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# Effects of Urbanization on Landscape Patterns in the Middle Reaches of the Yangtze River Region

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Abstract: The middle reaches of the Yangtze River region (MRYRR) are China's first trans-regional urban agglomeration, located in the center of the Yangtze River Economic Belt. The MRYRR is an important ecological reserve, and its land cover changes are affected by both socio-economic development and geographical environment. In this paper, Landsat ETM/TM/OLI remote sensing images were used to monitor land use and landscape patterns from 1990 to 2015. Through supervised classification, land use transfer matrix, landscape pattern metrics and correlation analysis, the spatialtemporal patterns of land use change and its relationship with socio-economic in the study area were revealed. The results showed that: (1) the main land use types in the study area were cropland (CL) and forestland (FL), accounting for more than three-quarters of the study area. During the study period, built-up land (BL) increased, CL decreased, FL increased first and then decreased; (2) the BL expanded mainly by occupying CL and FL, and regional landscape pattern was gradually fragmented, with complex patch shape and increasing diversity and heterogeneity. Among them, the BL is gradually gathered, and the FL and CL are gradually fragmented; (3) in the past 25 years, the urbanization process in this region has been obvious, and the Gross Domestic Product (GDP) has increased by 36 times. The socioeconomic variables were positively correlated with BL, orchard (OL) and Shannon diversity index (SHID), and negatively correlated with CL, Wasteland (WL), mean patch size (MPS) and contagion size (CONTAG). The results showed that the urbanization development has a great impact on the region, and the ecological protection task is still challenging. It is necessary to protect high-quality cropland and draw a red line for ecological protection. We should strengthen the construction of ecological corridors and ecological nodes to adapt to regional sustainable development.

**Keywords:** urbanization; land use transition; landscape patterns; middle reaches of the Yangtze River region; correlation analysis



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## 1. Introduction

Since the 20th century, with the rapid development of economy and the rapid increase of urban population, the intensification of human activities such as urbanization and industrialization have had a serious impact on regional land use, vegetation cover and ecological environment [1-3]. Therefore, a series of ecological problems have emerged, such as climate warming, water pollution, low forest efficiency, soil erosion, etc., [4,5]. Deforestation, urban construction and over exploitation of tourism resources destroy the natural growth of regional vegetation, resulting in soil erosion, low vegetation coverage, fragmentation of vegetation patches and other problems, which have a significant impact on the overall regional ecological environment balance of the region, and endanger the integrity and sustainability of the ecosystem [6,7]. As the world population continues to increase, the global urbanization process will accelerate, especially in developing countries [8]. With destruction of the ecological environment and the decline of forest coverage, China's urbanization rate increased from 17.90% in 1978 to 60.60% in 2019 [9-11]. Forest cover in MRYRR is decreasing, which exacerbates the phenomenon of soil erosion [12,13]. Therefore, the Sediment content of the Yangtze River Basin is relatively high, ranking the fourth in the world with a value of  $1.18 \text{ kg} \cdot \text{m}^{-3}$ , and washing away as much as 900 million tons of sediment every year [14]. However, there are relatively few studies on land use change and its driving factors in MRYRR. Therefore, it is of great significance to study the change of regional land use and landscape pattern and its driving factors.

Spatial and temporal patterns of land use types and landscape patterns were the important topics in global change and land science [15,16]. The Land Use/Cover Change (LUCC) scientific research program was jointly developed and published by the International Geosphere Biosphere Program (IGBP) and the International Human Dimensions Program on Global Environmental Change (IHDP) in 1995 [17]. Spatial and temporal pattern analysis of regional land use change was the most basic content and the earliest research field of this research program [18,19]. Landscape pattern analysis method was defined as patch type, quantity and spatial distribution in landscape structure [20]. Analysis and research on land use and landscape patterns analysis gradually shifted from simple and intuitive qualitative research to quantitative analysis combined with spatial distribution [21]. The main representatives of land use and landscape patterns researches are Forman [22], Pickett [23], Turner [24], Risser [25], Wang [26], Wu [27], etc. With the development of RS and GIS technology, since the 21st century, Alejandro [28], Ellis [29], Munroe [30], Fu [31], Louisa [32] and other representative studies have laid a good foundation for land use and landscape pattern research.

