SPATIAL-TEMPORAL CHARACTERISTICS AND DRIVING FORCES OF LAND USE CHANGE IN THE CENTRAL PLAINS URBAN AGGLOMERATION OF CHINA FROM THE PERSPECTIVE OF FUNCTIONAL ZONING

WANG, H.[1,2] – WANG, H. R.[1*] – ZHU, X. Y.[1] – WANG, K. D.[1]

[1]*School of Computer Science and Technology, Zhengzhou University of Light Industry, Zhengzhou, China*

[2]*Key Laboratory of Urban Land Resources Monitoring and Simulation, Ministry of Natural Resources, Shenzhen, China*

[*]*Corresponding author*
e-mail: whr5562@163.com

(Received 30th Jul 2024; accepted 4th Nov 2024)

Abstract. Functional zoning is an effective method to disclose the spatial diversity of land and a prerequisite for the optimization of national land space. We explore the spatial and temporal characteristics of land use in the Central Plains urban agglomeration from 1990 to 2020, and the GWLR (geographically weighted-logistic regression) model was used to investigate the key driving elements for the land change in the urban agglomeration as a whole and in different land use function zones. The results indicate that (1) the most significant changes occurred on cultivated and construction land, with land use change intensities of 1.42% and 1.36%, respectively. (2) There are obvious differences in changes among different land function zones. The core economic zone has the highest proportion of change from cultivated land to construction land; within the urban and main agricultural production zones, due to the lack of natural forest and grass growing conditions, the change in land type is also manifested as the extension of construction land. (3) There are large differences among the motivating elements of cultivated land and construction land change in varied eras and different land use function zones, and changes in construction land are more influenced by socio-economic factors.
Keywords: *LUCC, spatial-temporal evolution, GWLR, Central Plains urban agglomeration, spatial heterogeneity; driving mechanism*

Introduction

Land use/cover change is an essential representation of the status of human-nature interactions and fundamental to research sustainable development and global environmental change (Hailu et al., 2020). With the rapid growth of the population, urbanization and industrialization, human-land conflicts have been increasing, and environmental problems have proliferated (Liu and Long, 2016). Urban agglomerations, as the areas with the most drastic and concentrated land use changes (Li et al., 2022b), focus on their spatial and temporal changes in land use patterns and driving mechanisms, which have important research value for the rational distribution of land resources and the promotion of sustainable development of social, economic and ecological environments.

Throughout China and abroad, study of land use changes and driving mechanisms of urban agglomerations has always been the focus of scholars and governments. Relevant scholars mainly focus on relatively mature urban agglomerations such as Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta urban agglomerations, etc. (Lu and Zhang, 2022; Niu et al., 2022; Wen et al., 2023); the land use and driving mechanism

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

of the "developing" urban agglomerations in the central and western parts of the country have not been sufficiently explored. Socio-economic and topographic differences within urban agglomerations, as well as certain conflicts or coordination between general development plans and local development plans, can lead to significant spatial differences in land use changes (Zhang et al., 2019). Functional zoning, as an effective mean of revealing the spatial heterogeneity of land, is also a prerequisite for the optimization of national land space, and is binding on all types of land use development activities (Wang et al., 2022). Existing research on land use and its driving mechanism in urban agglomerations is mostly from the perspective of urban agglomerations as a whole, and the investigation of the differences between various land use function zones of urban agglomerations is relatively weak. Although some scholars have considered analyzing land use changes in urban agglomerations from different levels of administrative divisions (He et al., 2022), they failed to break through the geospatial limitations; some scholars have also divided functional areas from socio-economic and natural resource dimensions (Miao et al., 2021), but less consideration has been given to the land use characteristics of the urban agglomerations themselves. Scholars mainly depict the features of land use temporal changes by constructing LULC dynamic attitude models and comprehensive land use index models (Han et al., 2021; Yang et al., 2022b); the CLUE-S model, landscape pattern index method and geo-information Tupu are employed to track changes in land use temporal and spatial patterns (Dutta and Das, 2019; Bosch et al., 2020; Yang et al., 2022a). Among them, geo-information Tupu (Tang and Li, 2020), as a geospatial and temporal analysis methodology, has shown obvious advantages in analyzing land use.

Regression analysis (Zhu et al., 2019), correlation analysis (Li et al., 2018), and principal component analysis (Xie and Li, 2021) are the main driving force analysis methods, however, these models are difficult to reflect the characteristics of spatial differentiation and spatial distribution of research objects. With the continuous advancement of GIS technology and the deepening of driver research, methods such as geographic probes (Ju et al., 2022) and GWR model (Kong et al., 2021)[12], which consider spatial factors, have been gradually applied in the research of driver mechanisms.

“The 14th Five-Year Plan” states that “China will improve the spatial layout of urbanization and continue to develop urban agglomeration and core metropolitan areas”. As a typical representative of “developing” urban agglomeration in central and western China, the status of urban agglomeration will be further upgraded as the Zhengzhou Metropolitan Area Development Plan has been formally reviewed by the National Development and Reform Commission in 2023. Therefore, the Central Plains urban agglomeration is chosen as the subject area for this research.

The objectives of this study were to: (1) construct a comprehensive evaluation model from three dimensions, namely, natural, socioeconomic and land use evolutionary characteristics to carry out functional zoning of urban agglomeration,(2) use geo-information Tupu to analyze the characteristics of land use evolution of urban agglomeration as a whole and different land use type areas, and (3) use the geographically weighted-logistic regression (GWLR) model to explore the spatial variation of the key factors from the urban agglomeration as a whole and different land use type areas. This study aims to serve as a theoretical foundation for the strategic planning of land-use space in the Central Plains urban agglomeration and the adjustment of urban agglomeration-driven policies.

Study area and data processing

Study area

Based on the Central Plains urban agglomeration Development Plan released by the National Development and Reform Commission in December 2016, the Central Plains urban agglomeration studied in this paper covers 30 prefecture-level cities dispersed in 5 provinces (*Figure 1*). The urban agglomeration is situated in the midst of China's economic expansion from east to west, combining open coastal regions with the central and western regions, in the transition zone of the north–south climate and the transition zone from the second to the third step, covering an area of 287,000 square kilometers. By the end of 2020, the regional GDP of the urban agglomeration grew at an average annual rate of 5.9%, accounting for 8.0% of the country's GPD, and had reached 812.66 billion yuan; the local general public budget revenue reached 598.7 billion yuan; social consumer goods were sold for a total of 344.54 billion yuan in retail sales. The added value of tertiary industries continues to rise, under the new normal, the financial system is further optimized, and tertiary industries have taken over as the primary engine of economic growth in the study region.

