Spatial-Temporal Dynamics of Land Use and Cover Change and Multi-Scenario Analysing - A Case Study of Chang-Zhu-Tan Urban Agglomeration

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Abstract. Land use and cover change (LUCC) can help us understanding of the evolu-tion of urban ecological environment. This study investigated the dynamic changes of LUCC in the Chang-Zhu-Tan urban agglomeration (CZT) and identify its driving factors from 2000 to 2020. Additionally, we predicted the land use and land cover (LULC) in 2030 of CZT. The results revealed substantial loss of cropland and forest, comprising 6.90% and 2.42% re-spectively, contributed to 97.47% of new construction land. Spatially, the LUCC displayed a "center-periphery" distribution pattern, demonstrating outward spatial expansion. Cropland and forest loss areas were concentrat-ed in urban regions, aligning with the spatial development of urban expan-sion along the river. All scenarios presented a ecological deterioration in CZT in 2030. Overall, our study helps to accurately re-veal the spatial-temporal evolution of urban ecosystems.

Keywords: Land use and cover change, PLUS, Chang-Zhu-Tan urban agglomeration.

1 Introduction

Ecosystems extend a myriad of services to humanity, encompassing both direct and indirect benefits [1,2]. These services, known as ecosystem services (ES), constitute a wide range of environmental benefits and conditions that are essential for the continuation of human life and the pursuit of sustainable development, all of which are formed and sustained by ecological processes and the very fabric of ecosystems [3,4]. The changes in land use and cover (LUCC) introduce intricate impacts on ecosystems, marking themselves as crucial determinants in the exploration of the spatial and temporal alterations of ES. The diversity in land use categories, evidenced by varying rates of land cover, significantly influences the delivery of ecosystem services, with each type playing distinct and pivotal roles [5-7]. Furthermore, LUCC not only mirrors ecological dynamics but also directly precipitates shifts in types of ecosystems, alongside their regional and spatial distributions. These alterations, in turn, bear implications for the structural and functional dynamics of ecosystem services. Employing simulation techniques for modeling land use and cover transitions, including but not limited to CA-Markov [8], FLUS [9], and CLUE-S [10], facilitates a refined assessment of shifts in the valuation of ecosystem services. Despite these models delivering commendable predictive insights, their capabilities are somewhat limited in decoding the dynamic intricacies associated with specific land use transformations [11,12]. In light of these considerations, the present research integrates multiple data sources (for instance, land use data) to elucidate the LUCC within the Chang-Zhu-

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Tan (CZT) urban cluster and to dissect the evolving patterns and underlying drivers of these changes across the last two decades. The objectives of this study are as follows:

(1) Quantitatively analyze the spatial-temporal dynamics of LUCC in CZT from 2000 to 2020.

(2) Simulating the spatial-temporal dynamics of LUCC of CZT in 2030 under dif-ferent scenarios.

2 Study area and data

2.1 Study area

The Chang-Zhu-Tan (CZT) region, nestled in the heart of Hunan Province, China, encapsulates the urban areas of Changsha, Zhuzhou, and Xiangtan. Geographically positioned within the coordinates of 26°03’N to 28°41’N and 111°53’E to 114°15’E, CZT constitutes an integral segment of the "Middle Yangtze River Urban Agglomeration" as depicted in Figure 1. Covering an expansive territory of roughly 27,400 square kilometers, this area is inclusive of nine cities at the prefecture level and sixteen at the county level, collectively housing a populace nearing 13 million individuals. It is characterized by its high pop-ulation density, making it one of China's densely populated regions. The region expe-riences a subtropical monsoon climate and benefits from an abundance of water re-sources. The Xiangjiang River, the largest river in Hunan, flows from north to south through the urban agglomeration, and its tributaries provide plentiful hydrological conditions for the entire region. In CZT, hills and basins are intertwined, forming a unique geographic pattern. Its layout is interspersed with forests, water bodies, and ecological green heart conservation areas.

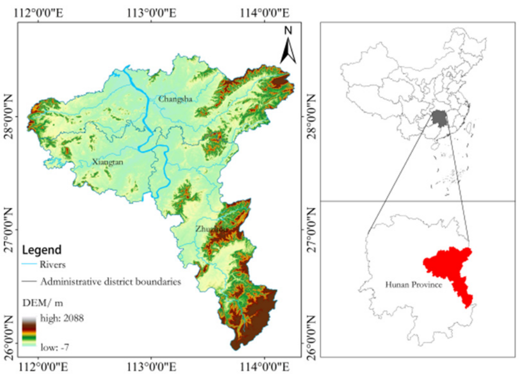

Figure 1. Location and general situation of CZT.