In recent years, scholars have done a lot of research on the landscape patterns. Methods mainly focus on land use transfer matrix, dynamic change mathematical model, landscape measurement, gradient analysis, etc. [33–35]. Its achievements mainly focused on landscape patterns change [36], urbanization process and ecological eco-environment effects [37], driving mechanism [38], and land use model simulation and prediction [39]. Based on the vegetation map, Ma et al. chose a variety of landscape metrics to analyze and evaluate the landscape fragmentation in Dongling Mountain [40]. Zhang et al. established ecological risk index based on remote sensing data and analyze the temporal and spatial characteristics of ecological risk in Shiyang River Basin by using landscape indicators, which is of great significance to optimizing the land use structure and landscape pattern of the basin and maintaining the ecological function of the basin [41]. Qi et al. analyzed the landscape patterns of small and medium-sized cities in the Yangtze River Delta and Xinjiang and discussed the differences and driving factors of land use and landscape pattern change among regions based on population and economic data [42]. Fan et al. [43], Kim et al. [44], Huang et al. [45] and Asimeh et al. [46] analyzed and discussed the changes of land use and landscape patterns in different regions, obtaining important enlightenment, which providing important theoretical basis for regional land use planning and landscape optimization. However, studies on land use and landscape patterns changes in China were mainly concentrated in cities [47,48], and study areas were mainly concentrated in the

eastern coastal area [49]. The quantitative analysis of land use change and socio-economic driving forces of typical urban agglomerations in MRYRR is relatively rare.

Urban agglomeration in the MRYRR was the first approved national urban agglomeration in China [50]. MRYRR was the second largest urban agglomeration in China after the Yangtze River Delta urban agglomeration [51]. In April 2015, the development plan of MRYRR urban agglomeration was released, indicating that MRYRR urban agglomeration has become a key area for the implementation of ecological priority green development strategy in the Yangtze River economic belt [52,53]. Under the national strategy of coordinated regional development and the strategy of the rise of central China, the Yangtze River Delta urban agglomeration, as an important part of the Yangtze River Economic Belt, played a key role and was the core hub connecting the central and western regions with the Yangtze River Delta and the Hong Kong-Macao Bay area in Guangdong [54]. The MRYRR includes Hubei Province, Hunan Province and Jiangxi Province. Due to its unique mountainous terrain, geographical environment and climate characteristics, this area was rich in natural vegetation resources and was an important ecological protection area in China [50]. This area connected the upper and lower reaches of the Yangtze River and had obvious transition characteristics. Regional natural ecological development was of great significance for maintaining the ecological sustainable development of the whole Yangtze River basin [55,56]. The urbanization process in this area was typical and representative. It was of great significance to study the spatio-temporal changes of land use and landscape patterns and their coupling coordination with social, economic and ecological environmental systems.

Based on the remote sensing data and socio-economic data from 2000 to 2015, this study selected the MRYRR (Hubei Province, Hunan Province and Jiangxi Province) to analyze the change characteristics and evolution trend of land use and landscape patterns and determine the driving factors of land use and landscape pattern in this region. The purposes were to: (1) reveal the spatial-temporal dynamic characteristics of land use in the MRYRR; (2) evoke the trend of landscape patterns in the MRYRR; (3) analyze the relationship between social, economic and population factors and land use, and landscape pattern change. This study could provide scientific reference for regional urbanization sustainable development and ecological environment construction measures.

# 2. Study Area

The MRYRR includes Hubei Province, Hunan Province and Jiangxi Province ( $24^{\circ}25'$  N– $33^{\circ}16'$  N,  $108^{\circ}24'$  E– $118^{\circ}23'$  E), with a total area of 564,000 km<sup>2</sup> (Figure 1). The regional climate type is subtropical monsoon climate, with precipitation of  $1000-1600 \text{ mm} \cdot a^{-1}$  and annual average temperature of 16–18 °C [57]. The MRYRR mainly consists of mountainous hills and plains, which account for 48.3% and 14.8% of the area, respectively. The area has an average altitude of about 1500 m [36]. MRYRR has three agglomeration areas, including Wuhan Metropolitan Area, Poyang Lake Metropolitan area and Changsha-Zhuzhou-Tan Metropolitan area, making MRYRR one of the most important national urban agglomerations in China [58]. In 2018, the total population of this region was 174.38 million, accounting for 12.7% of the total population of China, with a GDP of 9.8 trillion yuan. The urbanization level exceeded 50%, with frequent human economic activities and large regional disturbances [59].



Figure 1. Locations of the MRYRR.