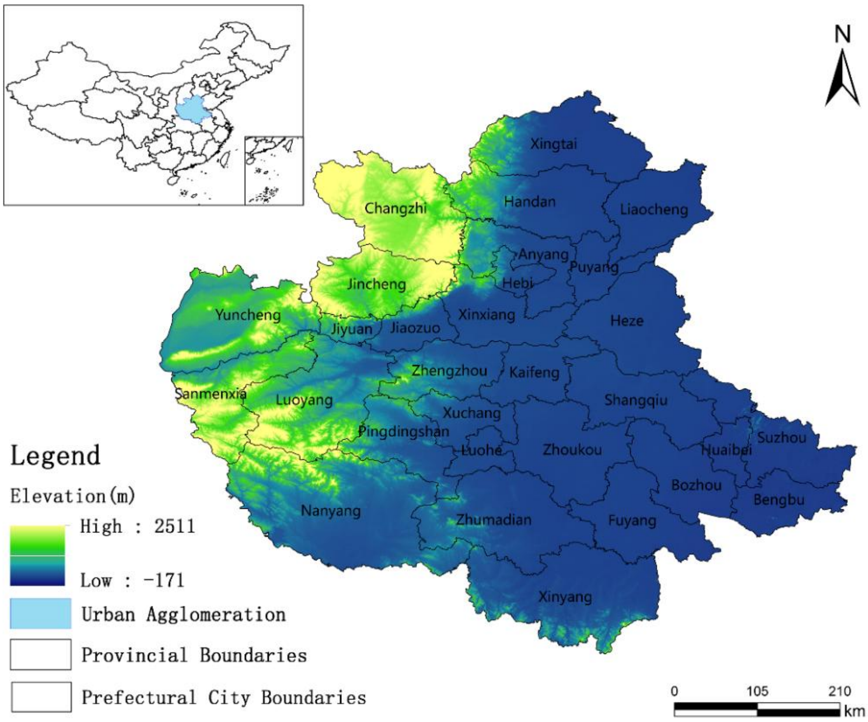

Figure 1. *Geographic location and administrative division in the study area*

Data source and processing

Land use data, digital elevation models (DEM), basic geographic information data and socioeconomic development data make up the majority of the research data. The land use data are obtained from the GlobeLand30 dataset which provided by the National Center for Basic Geographic Information (http://www.ngcc.cn/ngcc/), and the land types cover ten categories: cropland, forests, grasslands, shrublands, wetlands, water bodies, tundra, artificial surfaces, bare ground, glaciers and permanent snow. DEM data were gained

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

from the Geospatial Data Cloud (http://www.gscloud.cn/), and the data product used was the ASTER GDEM V2 global digital elevation dataset officially released in 2015. Both the spatial scale of land use data and DEM data are 30 m. The slope data were calculated from ArcGIS 10.2 spatial analysis based on the DEM data. The Chinese Academy of Sciences' Data Center for Resource and Environmental Sciences (https://www.resdc.cn/) provided both the basic geographic information data and the GDP spatial distribution km grid in the socioeconomic data. The spatial scale of the GDP data was 1 km. Other socioeconomic development data are obtained from the relevant provincial Statistical Yearbooks and district and county social development statistical bulletins.

Data on land use were interpreted visually and checked for accuracy by human-computer interaction, and land use data were extracted from the Central Plains urban agglomeration for 1990, 2000, 2010 and 2020. To make the construction and analysis of the land use transformation map easier, the land use types in the research region were separated into six groups: cultivated land, forestland, grassland, water area, construction land, and unused land. These groupings were then assigned numerical codes which were assigned as 1, 2, 3, 4, 5 and 6 (*Figure 2*). At the same time, to facilitate the regression model analysis, all data were converted to raster data with 30 m resolution and aligned to the same coordinate system (Aisa_lambert_Conformal_Conic).

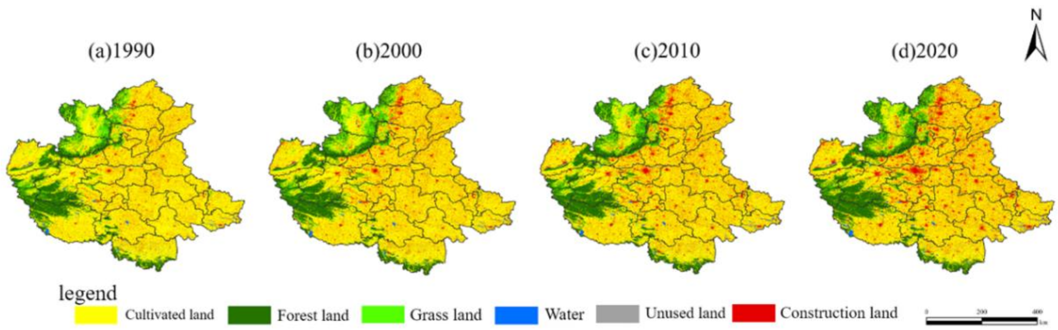

Figure 2. *LUCC map of the Central Plains urban agglomeration in 1990, 2000, 2010 and 2020*

Methods

Spatial and temporal land use change analysis methods

LULC dynamic attitude

LULC dynamic attitude (Wang et al., 2023) is the change in the amount of a specific land use category over a specific time period in a research area and is expressed as:

$$K = \frac{U_e - U_s}{U_s} \times \frac{1}{T} \times 100\% \quad \text{(Eq.1)}$$

where K stands for the dynamic attitude of a land use category in the research era, U_s and U_e stand for the areas of a land use category at the start and the end of the research era, respectively, and T stand for the time era. When T is set to year, K indicates the yearly rate of change of a land use category in the research era.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

Land use intensity

Land use intensity, which is used to measure the strength of various types of land change (Zhu et al., 2022), is expressed as follows:

$$S = \frac{U_i}{U} \times \frac{1}{T} \times 100\% \quad \text{(Eq.2)}$$

where S is the intensity of a specific category of land use change (the larger the value is, the more drastic the shift in the land use pattern is), U_i is the absolute change in the ith land use category in the research period, $U$is the entire change in each land use category, and $T$is the length of the research era. The unit is years.

Chord diagram visualization model

A chord diagram is an effective method for the visual representation of interrelationships between a large amount of complex data (Zhen et al., 2022), which can reflect the number and flow relationships of transitions between various land t categories in the process of land use change. In the paper, the land use transfer matrix is visualized in a chord diagram using the origin to construct a land use/land cover quantity change model.

Geo-information Tupu

Considering the accessibility of data, the spatial cell of the Tupu was selected as a 30 m × 30 m grid cell, and the temporal cells were 1990-2000, 2000-2010 and 2010-2020. The land use categories' coded values for the two eras before and after were put through algebraic operations using the raster calculator feature of the ArcGIS 10.2 software, the new and shrinking scales of land use categories are further extracted from them to construct maps of the arising and declining of the three time periods (Yang et al., 2019).

Land function zoning methods

Construction of the evaluation index system and weights

Using counties and districts as the study's main organizational units, and on the basis of the criteria of operability, representativeness, and independence, variables that can characterize natural resources, socioeconomic and land use evolutionary characteristics are selected to establish a comprehensive evaluation index system (*Table 1*) and determine the index weights using the information entropy method (Lin and Chen, 2022).