2.2 Data sources and processing

Data pertaining to land use, characterized by a 30-meter resolution, along with Gross Domestic Product (GDP) statistics, were acquired from the Resource Environment Science and Data Center affiliated with the Chinese Academy of Sciences. This land use dataset is segmented into six distinct categories: cropland, forest, grassland, water bodies, urban or constructed areas, and territories that remain unutilized. The delineation of administrative borders within the Chang-Zhu-Tan (CZT) area was procured from the National Geographic Information Resources

Catalog Service System. Road network information was derived from Open Street Map, enhancing the geographical data repository. The Normalized Difference Vegetation Index (NDVI), capturing vegetation density with a spatial resolution of 30 meters, was sourced from the National Ecological Science Data Center. Data on population density, presented with a 100-meter spatial resolution, was obtained from the WorldPop project [13]. Climatic datasets, including temperature and precipitation, were secured from the National Earth System Science Data Repository, each with a spatial granularity of 1 kilometer. Slope metrics were computed utilizing data from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) as documented by Tom et al., 2007 [14]. The formulation of prospective planning elements drew upon Hunan Province's 14th Five-Year Plan for traffic and transportation, specifically referencing envisioned expansions in highways and railways by the year 2030. This entailed calculating Euclidean distances to anticipated traffic infrastructures and incorporating these projections as future traffic data within the LEAS model. In efforts to harmonize spatial analysis, all utilized spatial data underwent standardization to conform to the WGS_1984_UTM_Zone_49N projection system. Moreover, spatial data of varying resolutions was resampled to a consistent resolution of 90 meters, ensuring uniformity in row and column counts across datasets.

3 Method

3.1 Simulating land use changes under different scenarios

In this research, the Prediction of Land Use Scenarios (PLUS) model is employed to forecast the trajectory of land use and land cover (LULC) changes within the Chang-Zhu-Tan (CZT) region. The PLUS model, an advanced iteration of the FLUS model, incorporates both policy-oriented and directive elements to refine land use predictions. This enhancement is realized through the integration of the Land Use Scenario Simulation (LEAS) module and the Comprehensive Assessment of Regional Strategies (CARS) module, both of which leverage the Markov module for the quantitative forecasting of land use requirements. Consequently, the PLUS model achieves a heightened level of precision in its simulations, offering a more nuanced understanding of the drivers behind diverse land use transitions and ensuring a superior quality of simulation outcomes.

3.1.1 Driving factors

Alterations in land use are predominantly shaped by the interplay of natural environmental conditions, the trajectory of socio-economic growth, and the strategic positioning of transportation infrastructures [15]. In this investigation, factors such as Digital Elevation Models (DEM), slope gradients, atmospheric temperatures, and precipitation levels are identified as key natural determinants influencing land use dynamics. The course of socio-economic advancement plays a crucial role in steering the patterns of land use transformations. Particularly, in regions marked by robust economic activity, high population density, and significant human intervention, agricultural lands are frequently repurposed into areas designated for construction. To examine these influences, this study incorporates Gross Domestic Product (GDP), population density metrics, and nocturnal illumination data as indicators of socio-economic progress driving land use modifications. Furthermore, the conditions surrounding transportation networks also exert a notable influence on the modification of land use patterns. Hence, this research evaluates the proximity to highways, railways, and waterways as critical transportation-related factors that impact land use transitions. With the development of the Chang-Zhu-Tan (CZT) region, the expansion and enhanced connectivity of its transportation infrastructure are anticipated to substantially augment its capacity to influence regional land use.

3.1.2 Weights

Field weight indicates the expansion potential of a land type, with values close to 1 signifying stronger expansion potential, and values approaching 0 denoting weaker expansion capability. In this study, we adopted the method of determining field weight factors proposed by Wang et al. [16] and quantified the expansion ability of each type of land based on the total area change of each type of land patch. Notably, construction land exhibited the highest expansion ability, with a field weight value of 1, while the unused land has the lowest expansion ability, with a field weight value of 0.1 (Table 1).