#### 3. Materials and Methods

# 3.1. Data Sources and Processiong

The data form Landsat TM/ETM/OLI remote sensing images (https://www.usgs. gov/, accessed on 14 August 2021) in 1990, 2000, 2010 and 2015 were used in this study [60]. Combined with the 2017 China land cover classification standard system and the land use characteristics of land use types in the study area, supervision and classification were carried out. Land use types were divided into eight types: cropland (CL), forestland (FL), shrubland (SL), orchard (OL), grassland (GL), waterbodies (WB), built-up land (BL) and wasteland (WL) (Table 1). One hundred and sixty samples were randomly selected, and high-resolution images were used to detect Google Earth ( $10 \times 10 \text{ m}^2$ ) and interpret the accuracy. The overall accuracy was above 74% and kappa coefficient was above 0.70. All operations were performed using the ENVI 5.3 software. Socioeconomic factors (population, urban residents, rural residents, GDP, per capita GDP, primary sector, secondary sector, tertiary sector) are derived from the statistical yearbook [61–64].

Table 1. Land use types in the study area (based on the Chinese National Standard and Yi) [65,66].

Land Cover Types	Description
Grassland (GL)	Refers to growing herbaceous plants, including pasture or mainly pasture.
	Refers to land for planting crops, including cultivated land, new open
Cropland (CL)	wasteland, wheeled land, and crop fields so as to cultivate rice, lotus root,
	and other aquatic crops.
Forestland (FL)	It mainly refers to natural forests and plantations
Shrubland (SL)	Short woodlands and shrubs.
Orchard (OL)	Refers to many years of intensive planting of woody and herbaceous crops
Officiatu (OL)	for the intensive management of fruit, leaves, roots, stems, and juices.
Built up land (BL)	All types of manmade structures: Residential, industrial, agricultural
Duni-up land (DL)	commercial and services; transportation and utilities.
	Refers to natural land waters and land for water conservancy facilities,
Waterbodies (WB)	including reservoirs, ponds, rivers, lakes, snow, oceans and submerged
	land, etc.
Wasteland (WL)	The surface is rock or gravel, bare soils, sand, and bare stone.

# 3.2. Study Methods

3.2.1. Land Use Transfer Matrix

Land use transfer matrix is a two-dimensional matrix based on the relationship between land cover change in two different periods in the same region. By analyzing the transformation matrix, we can get the conversion between two different periods of different land categories. It can not only reflect the area of various land types at a static time point, but also reflect the output information of land cover in the early stage and the income information in the later stage. Land use transfer matrix can visually describe the spatio-temporal change process of land use [67].

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & \cdots & S_{1n} \\ S_{21} & S_{22} & S_{23} & \cdots & S_{2n} \\ S_{31} & S_{32} & S_{33} & \cdots & S_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ S_{n1} & S_{n2} & S_{n3} & \cdots & S_{nn} \end{bmatrix}$$
(1)

where  $S_{ij}$  is the area of class *i* land converted into class *j* (The *i* = *j* represents the unchanged area of a certain land use type); *i* and *j* respectively represent the land use types before and after the transfer. *n* is the number of land use types (*n* = 8 in this paper).

In order to clearly express the data of land use transfer from 1990 to 2015, we made a graph called circos and listed the data as Appendix A (Figure 2 and Tables 3–6). Graphing method used the template (http://mkweb.bcgsc.ca/tableviewer/ accessed on 14 August 2021) by Canada's Michael Smith Genome Sciences Centre (CMSGSC) [68]. The illustration is as follows:



**Figure 2.** An explanation of the circos chart. Each stripe represents the occurrence of a transformation process at two different times, and the color represents the land use types. (a) The area of  $A_1$  transformed into other land use types; (b) The types of land use transformed from  $A_1$ ; (c) The total area of  $A_1$  transformed out and transformed into; (d) The area of  $A_1$  transformed from other land use types; (e) The types of land use transformed into  $A_1$ ; (f) The proportion of each land use types in transferred from  $A_1$ ; (g) The proportion of each land use types in transferred into  $A_1$ ; (h) The total amount of  $A_1$  transferred into and transferred out.

#### 3.2.2. Quantification of Landscape Patterns

Landscape metrics are widely used to quantitatively describe the changes of regional landscape patterns [69,70]. According to the diversity of land use types in the study area, relevant metrics were selected, mainly including landscape metrics that could reflect area, density, diversity, connectivity and shape (Table 2). Fragstats 3.3 software is used to calculate the landscape metrics.

#### 3.2.3. Statistical Analysis

Statistical correlations among land use types (CL, FL, SL, OL, GL, WB, BL and WL), landscape patterns (PD, LPI, MPS, NP, SHDI, and CONTAG) and urbanization metrics (POP, RUR, URR, GDP, PGDP, PRI, SEC, TER) were calculated. *p* value less than 0.05 was considered a significant correlation [71]. All statistical analyses were performed using SPSS 20 software.