Comprehensive evaluation and zoning

Based on the standardized index data and the weight values determined by the information entropy weighting method, a comprehensive evaluation model (Yang et al., 2017) was used to evaluate the social economy, natural resources and characteristics of land use evolution of the research area, and its calculation formula was:

$$S_i = \sum_{j=1}^{n} w_j \times x_{ij} \quad \text{(Eq.3)}$$

where S_i is the comprehensive evaluation score, w_j is the index weight, and x_{ij} is the standardized individual index value.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

Table 1. *Comprehensive evaluation system and weights of land use*

Target layer	Index layer	weight
Social economic	Citizen	0.12
	Real GDP per capita	0.15
	population density	0.51
	Urban per capita disposable income	0.06
	Fixed investment growth rate	0.03
	Proportion of expenditure on education	0.11
	Proportion of secondary and tertiary industries	0.03
Natural resources	rainfall	0.07
	Forest coverage	0.49
	Water index	0.32
	Land reclamation rate	0.02
	Utilization rate of construction land	0.09
Characteristics of land use evolution	Land use intensity of cultivated land	0.01
	Land use intensity of forest land	0.22
	Land use intensity of grass land	0.22
	Land use intensity of water area	0.17
	Land use intensity of unused land	0.38
	Land use intensity of construction land	0.01

The spatial association index Getis-Ord Gi* (Yang et al., 2017) was used to identify hot and cold spots. It is calculated by the formula:

$$G_i^*(d) = \sum_{i=1}^{n} w_{ij}(d)x_j \,/\, \sum_{j=1}^{n} x_j \quad \text{(Eq.4)}$$

where the Z-normalization treatment equation is:

$$Z(G_i^*) = \frac{G - E(G_i^*)}{\sqrt{V(G_i^*)}} \quad \text{(Eq.5)}$$

where $E(G_i^*)$ and $V(G_i^*)$ stand for the expectation and the number of variances, respectively; w_{ij} stands for the spatial weights. If $Z(G_i^*)$ is positive and significant, the nearby values are comparatively high (above the mean) and is the hot spot (high value clustering); in contrast, if $Z(G_i^*)$ is negative and significant, the nearby area is a cold spot (low value clustering).

Driving force method

Driving force indicator

Based on the results of land use category classification of the Central Plains urban agglomeration in 1990, 2000, 2010 and 2020, the most substantial changes have occurred in cultivated land and construction land, hence the next section focuses mostly on the mechanisms that have caused these changes in these two land categories. Previous research (Li et al., 2022a; Zhang et al., 2022) has indicated that the driving elements of the two land type changes are not exactly the same, and different driving indicators need to be selected. Considering the scientific nature and availability of the driving factors and their relevance to regional land use changes, the driving indicators of cultivated land were

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

selected from natural conditions, location transportation and economic development, among which the location traffic factor was constructed by the expert scoring method (Kamali, 2017) to calculate the weights (*Table 2*).

Table 2. *Indicators of driving factors of cultivated land evolution*

Category	**Variables**	**Definition**	**Assignment / Unit / Description**
Dependent variable	Y	Cultivated land changes (1990-2000,2000-2010,2010-2020)	0or 1
Natural conditions factors	Dem	DEM	meters
	Slope	Slope	degree
Social economy factors	Pop	Population density	People/k^2m
	Citizen	Urbanization rate	%
	PGDP	GDP per capita	Million yuan
	FD	Public finance expenditure as a percentage of regional GDP	%
	TS	Value added of tertiary industry	%
Location and Transportation factors	Traffic	Nearest distance according to district and county centers (0.4)	km
		Nearest distance according to road (provincial road, national road, highway) (0.3)	km
		Nearest distance according to railroad (0.3)	km

The primary determinants of construction land change include natural conditions, neighborhood variables, and the social economy. Depending on whether driving factors are available, the following driving indicators are selected (*Table 3*).

Table 3. *Indicators of driving factors of construction land evolution*

Category	**Variables**	**Definition**	**Assignment / Unit / Description**
Dependent variable	Y	Construction land changes (1990-2000,2000-2010,2010-2020)	0or 1
Natural conditions factors	Dem	DEM	meters
	Slope	Slope	degree
Social economy factors	Pop	Population density	people/k^2m
	industry	Total industrial output	Million yuan
	invest	Fixed investment growth rate	%
Location and Transportation factors	center	Nearest distance according to district and county centers	km
	road	Nearest distance according to road (provincial road, national road, highway)	km
	river	Nearest distance according to river	km

GWLR model

The GWLR model, an extension of the traditional logistic regression model, not only takes into account the spatial characteristics of land class changes but also overcomes the drawback that the GWR (geographically weighted regression) model may make the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

results close to the traditional linear regression due to the overlap of numerous coordinates (Jin et al., 2022), and the model is set up in the following form:

$$Log\,\frac{p}{1-p} = \beta_0(u_i, v_i) + \sum_{k=1}^{m} \beta_k(u_i, v_i)x_{ik} + \varepsilon_i \quad \text{(Eq.6)}$$

where p stands for the probability of the land use change event, $x_{ik}(k = 1,2,\ldots,m)$ stands for the value of the independent variable at location i, (u_i, v_i) stands for the coordinate of the regression analysis point, $\beta_0(u_i, v_i)$ stands for the intercept term, $\beta_k(u_i, v_i)(k = 1,2,\ldots,m)$ stands for the regression analysis coefficient, and ε_i is the error term. In the research, the Gaussian function is used to determine the weights, and the optimal bandwidth is calculated using the cross-validation method (Huang et al., 2010). Collinearity of all factors was tested in SPSS software to calculate the Variance Inflation Factor (VIF), and based on these results, the GWLR regression results were computed using GWR4.0 software.

Results

Analysis of land use change

Table 4 and *Figure 3* illustrate the characteristics of the changes in various land categories in urban agglomeration from 1990 to 2020. Cultivated land is the most prevalent land type in the research area, with the proportion exceeding 65% in all four periods: 73.18%, 70.51%, 68.08% and 65.73%. The proportion of forestland area ranged from 13.98% to 15.45%, and the percentage of construction land area ranged from 7.64% to 14.76%, and the percentage of grassland, water area and unused land was relatively low, demonstrating that the land use structure in the research area was dominated by agricultural production.