Table 1. Summary of field weights for different land types.

Cropland	Forest	Grassland	Water	Construction	Unused
0.490	0.522	0.025	0.115	1.000	0.100

3.1.3 Scenarios

This investigation delineates several distinct scenarios to simulate potential pathways of natural development within the Chang-Zhu-Tan (CZT) region by the year 2030. The scenarios elaborated include the Business as Usual Scenario (BAU, S1), the Ecosystem-Friendly Scenario (S2), the Cropland Protection Scenario (S3), and the Urban Development Scenario (S4), each characterized by unique policy and development orientations as detailed below:

(1) BAU (S1): This scenario projects the continuation of current trends in land use evolution, upholding the existing probabilities associated with land use type conversions and neighborhood influences. Utilizing land use data from 2010 and 2020, this scenario employs the integrated Markov module within the PLUS model to estimate the demand for various land types by 2030, serving as a foundational comparison point for alternative scenario configurations.

(2) Ecosystem Friendly Scenario (S2): Emphasizing ecological preservation within the CZT region, this scenario seeks to curtail urban expansion in favor of safeguarding forest areas and promoting environmentally considerate land utilization strategies. Measures include establishing ecological conservation zones, restricting the conversion of ecologically valuable land into developed land, and decreasing the likelihood of transforming forest, grassland, and aquatic zones into built-up areas by 10%.

(3) Cropland Protection Scenario (S3): This scenario underscores the importance of agricultural land conservation in CZT by implementing stringent farmland protection regulations. It aims to sustain the extant agricultural land area by limiting its conversion to

ecological or developed land, enhancing the conversion probability of forested and grassland areas into agricultural land by 20%.

(4) Urban Development Scenario (S4): Reflecting a phase of accelerated urban growth within CZT, this scenario envisions an expansion of urban boundaries and a substantial increase in development land. Consequently, it raises the probability of transitioning grasslands, agricultural fields, and water bodies into urban areas by 10%, while significantly reducing the conversion rate of developed land back to agricultural, forested, grassland, or aquatic zones by 70%.

4 Results

4.1 Accuracy assessment

The outcomes of the simulation for the year 2020, utilizing data observed in 2000 and 2010, underwent a comparison with actual observations recorded in 2020. Results from the assessment of accuracy reveal a Kappa coefficient valued at 0.885 and an overall accuracy (OA) rate of 0.93. These metrics underscore the Prediction of Land Use Scenarios (PLUS) model's commendable simulation precision within the Chang-Zhu-Tan (CZT) region [17]. Consequently, this model is deemed apt for projecting future land use and land cover (LULC) patterns in the specified area.

4.2 The spatial-temporal characteristics of land use changes from 2000 to 2020

The main types of land use in CZT are cropland, forest, grassland, water, construction land, and unused land. Among these, forest land and cropland dominate, accounting for the largest proportions, which were 94.23%, 92.31%, and 90.63% in the years 2000, 2010, and 2020, respectively (Table 2). Throughout these years, forest land had the highest proportion among six major land-use types, which are 63.78%, 62.99%, and 62.28%, respectively. The area of forest land decreased by 422.86 km2 from 2000 to 2020, with a decrease rate of 2.42%. The area of cropland also showed a declining trend over the past 20 years, the cover rate dropped from 30.45% to 28.35%. From 2000 to 2020, construction land showed an apparent expansion trend, its cover rate increased from 2.31% to 5.80%, and its area in 2020 was approximately 2.51 times than that of 2000. Although the area of water showed an increasing trend, the growth rate was slow. After 2010, the rates of reduction in the areas of arable and forest slowed, as did the increasing trend of construction land area.

Table 2. Land use areas and change rates from 2000 to 2020.

Land use	2000		2010		2020	
	Area/km2	Cover rate/%	Area/km2	Cover rate/%	Area/km2	Cover rate/%
Cropland	8559.32	30.45	8240.19	29.32	7968.55	28.35
Forest	17925.48	63.78	17704.64	62.99	17502.62	62.28
Grassland	448.75	1.61	444.46	1.59	434.28	1.55

Water	518.39	1.84	538.71	1.92	561.29	2.00
Construction land	649.27	2.31	1167.62	4.15	1631.23	5.80
Unused land	4.10	0.01	9.83	0.03	7.18	0.02

In terms of spatial distribution (Figure 2), construction land throughout CZT shares a common feature of being developed alongside the river, and they have dis-played a distinct expansion trend over a 20-year period. This expansion pattern is predominantly characterized by a pattern of "expansion along the river, concentration within the three cities, and dispersion outward." Notably, construction land in Changsha City has experienced rapid development both to the east and west along the Xiang River axis.