Structural Category	Landscape Metrics	Abbreviation	Description			
	Patch density	PD	Number of patches per unit area in a landscape			
Amer /Densites	Largest Patch Index	LPI	Area of the largest patch			
Alea/Delisity	Mean Patch Area	MPS	The average mean surface of patches			
	Number patches	NP	The total number of patches can reflect the spatial pattern of landscape			
Diversity	Shannon diversity index	SHDI	Detection of Landscape Diversity			
Connectivity	Patch Cohesion Index	COHESION	Increases as the patches of the corresponding patch type become less connected			
	Contagion index	CONTAG	The degree of aggregation and extension of certain patches within a landscape			
Shape	Landscape shape index	LSI	Represents the complexity of the boundary shape			

Table 2. Description of landscape metrics.

# 4. Results

## 4.1. Land Use Change in the MRYRR from 1990 to 2015

#### 4.1.1. Characteristics of Spatiotemporal Change of Land Use

From 1990 to 2015, the MRYRR experienced significant land use transfer changes. FL and CL were the main land use types in the study area, and the land use area in the order from large to small was always as follows: FL > CL > SL > WB > GL > BL > OL > WL (Figure 3). In 1990 and 2015, the proportion of CL was 31.47% and 30.41%, and that proportion of FL was 50.31% and 49.82%, respectively, the sum of which reached about 80% (Table 2, Figures 3 and 4). BL accounted for about 1.73% to 2.81% of the whole study area, showing an overall growth trend. The area of BL increased by 7.67%, 17.36% and 28.61%, respectively. CL and SL decreased, while FL and WL fluctuated greatly. OL showed a decreasing trend before 2000 and gradually increased after 2000.



Figure 3. Spatiotemporal change of land use types in the MRYRR from 1990 to 2015.



**Figure 4.** Changes in land use types in the MRYRR region from 1990 to 2015. The data in the color histogram represent the area of land use types in the study period (1990, 2000, 2010 and 2015) from left to right. Details of the abbreviations are shown in Table 2.

#### 4.1.2. Characteristics of Land Use Transfer Changes

From 1990 to 2000, the area of BL in the MRYRR increased by 749 km<sup>2</sup>, an increase of 7.67%. In the past 10 years, the total area of CL decreased by 1524 km<sup>2</sup> (0.86%). The total area of FL increased by 1179 km<sup>2</sup>, mainly from CL and SL. From 1990 to 2000, the intensity of land use type transfer within the study area was relatively high (Figure 5a). From 2000 to 2010, BL increased by 1825 km<sup>2</sup>, an increase of 17.36%. Among them, 1221 km<sup>2</sup> and 474 km<sup>2</sup> came from CL and FL. The OL area increased by 1048 km<sup>2</sup>, most of which came from FL. The area of CL decreased by 2042 km<sup>2</sup>, most of which was converted into FL, OL and WB. From 2000 to 2010, the intensity of transfer between land use types in this region was low, with the transfer proportion less than 20%. Among them, CL has the highest transfer intensity (Figure 5b).

From 2010 to 2015, BL increased by 3529 km<sup>2</sup>, an increase of 28.61%. Among them, the areas from CL and FL were 2123 km<sup>2</sup> and 1127 km<sup>2</sup> respectively. The changes of OL area mainly came from FL, with an increase of 2120 km<sup>2</sup>. The area of CL was decreased by 2450 km<sup>2</sup>, which was mainly transferred to BL. During this period, the intensity of transfer in the MRYRR was small, with the proportion of transfer less than 1.6%. In terms of land use transfer out, CL has the largest transfer out intensity, and the transfer out area accounts for 1.6% (Figure 5c). In the 25 years from 1990 to 2015, BL increased by 6103 km<sup>2</sup>, an increase of 62.52%, with an average annual increase of 244.12 km<sup>2</sup>. Various land use types have been transferred to BL, and CL and FL were the main land use types converted to BL. The area of FL decreased by 2808 km<sup>2</sup>, and FL transferred to CL (17.41%), SL (6.56%) and others (0.85%). The area of CL decreased by 6016 km<sup>2</sup>, with an annual decrease of 240.64 km<sup>2</sup> (20%). OL increased by 3005 km<sup>2</sup>, WL decreased by 273 km<sup>2</sup>, GL decreased by 656 km<sup>2</sup> and SL decreased by 1413 km<sup>2</sup> (Figure 5d).



**Figure 5.** Land use transfer flow charts in the MRYRR from 1990 to 2015. (a) Land use transfer flow chart from 1990 to 2000. (b) Land use transfer flow chart from 2000 to 2010. (c) Land use transfer flow chart from 2010 to 2015. (d) Land use transfer flow chart from 1990 to 2015.

