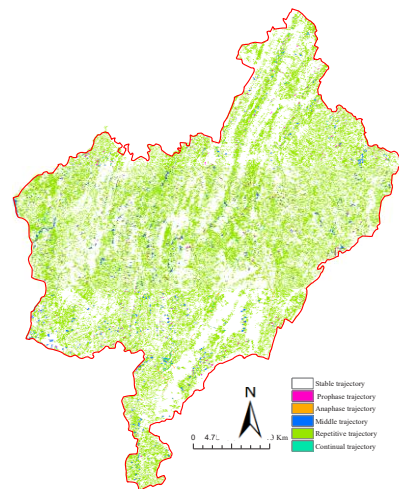

Fig.4: LULCC trajectory map of study region from 2000 to 2015

(Chen et al. 2020). The area was 9.35 km^2, which was the smallest of all the trajectory maps. Trajectory code 3335 comprised the largest area at 5.50 km^2. This was followed by trajectory code 1115, which accounted for 17.83% of the total area of the anaphase trajectory map. A major consequence is that this transition reduced ecosystem services that were previously rendered by the forestland and grassland. The other anaphase transition types comprised 2.18 km^2.

Middle trajectory map analysis: In the middle trajectory map, the land use types only transitioned during the period from 2005-2010 and remained unchanged during the other two periods (Chen et al. 2020). The area of the middle trajectory map was 55.21 km^2. Trajectory code 3311 covered the largest area at 36.95 km^2. Next code 3322 covered an area of 11.56 km^2, and code 2233 only covered 0.23 km^2. In this stage, it appeared that there was a large imbalance in grassland destruction. During each of these four periods, the phenomena of grassland restoration to agriculture persisted.

Repetitive trajectory map analysis: The repetitive trajectory map was the major land-use transition type, accounting for 34.35% of the total area. This was larger in area than any other trajectory map. Trajectory code 3133 had the largest area, accounting for 656.03 km^2. Codes 2122 and 3233 followed in prevalence, accounting for 19.37% and 15.06% of the study region, respectively. Due to the prominence of trajectory codes 3133 and 3233, the natural transition between grassland to forestland or cropland was very frequent.

Continual trajectory map analysis: The continual trajectory map comprised 25.60 km^2. Trajectory codes 3122 and 3211 were the major types of continual transition, accounting for 10.84 km^2 and 4.84 km^2, respectively. This indicates that the mutual transition between grassland and forestland to cropland occurred on a frequent basis under the context of human activities and land protection policies. Codes 3135 and 3235 represented the main transition types for the continual trajectory map throughout the study period, accounting for 6.06 km^2 and 4.02 km^2, respectively. This means a certain amount of grassland transitioned into built-up land due to the expansion of urbanization across the study region.

CONCLUSIONS

In this study, the LULC types at 2000, 2005, 2010 and 2015 were extracted from Landsat TM/OLI images using the SVM method, and the trajectory analysis method was applied to establish the trajectory maps illustrating three phases, to reveal the spatio-temporal variability of land use patterns and to explore the characteristics exhibited by the trajectories of change in the study region. During the period from 2000-2015, forestland and grassland dominated the study region, covering 86.79%, 88.54%, 86.13%, and 85.86% of the total land area, respectively. A net increase of 1.24%, 0.57%, 0.22%, and 0.24% was observed in forestland, cropland, water bodies, and built-up land, respectively, while unused land continuously declined (0.094%). Grassland was reduced to 2.73%. The major mutual conversion between grassland and forestland (Codes 13 or 31) occurred during the former two periods (from 2000-2005 and 2005-2010), accounting for 49.36% and 48.90% of the total land-use types converted, respectively. The repetitive trajectory type was the most prominent land-use transition type, covering the largest transition area of the total coverage trajectory map. By contrast, the anaphase transition type contributed to the smallest trajectory during the period from 2000-2015. The findings in this study demonstrate that trajectory analysis can provide an effective approach for detecting characteristics exhibited by the spatio-temporal change in LULCC patterns.

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