Overall, the most significant changes occurred in cultivated and construction land, with land use change intensities of 1.42% and 1.36% from 1990 to 2020, respectively. Cultivated land shows a continuous trend of shrinkage, and both inflow and outflow behaviors are more frequent. Outflow behaviors mainly show the shift of cultivated land to construction land, forestland and grassland, and inflow behaviors mainly show the transformation of forestland, grassland and water area to cultivated land. Due to the large total amount of cultivated land, the overall shrinking proportion is small, and the average annual change rate is only 0.34%. The area of forestland first slightly decreased and then slightly increased, mainly due to the effects of the compensation scheme of cultivated land in the early stage. Some forestland was reclaimed as cultivated land, and the expansion in the later stage could be related to the effective implementation of the policy of converting cultivated land to forest, while the outflow behavior of forestland to cultivated land intensified between 2010 and 2020, which slowed the rate of decrease (0.58%-0.44%). Grassland area first expanded slightly and then declined, with a general tendency of shrinkage. The main flow was cultivated land to forestland, the early expansion was mainly affected by the policy of converting farmland to grassland, and later, the outflow behavior of grassland to forestland and cultivated land increased to accelerate the area rate of decline. The water area exhibited a tendency of slightly dropping and then slightly expanding, with 0.56% change rate on average.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

Table 4. *Land use change in the Central Plains urban agglomeration from 1990 to 2020*

LULC Types	**1990**	**2000**	**2010**	**2020**	**LULC dynamic attitude (%)**				**Land use intensity(%)**			
	S/k^2m	S/k^2m	S/k^2m	S/k^2m	1990-2000	2000-2010	2010-2020	1990-2020	1990-2000	2000-2010	2010-2020	1990-2020
CUL	205267.3	197793.5	190983.09	184383.72	-0.36	-0.34	-0.35	-0.34	4.70	4.06	3.70	1.42
FL	39339.49	39222.30	41509.16	43348.83	-0.03	0.58	0.44	0.34	0.07	1.36	1.02	0.27
GL	11768.48	12228.63	10649.72	8233.85	0.39	-1.29	-2.27	-1.00	0.29	0.94	1.34	0.24
WL	2688.89	2335.62	2973.49	3141.64	-1.31	2.73	0.57	0.56	0.22	0.38	0.09	0.03
UL	25.49	15.25	8.08	4.88	-4.02	-4.70	-3.96	-2.70	0.006	0.004	0.002	0.001
COL	21424.20	28918.57	34390.35	41400.94	3.50	1.89	2.04	3.11	4.71	3.26	3.89	1.36

Note: CUL, FL, GL, WL, UL and COL denote cultivated land, forestland, grassland, water area, unused land and construction land, respectively, and S denotes area

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

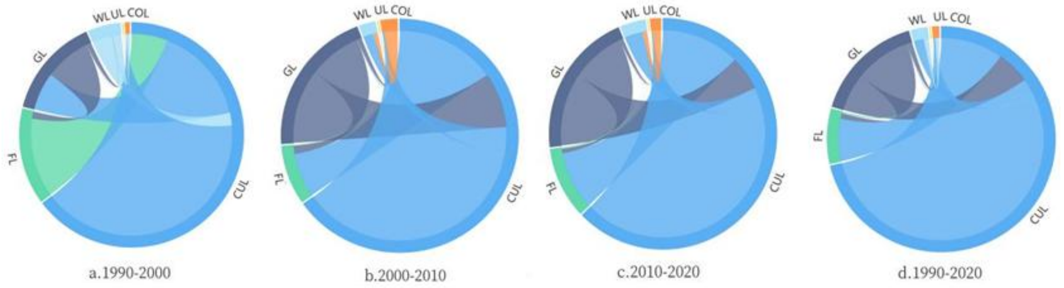

***Figure 3.** Trajectories of LUCC in the Central Plains urban agglomeration from 1990 to 2020*

The unused land area is smaller and shows a continuous shrinking trend, and its inflow and outflow behavior is relatively insignificant. Construction land has shown a continuous trend of expansion, with the rate of expansion decreasing and then increasing, reaching a peak of 3.5% in 1990-2000. The advancement of economic development and urbanization has resulted in a sharp surge in the requirement for land for construction activities, intensifying the outward expansion of construction land.

Classification of land functional areas in the Central Plains urban agglomeration

According to the comprehensive land use evaluation scores of counties and districts, the spatial association index of each county unit can be obtained by using the spatial association index model. The spatial association index is divided into five intervals from high to low values of clustering using the natural breakpoint approach (*Figure 4*).

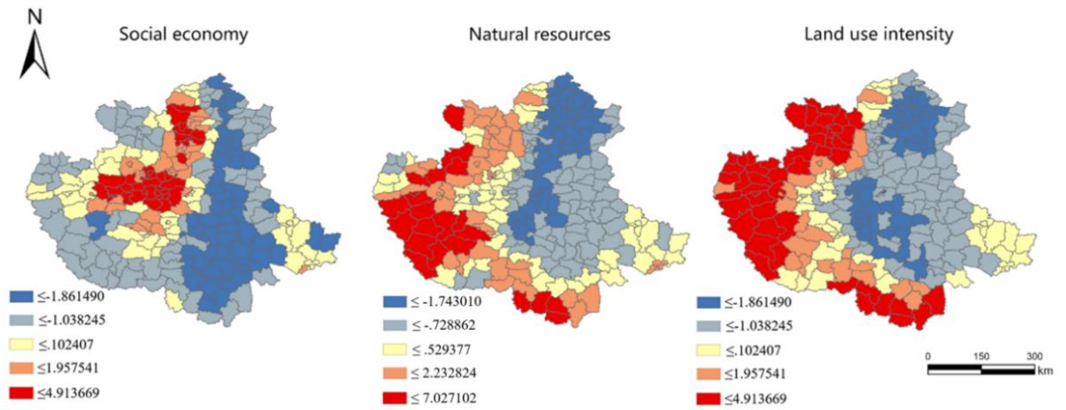

***Figure 4.** The distribution map of Getis-Ord Gi**

The spatial distribution maps of socioeconomic, natural resource and land use intensity integrated indices were overlaid and analyzed to establish a comprehensive land use zoning scheme for the county, and the type zones were designated considering the location characteristics and land function characteristics (*Figure 5*).

Core economic zone, this zone is an area with high socioeconomic concentration and high natural resource attributes and high land use intensity or counties and districts with high socioeconomic intensity but low resource environment and land use intensity, distributed in Zhengzhou City, Luoyang City and surrounding districts and counties, totaling 39 districts and counties, covering an area of 23140.58 km^2, accounting for 8.25%

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

of the total area. The region has a high level of urbanization and an outstanding contradiction between people and land. It should reduce the pace of expansion, focus on transformation and modernization, promote intensive advancement and utilization of land, and drive the rapid growth of the surrounding areas suitable for development with priority development as a guide.