# 4.2. Changes in Landscape Patterns in MRYRR from 1990 to 2015

#### 4.2.1. Changes Metrics of Landscape Scale in the Study Area

From 1990 to 2015, the PD of MRYRR increased and the landscape patterns became increasingly fragmented. The increase of SHDI indicated that the landscape pattern had became heterogeneous and fragmented. The LPI increased from 44.43 to 44.96 from 1990 to 2000, and then decreased to 44.13, indicating that the dominant patch became more and more obvious from 1990 to 2000, and then gradually fragmented. The MPS and CONTAG decreased, indicating that landscape patches became more fragmented. On the whole, with the development of urbanization, the landscape fragmentation in the MRYRR becomes more obvious, and the landscape heterogeneity is enhanced (Figure 6).

#### 4.2.2. Changes of Horizontal Pattern of Landscape Types in the Study Area

The LSI of BUL became complex, but patches are more concentrated. The COHESION of orchard increased before 2010, but after 2010, COHESION decreased. The patches of CL and FL became fragmented, with reduced connectivity and complex landscape shapes. During the period 1990 to 2015, the NP of BUL increased from 6232 to 7936, and the MPS increased from 1.57 km<sup>2</sup> to 2.00 km<sup>2</sup>, indicating that the BUL was more concentrated. At the same time, the NP and LSI of CL increased from 1990 to 2015, while the LPI and MPS decreased, which indicated that CL was gradually fragmented (Figure 7).



**Figure 6.** Landscape metrics in the MRYRR from 1990 to 2015. (a) Number of patches from 1990 to 2015. (b) Mean patch area from 1990 to 2015. (c) Patch density patches from 1990 to 2015. (d) Contagion index from 1990 to 2015. (e) Shannon's diversity index from 1990 to 2015. (f) Largest patch index from 1990 to 2015.



Figure 7. Landscape metrics on each type of land use in the MRYRR from 1990 to 2015.

The MPS of FL decreased from 64.45 km<sup>2</sup> to 59.56 km<sup>2</sup> during the period, and LSI decreased from 163.66 to 162.52 from 1990 to 2000, then increased to 164.71 in 2015. The COHESION was consistently at a high level (99.89%). The NP and MPS of WL firstly increased and then decreased. The MPS of SL gradually decreased (Figure 7).

# 4.3. *Urbanization Process and Its Relationship with Land Use and Landscape Pattern* 4.3.1. The Urbanization Process in MRYRR from 1990 to 2015

From 1990 to 2015, MRYRR underwent rapid and noticeable urbanization. The GDP and PGDP increased by 36.03 times and 30.45 times, respectively. The PRI, SEC and TER increased by 8.28 times, 25.72 times and 39.5 times, respectively. During the time, POP increased from 32.35 million to 92.09 million. The RUR was gradually flowed into the cities, making the increase of URR an important factor of urbanization development. Over the past 25 years, the urbanization level in the study area increased from 21.19% to 51.43%, an



increase of 2.43 times. The increase of BL in this study also indicated the rapid urbanization in the MRYRR (Figure 8).

**Figure 8.** Socio-economic indicators in the middle reaches of the Yangtze River region from 1990 to 2015.

4.3.2. The Relationship between Land Use Change, Urbanization and Landscape Driving Factors

The BL was negatively correlated with RUR and positively correlated with other factors. The correlation order was the TER > GDP > PGDP > SEC > PRI > RUR (p < 0.05). The area of CL was positively correlated with RUR (p < 0.05), and negatively correlated with other factors, except POP, and the correlation order was the PGDP > GDP > PRI > RUR > TER > SEC > URR (p < 0.05). SL was negatively correlated with POP and RUR (p < 0.01), while SL was positively correlated with RUR (p < 0.05) (p < 0.05) (Figure 9).

	POP	RUR	URR	GDP	PGDP	PRI	SEC	TER		
CL	-0.923	0.987*	-0.974*	-0.988*	-0.989*	-0.988*	-0.983*	-0.987*		High
FL	-0.435	0.696	-0.590	-0.797	-0.793	-0.735	-0.800	-0.837		
SL	-0.992**	0.972*	-0.996**	-0.933	-0.935	-0.958	-0.925	-0.914		
OL	0.727	-0.905	0.839	0.959*	0.957*	0.927	0.958*	0.977*		Lour
GL	-0.960*	0.857	-0.916	-0.769	-0.773	-0.827	-0.766	-0.720		LOW
WB	0.986*	-0.980*	0.997**	0.938	0.940	0.966*	0.934	0.911		
BL	0.829	-0.953*	0.912	0.984*	0.983*	0.965*	0.980*	0.996**		
WL	-0.868	0.983*	-0.945	-0.989*	-0.989*	-0.990**	-0.993**	-0.976*		High
NP	0.892*	-0.872	0.935	0.804	0.807	0.843	0.789	0.781		
MPS	-0.761	0.911	-0.858	-0.959*	-0.958*	-0.929	-0.955*	-0.980*		
PD	0.737	-0.894	0.837	0.947	0.945	0.913	0.942	0.971*		
CONTAG	-0.757	0.918	-0.860	-0.966*	-0.965*	-0.937	-0.964*	-0.984*		
SHDI	0.789	-0.943	0.889	0.983*	0.982*	0.960*	0.983*	0.993**		
LPI	-0.128	0.453	-0.313	-0.578	-0.573	-0.505	-0.591	0.619		