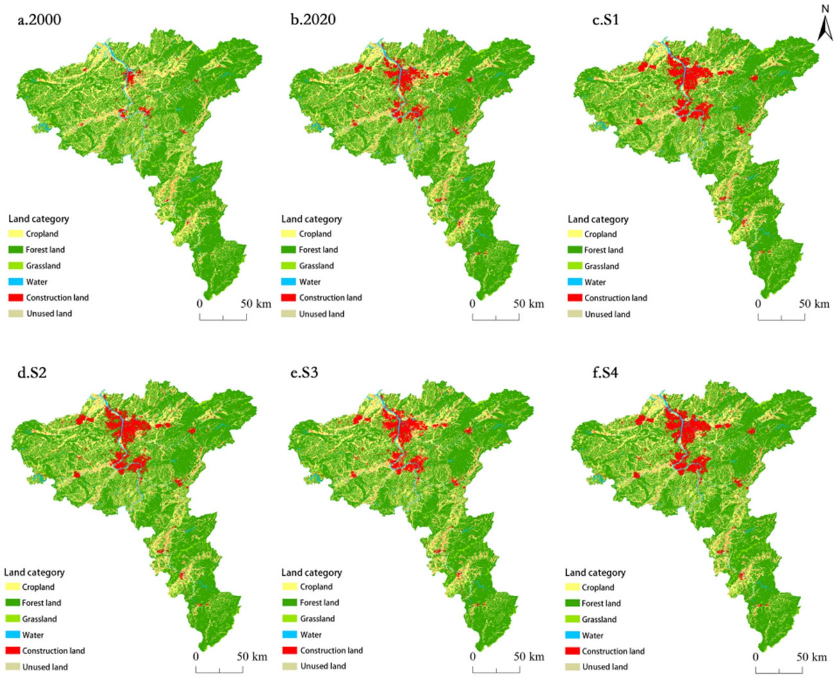

Figure 2. Spatial dynamics of land cover in 2000, 2020, and different scenarios in CZT. (a)Year 2000; (b) Year 2020; (c) Business as usual Scenario; (d) Ecosystem friendly scenario; (e) Cropland protection scenario; (f) Urban development scenario.

4.3 Analysis of land use change trajectory in CZT

We overlaid the land use change data and yielded the land use transfer change map of CZT from 2000 to 2020. The most significant land use changes in CZT over the past two decades have primarily occurred along the Xiang River. These changes exhibit a distinct spatial clustering pattern, aligning with the primary urban areas of Changsha, Zhuzhou, and Xiangtan.

The most substantial changes over the 20-year period occurred in cropland, with a total change of 1418.43 km2 and a net outflow of 590.77 km2 (Table 3). Among this, 55.01% of the cropland was transitioned into construction land, making it the main source of construction land expansion. Additionally, 37.20% of the cropland converted into forest, accounting for 84.08% of forest inflows. Although the trans-formation of cropland into forest accounts for 82.55% of the total inflow into forest, the total conversion area between the two land types remained relatively balanced, indicating a weak trend of cropland converting into forest land.

Construction land, being the most drastically growing category within the past 20 years in CZT, had an inflow area of 1043.39 km2, with only 61.45 km2 outflow. This reflects the rapid urbanization development of CZT. Meanwhile, construction land also transformed into cropland and forest, covering an area of 56.4 km2, making it the main direction of outflow. Notably, a certain proportion of forest, cropland, and construction land has been transformed into water areas. Although the net inflow area is relatively small, it still constitutes an unignorable part of the land use change in CZT.

Table 3. Land cover and land use transfer matric in CZT from 2000 to 2020.