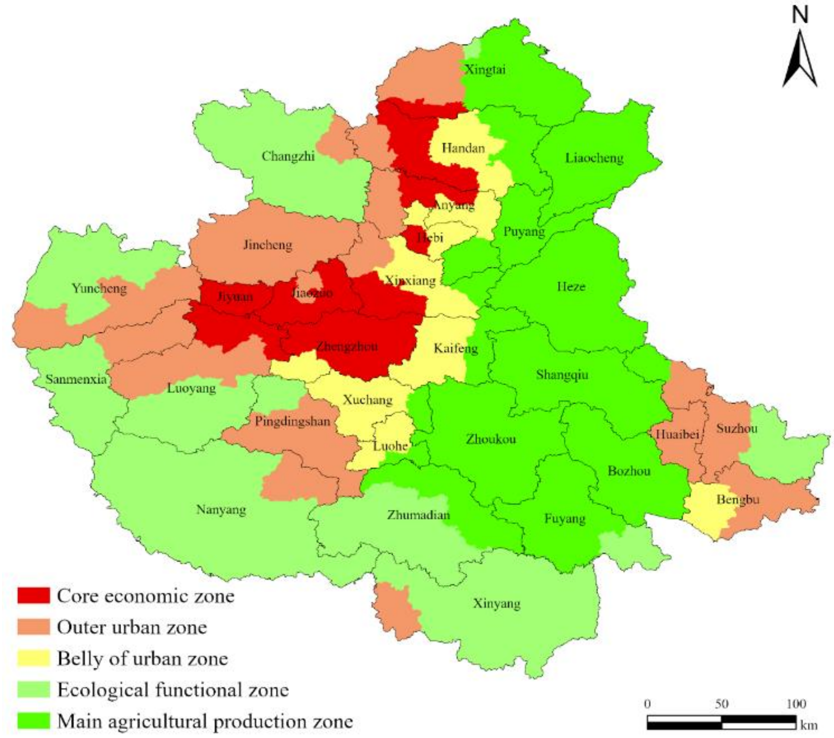

Figure 5. *Division of land use function zones in the Central Plains urban agglomeration*

Outer urban zone, this type of area has high socioeconomic comprehensive value, while natural resource value and land use intensity are also medium and above, distributed across Xingtai, Handan, Jincheng and other places, comprising 53 districts and counties, occupying 56387.41 km^2, representing 20.10% of the whole area. It is a key area for the implementation of industrial transfer, urbanization and industrialization in the urban agglomeration with high potential for land development and utilization.

Belly of urban zone, the area where the comprehensive socioeconomic value is in the middle range, but the intensity of natural resources and land use is in the low or very low range, distributed across Handan, Anyang, Hebi, and a total of 38 districts and counties, covering an area of 23733.57 km^2, accounting for 8.46% of the total area. This area is a comprehensive area of land use with relatively weak natural resource carrying capacity, and should be developed moderately.

Ecological functional zone, this zone is an area with low socioeconomic intensity but high natural resources environment or high land use intensity, mainly situated in the southwest of the research area, with 56 districts and counties, covering an area of 90216.26 km^2, accounting for 32.16% of the total area. This area has a good ecological environment and should be moderately developed economically while maintaining the ecological functional service function.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

Main agricultural production zone, this region has low socioeconomic, resource environment and land use intensity evaluation values, and the overall terrain is relatively flat and dominated by agricultural production, covering 83 districts and counties such as Xingtai and Liaocheng, with an area of 87,047.26 km^2, accounting for 31.03% of the total area. On the basis of maintaining the leading function of agricultural production, the region should be moderately industrialized and urbanized to promote agriculture with industry and increase the input–output efficiency of land.

Arising Tupu analysis and declining Tupu analysis

By combining the arising Tupu (*Figures 6-9*) and the Tupu structure table (*Table 5*), it is evident that throughout the 1990-2020 period, the proportion of newly constructed land within the change area consistently accounted for the largest share, with this proportion exceeding 39% in all three sub-periods. This is followed by newly increased cultivated land, forestland, grassland, and water areas, while newly unused land remained minimal. The proportion of newly cultivated land initially decreased from 22.42% to 20.46%, before rising to 23.94%. The initial reduction is attributed to the accelerated urbanization process and the policy of converting farmland to forests and grasslands, while the later increase resulted from the implementation of farmland protection policies. Newly increased forestland showed a continuous upward trend, while newly increased grassland consistently declined. Additionally, the proportion of newly enhanced construction land initially decreased before rising again, while newly enhanced water areas expanded before contracting.

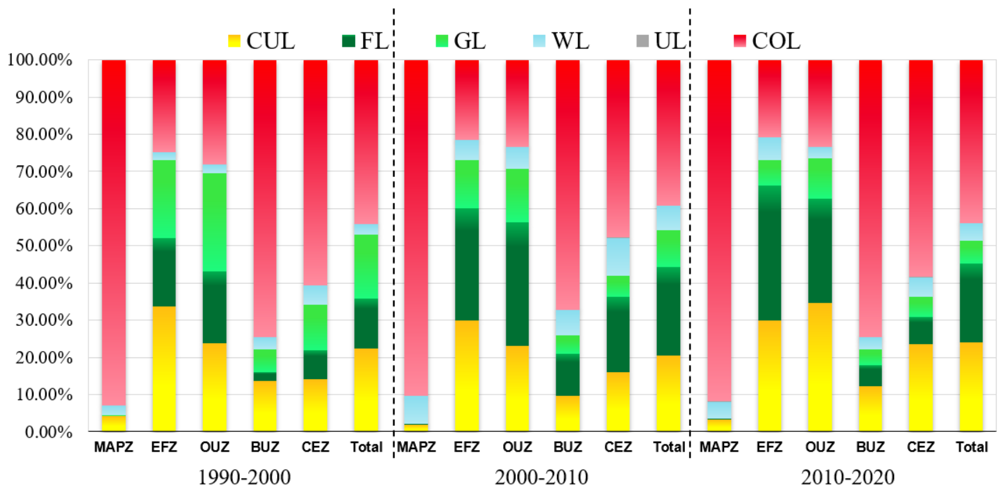

***Figure 6.** Proportion of Newly Added Land Types in Different Land Functional Zones from 1990 to 2020*

There are obvious differences in land use change among different land functional zones: the new construction land is mainly in the main agricultural production zone and urban hinterland, and the other land types increase less. The area of newly added cultivated land in the ecological functional zone is always greater than the area of newly added construction land, and the area of newly added forest land is the largest after 2000. This is related to the coexistence of hilly terrain and basin. The area of forestland, grassland and construction land in outer urban zone has expanded rapidly.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