**Figure 9.** Correlation of land use, landscape patterns and other factors in the MRYRR from 1999 to 2015. Green represents negative relationships and red represents positive relationships. The lighter the color, the weaker the correlation. The data in the frame represents the correlation coefficients between land use types. \* Means that p less than 0.05; \*\* means that p less than 0.01. Details of the abbreviations are shown in Table A1.

BL and OL were significantly positively correlated with economic factors (GDP, PGDP, SEC and TER), while CL, SL and WL were significantly negatively correlated with economic factors. From the perspective of landscape patterns, NP was positively correlated with POP. PD was positively correlated with TER. MPS and CONTAG were negatively correlated with GDP, PGDP, SEC and TER, and SHDI was positively correlated with GDP, PGDP, PRI, SEC and TER (Figure 9).

#### 5. Discussion

Social and economic development, urbanization level and geographical conditions were important factors affecting the changes of regional land use types and landscape patterns [72,73]. This study revealed the spatial-temporal patterns and driving factors of land use change in MRYRR over the past 25 years. According to the research results, BL and OL increased by 1.08% and 0.54%, respectively, from 1990 to 2015, CL and FL decreased by 1.06% and 0.49% respectively (Figure 4 and Table 2). Compared with China's coastal urban agglomerations, MRYRR has less land use change. For example, BL in the Yangtze River Delta increased by 8.68% and CL decreased by 9.98%, CL and FL decreased by 7.12% and 2.26%, respectively [74,75]. The changes of land use types and landscape patterns in the MRYRR were consistent with its socio-economic level, geographical conditions and national development policies.

At the socioeconomic level, urbanization was an important driving force of landscape pattern change. The Yangtze River Delta and the Pearl River Delta were located in the coastal areas, opening up to the outside world earlier and developing rapidly. The demand for BL was strong, leading to the acceleration of CL reduction [76–78]. Statistics showed that the development intensity of Shanghai and Beijing were 36.5% and 48%; however, the development intensity in London and Tokyo was only 23.75% and 29.4% [79]. MRYRR, located in central and western China, has relatively slow economic development and urban population growth, and has a weak impact on CL and FL. Since 2016, the development of the Yangtze River economic belt had been implemented as a national strategy, and the economic development would increase rapidly. Therefore, the land use change in the study area should learn from the development experience and lessons of other regions in order to adapt to the sustainable development of social economy and environment.

At the level of natural environment, geographical environment has a restriction effect on land use changes. The Yangtze River Delta and the Pearl River Delta were mainly deltas and alluvial plains formed by the estuaries. The lack of natural barriers in mountainous regions limits land development and promotes land use disorder. Hilly areas in the three provinces of the MRYRR made up more than half of the total area [80,81]. Even in the middle delta of Wuhan, Changsha and Nanchang, the capital cities of the study area, there were still a large number of mountainous areas, which restrict the expansion of urbanization to a certain extent. However, with the development of urbanization in the past 25 years, the landscape fragmentation in this area became more and more serious, and the complexity of patch shape increased, even in the marginal areas, which had a negative impact on the maintenance of its ecosystem function.

At the level of national development strategies, land use was also affected by policies. The MRYRR area has implemented the Yangtze River Shelterbelt and the project of Grain to Green. In recent years, the implementation of ecological engineering and the promulgation of protection policies provided favorable conditions for the landscape ecological protection in this region, and also affected the landscape patterns [82,83]. SL has been the dominant land type in the study area for the past 25 years, and the area still maintains a high proportion of natural ecosystems, which provides a basis for development based on ecological conservation. However, due to the high intensity of human activities, the CL and FL in the region decreased, and the degree of landscape fragmentation was still increasing. Therefore, the protection of basic farmland and the control of urban expansion

scale should be done well, and the maintenance of natural ecosystem connectivity should be strengthened.