Land use	Transferred area/km2						Total /km2
	Cropland	Forest	Grassl and	Water	Constru ction	Unused	
Cropland	-	373.6 7	6.78	70.81	552.61	0.73	1004.60
Forest	341.63	-	19.63	37.68	464.36	3.80	867.10
Grassland	5.12	32.46	-	1.40	3.77	0.00	42.75
Water	29.69	18.86	0.72	-	22.63	0.29	72.19
Construction land	37.37	19.13	0.23	4.70	-	0.02	61.45
Unused land	0.02	0.28	0.91	0.51	0.02	-	1.74
Total /km2	413.83	444.4 0	28.27	115.1 0	1043.39	4.84	2049.83

4.4 Simulation of land use changes in CZT

By 2030, the analysis of the spatial patterns of land use across the four scenarios within the Chang-Zhu-Tan (CZT) area reveals consistent trends (as illustrated in Figure 2 c-f). The expansion of constructed areas persists, following the developmental trajectory of "progressing along the riverbanks, concentrating in the tri-city area, and expanding outward." In comparison to the year 2020, the extents of forested areas, agricultural fields, grasslands, aquatic zones, and unutilized lands exhibit a decreasing pattern across all scenarios, whereas the domain of constructed land evidences an increasing trend. This indicates that, by the year 2030, the urban expansion within the CZT region is not mitigated by any of the proposed scenarios.

Compared to the year 2020, cropland and forest are the main lost categories under the four scenarios. The proportions of cropland have decreased by 0.14%, 1.13%, 0.95%, and 0.63% under the scenarios of farmland protection, ecological protection, urban development, and BAU, respectively. Similarly, the proportions of forest land have decreased by 0.9%, 0.09%, 0.85%, and 0.75%, respectively. In all four scenarios, the lost cropland and forest are mainly transformed into construction land. Under the scenarios of cropland protection, ecological protection, and BAU, forest, and cropland contribute significantly to the expansion of construction land, with cropland contributions of 58.25 km2, 336.52 km2, and 240.59 km2, respectively, and forest land contributing 246.39 km2, 11.32 km2, and 158.89 km2, respectively. In the urban development scenario, which prioritizes urbanization in CZT, cropland plays a central role in the transition, contributing the most to the transformation into construction land. Specifically, 283.6 km2 of its lost area is converted to construction land.

Compared to the BAU scenario, the Cropland Protection scenario saw an increment of 0.49% in cropland coverage, whereas forest and constructed areas experienced reductions of 0.15% and 0.42%, respectively. Within the ambit of the Ecosystem Protection scenario, forest coverage augmented by 0.66%, while cropland and built-up areas saw decreases of 0.50% and 0.13%, in that order. Across these scenarios prioritizing ecological considerations, there is a discernible moderation in the pace of urbanization, with slight enhancements in the allocations for cropland and forest areas. Conversely, the Urban Development scenario accelerates the urbanization trajectory within the Chang-Zhu-Tan (CZT) region, resulting in the diminution of both cropland and forest areas.

5 Discussion and conclusion

This research contributes significantly to the understanding of large-scale Land Use and Cover Change (LUCC) dynamics over time and space. The findings from this study lay a robust groundwork for subsequent investigations in the domain of ecosystem service evaluations. It is recommended that future scholars extend upon the basis established here, by honing the analytical techniques and expanding the scope of the study framework, thereby enriching our comprehension of LUCC and its complex driving forces. Such a cyclic enhancement in research methodologies is expected to yield more detailed and precise evaluations of ecosystem services, thus supporting well-informed policymaking and the promotion of sustainable land management practices.

In this study, we developed a method to investigate the dynamic changes of LUCC in CZT from 2000 to 2020. The PLUS model was employed to reveal the driving factors affecting the LUCC. The findings of our investigation can be summarized as follows: 1) The land-use changes in CZT underwent significant transformations from 2000 to 2020, with a net decrease of 590.77 km2 and 422.86 km2 for agricultural and forest land, respectively, while the net increase of urban development land reached 981.94 km2. The conversion of cropland and forest was the cost of urbanization in CZT. The urban development in CZT exhibited a trend of "expansion along the river, aggregation of three cities, and outward expansion". 2) From a temporal perspective, the acceleration of urbanization has resulted in an overall decline in agricultural and forest land, particularly evident over the past two decades. Different policies have not effectively prevented the land use and cover change in CZT. However, protecting agricultural land can relatively reduce the loss of ES value. Therefore, it is crucial to focus on protecting areas suitable for urban development, considering natural conditions such as topography, temperature, and precipitation. Overall, our study helps to quickly and accurately reveal the spatial-temporal evolution of urban ecosystems.

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