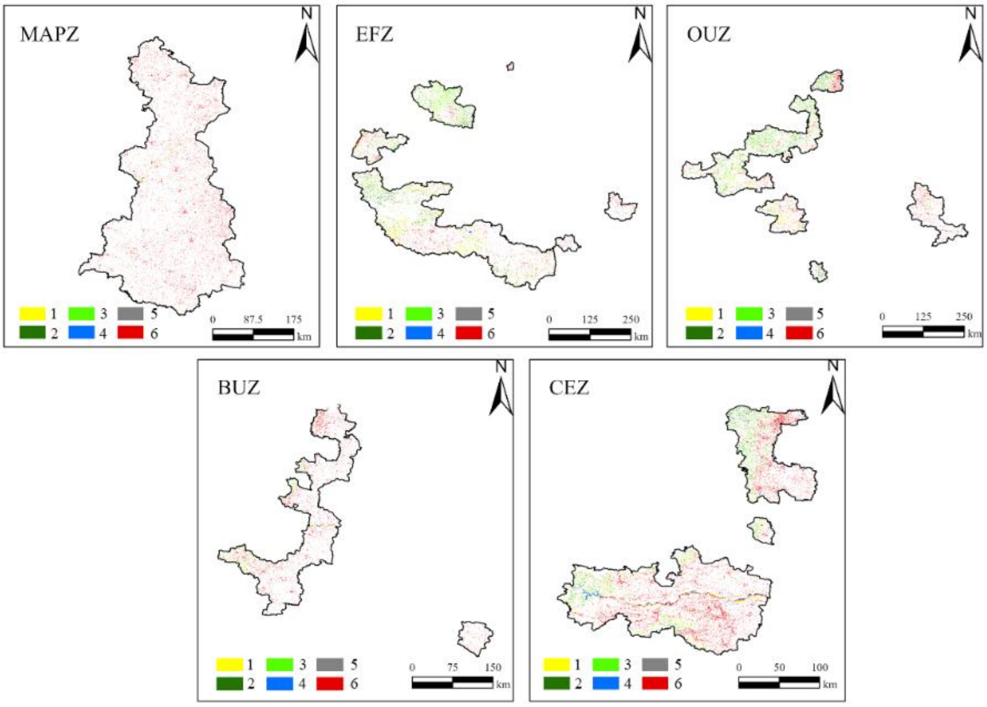

Figure 7. *Arising Tupu of land use of each sequential element in the Central Plains urban agglomeration from 1990-2000. Note: Nos. 1–6 represent cultivated land, forest land, grassland, water, unused land and construction land, respectively.*

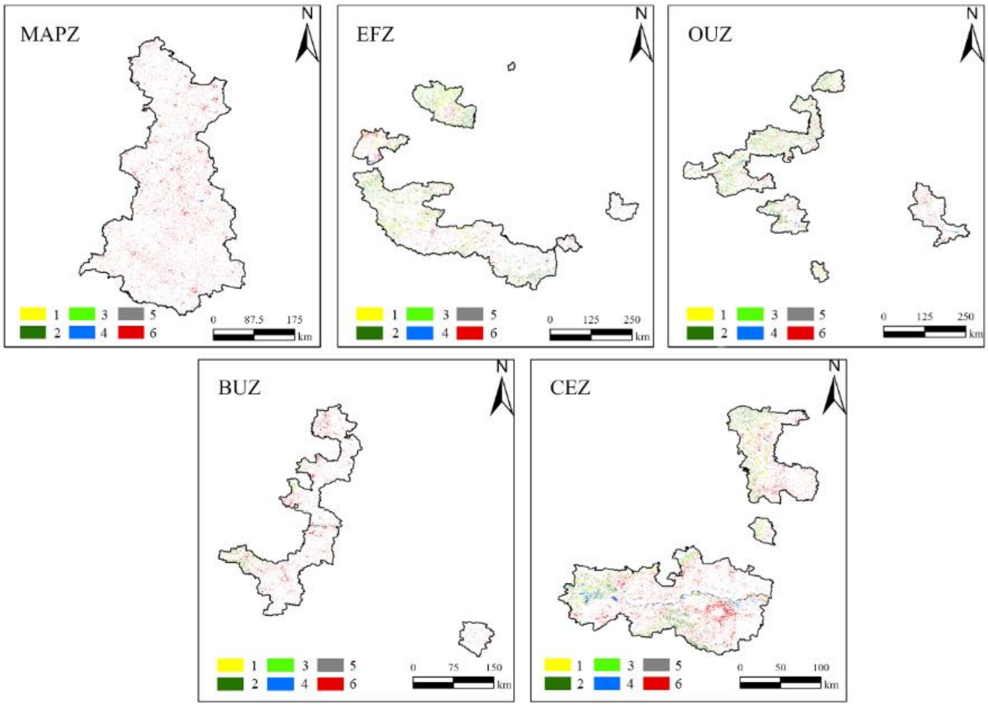

Figure 8. *Arising Tupu of land use of each sequential element in the Central Plains urban agglomeration from 2000-2010*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

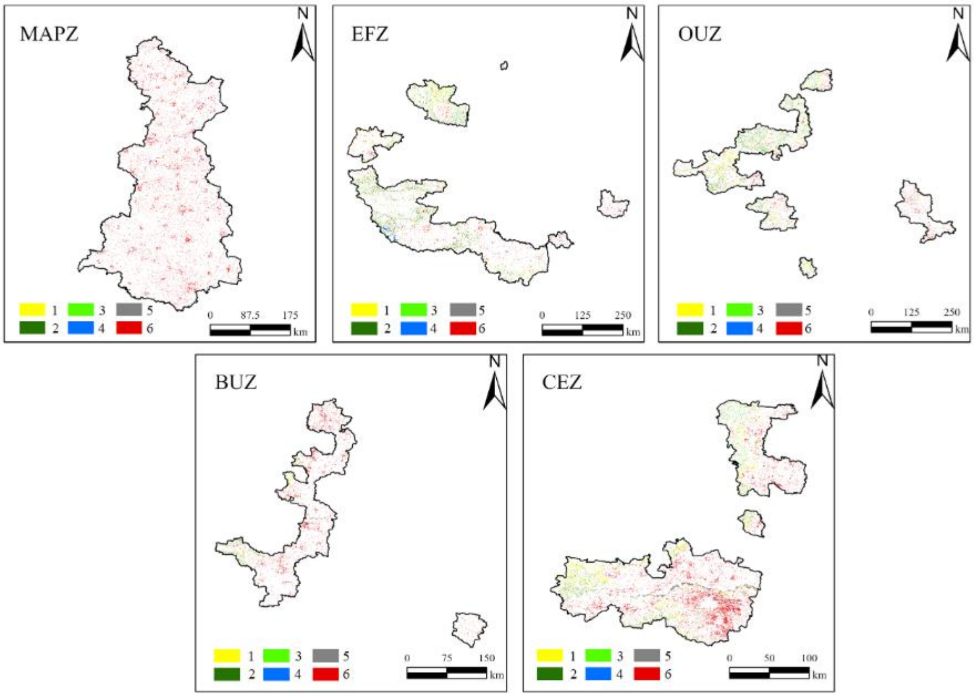

Figure 9. *Arising Tupu of land use of each sequential element in the Central Plains urban agglomeration from 2010-2020*

Table 5. *The structure list of arising Tupu of land use in the urban agglomeration* (km^2)