# 6. Conclusions

From 1990 to 2015, with the rapid development of urbanization, BL increased by more than half in MRYRR, mainly by occupying CL and FL. BL gradually aggregated into the main patch of the core urban area. At the same time, the CL and FL were fragmented. During this period, the overall landscape of MRYRR became more heterogeneous and fragmented. The increase of economic and demographic factors in the study area was positively correlated with BL, OL and SHID, and negatively correlated with CL, WL, MPS and CONTAG. Urbanization had a profound impact on the local land use and landscape patterns.

As the central region of the Yangtze River Economic Belt, the MRYRR is facing rapid economic development and the continuous improvement in urbanization, which may cause a strong negative impact on the existing ecological landscape patterns. This is already happening in the Yangtze River Delta and Pearl River Delta regions. The following measures should be adopted for a sustainable development: (1) The government should strictly implement the ecological protection strategies, delimiting ecological idle space and form strict systems; (2) The MRYRR has many mountains and hills. Urban roads and dams will lead to habitat fragmentation and ecological corridor fragmentation. Therefore, the connectivity of ecological patches should be increased to improve ecological nodes and corridors; (3) The MRYRR is the site of the Three Gorges Dam and needs strong water conservation forests to improve forest ecosystem services. This study has important reference value for ecological development and rational planning of land development, and utilization in the Yangtze River Basin and other similar regions.

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# Appendix A

**Table A1.** Land use types, landscape metrics and other factors abbreviations.

Types	Abbreviation	Content
	GL	Grassland
	CL	Cropland
	SL	Shrubland
I and use types	OL	Orchard
Land use types	BL	Built-up land
	WL	Wasteland
	WB	Water bodies
	FL	Forestland

Types	Abbreviation	Content
	NP	Number patches
	PD	Patch density
	LPI	Largest Patch Index
Landa con a matrica	MPS	Mean Patch Area
Landscape metrics	CONTAG	Contagion index
	SHID	Shannon diversity index
	COHESION	Patch Cohesion Index
	LSI	Landscape shape index
	POP	Population
	RUR	Rural residents
	URR	Urban residents
	GDP	Gross domestic product
Socioeconomic factors	PGDP	Per capital Gross domestic product
	PRI	Primary sector
	SEC	Secondary sector
	TER	Tertiary sector
Others	MRYRR	Middle reaches of the Yangtze River region

Table A1. Cont.

Table A2. Changes in area of land use types in the MRYRR region from 1990 to 2015.

Land Use – Types	1990		2	000	2	010	2015		
	Area (km²)	Percentage (%)	Area (km <sup>2</sup> )	Percentage (%)	Area (km²)	Percentage (%)	Area (km <sup>2</sup> )	Percentage (%)	
CL	177,513	31.47	175,989	31.2	173,947	30.84	171,497	30.41	
FL	283,779	50.31	284,958	50.52	284,246	50.4	280,971	49.82	
SL	41,060	7.28	40,458	7.17	39,899	7.07	39,647	7.03	
OL	3072	0.54	2909	0.52	3957	0.7	6077	1.08	
GL	22,786	4.04	22,403	3.97	21,931	3.89	22,130	3.92	
WB	23,945	4.25	24,687	4.38	25,784	4.58	26,003	4.61	
BL	9762	1.73	10,511	1.86	12,336	2.19	15,865	2.81	
WL	2083	0.37	2085	0.37	1900	0.34	1810	0.32	

Table A3. Land use transfer matrix in the middle reaches of the Yangtze River from 1990 to 2000 (km<sup>2</sup>).

	CL	FL	SL	OL	GL	WB	BL	WL	1990
CL	102,176.00	51,661.00	5242.00	772.00	3736.00	7555.00	6080.00	291.00	177,513.00
FL	49,664.00	199,864.00	18,792.00	1146.00	9799.00	2891.00	1583.00	40.00	283,779.00
SL	6363.00	19,093.00	14,581.00	125.00	223.00	472.00	196.00	7.00	41,060.00
OL	797.00	1215.00	144.00	590.00	0.00	0.00	326.00	0.00	3072.00
GL	3980.00	8010.00	1026.00	103.00	8632.00	0.00	390.00	645.00	22,786.00
WB	7180.00	3138.00	673.00	173.00	0.00	12,781.00	0.00	0.00	23,945.00
BL	5579.00	1929.00	0.00	0.00	0.00	306.00	1916.00	32.00	9762.00
WL	250.00	48.00	0.00	0.00	13.00	682.00	20.00	1070.00	2083.00
2000	175,989.00	284,958.00	40,458.00	2909.00	22,403.00	24,687.00	10,511.00	2085.00	64,500.00

NOTE: The data in each row added up to the total area of land use in the same category in 1990, and the data in each column equalled the total area of land use in the same category in 2000. The data in each cell represented the area of the row land use type transferred to column land use type from 1990 to 2000. The total area of the study area is 64,500 km<sup>2</sup>.

	CL	FL	SL	OL	GL	WB	BL	WL	2000
CL	173,418.00	162.00	22.00	157.00	15.00	969.00	1221.00	25.00	177,513.00
FL	194.00	283,100.00	40.00	966.00	34.00	149.00	474.00	1.00	283,779.00
SL	20.00	504.00	39,803.00	54.00	3.00	30.00	41.00	3.00	41,060.00
OL	6.00	127.00	8.00	2738.00	5.00	9.00	16.00	0.00	3072.00
GL	59.00	331.00	26.00	37.00	21,846.00	69.00	30.00	5.00	22,786.00
WB	227.00	19.00	0.00	3.00	25.00	24,172.00	82.00	159.00	23,945.00
BL	7.00	3.00	0.00	2.00	0.00	23.00	10,471.00	5.00	9762.00
WL	16.00	0.00	0.00	0.00	3.00	363.00	1.00	1702.00	2083.00
2010	173,947.00	284,246.00	39,899.00	3957.00	21,931.00	25,784.00	12,336.00	1900.00	64,500.00

Table A4. Land use transfer matrix in the middle reaches of the Yangtze River from 2000 to 2010 (km<sup>2</sup>).

Note: The data in each row added up to the total area of land use in the same category in 2000, and the data in each column equalled the total area of land use in the same category in 2010. The data in each cell represented the area of the row land use type transferred to column land use type from 2000 to 2010. The total area of the study area is 64,500 km<sup>2</sup>.

Table A5. Land use transfer matrix in the middle reaches of the Yangtze River from 2010 to 2015 (km<sup>2</sup>).

	CL	FL	SL	OL	GL	WB	BL	WL	2010
CL	171,180.00	65.00	3.00	240.00	15.00	316.00	2123.00	5.00	173,947.00
FL	96.00	280,644.00	38.00	1871.00	394.00	76.00	1127.00	0.00	284,246.00
SL	5.00	37.00	39,588.00	112.00	20.00	16.00	121.00	0.00	39,899.00
OL	18.00	132.00	8.00	3757.00	6.00	10.00	26.00	0.00	3957.00
GL	11.00	33.00	2.00	88.00	21,683.00	8.00	105.00	1.00	21,931.00
WB	127.00	24.00	6.00	3.00	11.00	25,450.00	145.00	18.00	25,784.00
BL	59.00	36.00	2.00	5.00	0.00	16.00	12,218.00	0.00	12,336.00
WL	1.00	0.00	0.00	1.00	1.00	111.00	0.00	1786.00	1900.00
2015	171,497.00	280,971.00	39,647.00	6077.00	22,130.00	26,003.00	15,865.00	1810.00	64,500.00

Note: The data in each row added up to the total area of land use in the same category in 2010, and the data in each column equalled the total area of land use in the same category in 2015. The data in each cell represented the area of the row land use type transferred to column land use type from 2010 to 2015. The total area of the study area is 64,500 km<sup>2</sup>.

Table A6. Land use transfer matrix in the middle reaches of the Yangtze River from 1990 to 2015.

	CL	FL	SL	OL	GL	WB	BL	WL	1990
CL	99,138.00	50,062.00	5152.00	1502.00	3658.00	8751.00	8950.00	300.00	177,513.00
FL	48,910.00	197,041.00	18,427.00	3260.00	9887.00	3075.00	3134.00	45.00	283,779.00
SL	6284.00	18,577.00	13,675.00	270.00	1404.00	483.00	361.00	6.00	41,060.00
OL	780.00	1199.00	136.00	658.00	160.00	74.00	62.00	3.00	3072.00
GL	3943.00	9626.00	1802.00	251.00	6498.00	365.00	284.00	17.00	22,786.00
WB	6868.00	3014.00	303.00	89.00	390.00	11,689.00	1047.00	545.00	23,945.00
BL	5327.00	1406.00	146.00	44.00	120.00	691.00	1991.00	37.00	9762.00
WL	247.00	46.00	6.00	3.00	13.00	875.00	36.00	857.00	2083.00
2015	171,497.00	280,971.00	39,647.00	6077.00	22,130.00	26,003.00	15,865.00	1810.00	64,500.00

Note: The data in each row added up to the total area of land use in the same category in 1990, and the data in each column equalled the total area of land use in the same category in 2015. The data in each cell represented the area of the row land use type transferred to column land use type from 1990 to 2015. The total area of the study area is 64,500 km<sup>2</sup>.

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