Period	Zone	Invariant region	CUL	FL	GL	WL	UL	COL
1990-2000 +	MAPZ	84305.67	117.3	0.67	0.75	75.03	0.28	2541.51
	EFZ	83963.46	2099.07	1147.43	1308.41	133.12	6.17	1549.45
	OUZ	51356.61	1194.3	975.77	1328.15	109.53	0.84	1418.18
	BUZ	22670.11	144.64	25.72	65.05	35.73	0.02	791.81
	CEZ	20995.15	304.51	162.98	264.41	113.2	0.52	1298.33
	Total	263291	3859.77	2312.74	2966.82	466.71	7.83	7599.49
2000-2010	MAPZ	84665.28	44.73	2.29	3.04	180.01	0.11	2145.74
	EFZ	84370.38	1636.73	1652.62	715.22	296.32	0.97	1174.87
	OUZ	52185.49	970.96	1390.82	607.9	247.46	1.3	979.45
	BUZ	22765.78	93.25	108.83	48.91	64.91	0.86	650.53
	CEZ	21318.51	290.77	369.11	105.19	183.82	2.4	869.29
	Total	265305.44	3036.43	3523.78	1480	973	5.64	5820
2010-2020	MAPZ	83799.06	106.48	6.23	0.36	149.23	0.31	2979.53
	EFZ	84482.11	1714.16	2076.24	391.34	347.33	1.7	1194.22
	OUZ	52001.69	1519.96	1221.5	478.53	132.97	0.5	1028.25
	BUZ	22592.29	138.31	66.76	47.07	37.6	0.1	850.95
	CEZ	21066.65	485.67	155.5	111.08	108.97	1.15	1210.08
	Total	263941.79	3964.58	3526.23	1028.38	776.1	3.76	7263.03

Note: MAPZ, EFZ, OUZ, BUZ and CEZ denote main agricultural production zone, ecological functional zone, outer urban zone, belly of urban zone and core economic zone, respectively

Combined with the declining Tupu (*Figures 10-12*) and the declining Tupu structure table (*Table 6*), it can be noticed that the entire change is somewhat similar to the rising potential space, and among the three phases of change, the cultivated land area that has

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

shrunk is consistently the largest, showing a trend that first goes down and then up, followed by shrunken grassland area, shrunken forestland, shrunken water and shrunken construction land, and shrunken unused land area is relatively small. The tendency of the shrinking construction land is one of first increase and then subsequent decrease. The former is a result of the regional implementation of the policy of relating urban and rural construction land increase and decrease, prompting people to take back vacant and vacant rural construction land and convert it into cultivated land. The latter is due to China's unique urban–rural dual structure social system; the regional urban village and hollow village problems are serious, resulting abandoned rural settlements and other challenges.

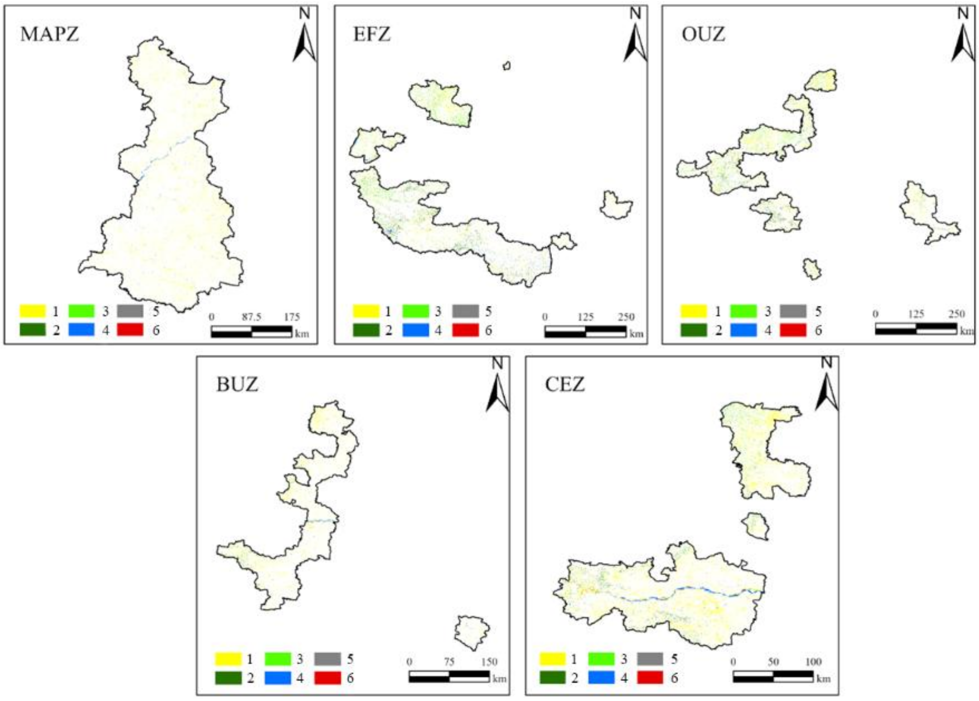

Figure 10. *Declining Tupu of land use of each sequential element in the Central Plains urban agglomeration from 1990 to 2000*

There was a significant difference in land use changes among the major land function areas. The proportion of arable land shrinking was large in the core economic zone, the belly of urban zone and the outer urban zone. The rate of forest land reduction in the outer urban zone and ecological functional zone gradually decreased, while the reduction in grassland area increased significantly.

Driving force analysis

To avoid spatial autocorrelation between data from adjacent plots, random stratified sampling was used. A total of 8810 sample points were taken in the three periods, including 3034 sample points and 2000 sample points of cultivated land from 1990 to 2000. Variable 0 and variable 1 have approximately the same number of samples, thus ensuring that unchanged and changed land use types have approximately the same prediction accuracy. All factor data were normalized and covariance was detected in SPSS 24.0 software, and VIF (Variance inflation factor) < 10 in the results, which could be entered into the regression model (Li et al., 2018).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

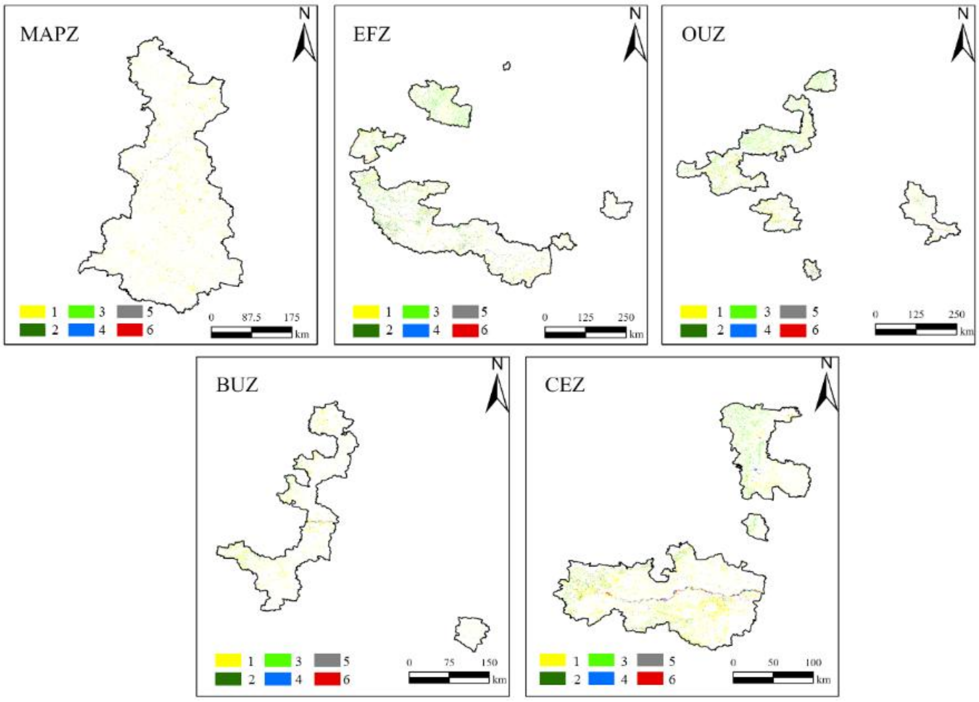

Figure 11. *Declining Tupu of land use of each sequential element in the Central Plains urban agglomeration from 2000 to 2010*

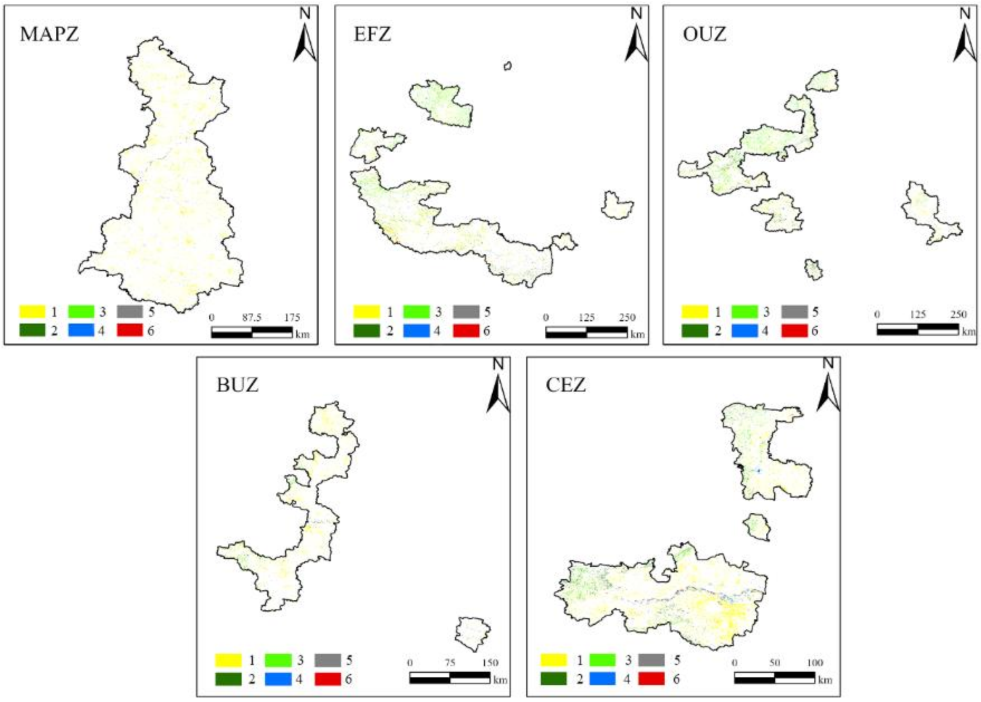

Figure 12. *Declining Tupu of land use of each sequential element in the Central Plains urban agglomeration from 2010 to 2020*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

***Table 6.** The structure list of declining Tupu of land use in the urban agglomeration (km^2)*

Period	Zone	Invariant region	CUL	FL	GL	WL	UL	COL
1990-2000	MAPZ	84305.67	2566.34	6.16	11.48	131.69	0.65	19.21
	EFZ	83963.46	3121.67	1370.88	1341.15	367.65	15.80	26.49
	OUZ	51356.61	3107.77	829.54	961.09	103.78	1.07	23.53
	BUZ	22670.11	882.30	62.08	52.95	58.26	0.15	7.23
	CEZ	20995.15	1655.25	161.24	139.85	158.58	0.40	28.63
	Total	263291.00	11333.33	2429.9	2506.52	819.96	18.07	105.09
2000-2010	MAPZ	84665.28	2256.48	1.00	1.41	47.48	0.35	69.21
	EFZ	84370.38	2950.97	787.55	1496.44	108.04	10.69	123.04
	OUZ	52185.49	2489.70	365.56	1210.91	60.88	1.10	69.75
	BUZ	22765.78	829.81	12.65	75.38	32.23	0.03	17.18
	CEZ	21318.51	1319.81	70.16	274.99	86.09	0.64	68.9
	Total	265305.44	9846.77	1236.92	3059.13	334.72	12.81	348.08
2010-2020	MAPZ	83799.06	3076.97	1.76	3.10	122.01	0.11	38.19
	EFZ	84482.11	3064.00	723.06	1618.2	202.98	2.52	114.22
	OUZ	52001.69	2056.82	691.31	1479.23	108.62	1.17	44.55
	BUZ	22592.29	949.04	37.94	84.24	56.49	0.84	12.24
	CEZ	21066.65	1417.09	232.52	259.43	117.85	2.31	43.27
	Total	263941.79	10563.92	1686.59	3444.20	607.95	6.95	252.47

Analysis of cultivated land drivers

The driving factors and influence intensity of cultivated land change changed with time (*Figure 13*). The fluctuation of cultivated land during 30 years was always affected by natural factors, and changes in cultivated land in the southern region were mainly influenced by altitude. The degree of slope influence showed an obvious trend of higher in the west and lower in the east. Population density had inhibitory effect on cultivated land change from 1990 to 2010. Both the urbanization rate and per capita GDP had suppressive effects on fluctuations in cultivated land. The proportion of fiscal expenditure and the added value of the tertiary industry showed a significant negative effect in some areas. The impact of regional traffic has increased significantly since 2010.

There were significant differences in cultivated land changes among different land functional zones (*Figure 14*). The main agricultural production zone are flat, and cultivated land is less affected by natural processes. From 1990 to 2000, cultivated land changes were primarily driven by the urbanization rate. After 2000, the influence of regional traffic on cultivated land transfer gradually deepened. Changes in cultivated land in ecological functional zone were mainly influenced by elevation and slope. Since 2010, changes in cultivated land have been primarily influenced by the proportion of fiscal expenditure. Population density, slope, industrial output value, and the proportion of fiscal expenditure are the main factors influencing changes in cultivated land in suburban areas. Most of the downtown area is located in the Huang-Huai-hai plain, some areas are located in the south Taihang Mountain, the overall low-lying. Arable land use will increase. In the core economic zone, GDP, population density, regional transportation and urbanization rate have been the main driving forces of regional cultivated land change.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

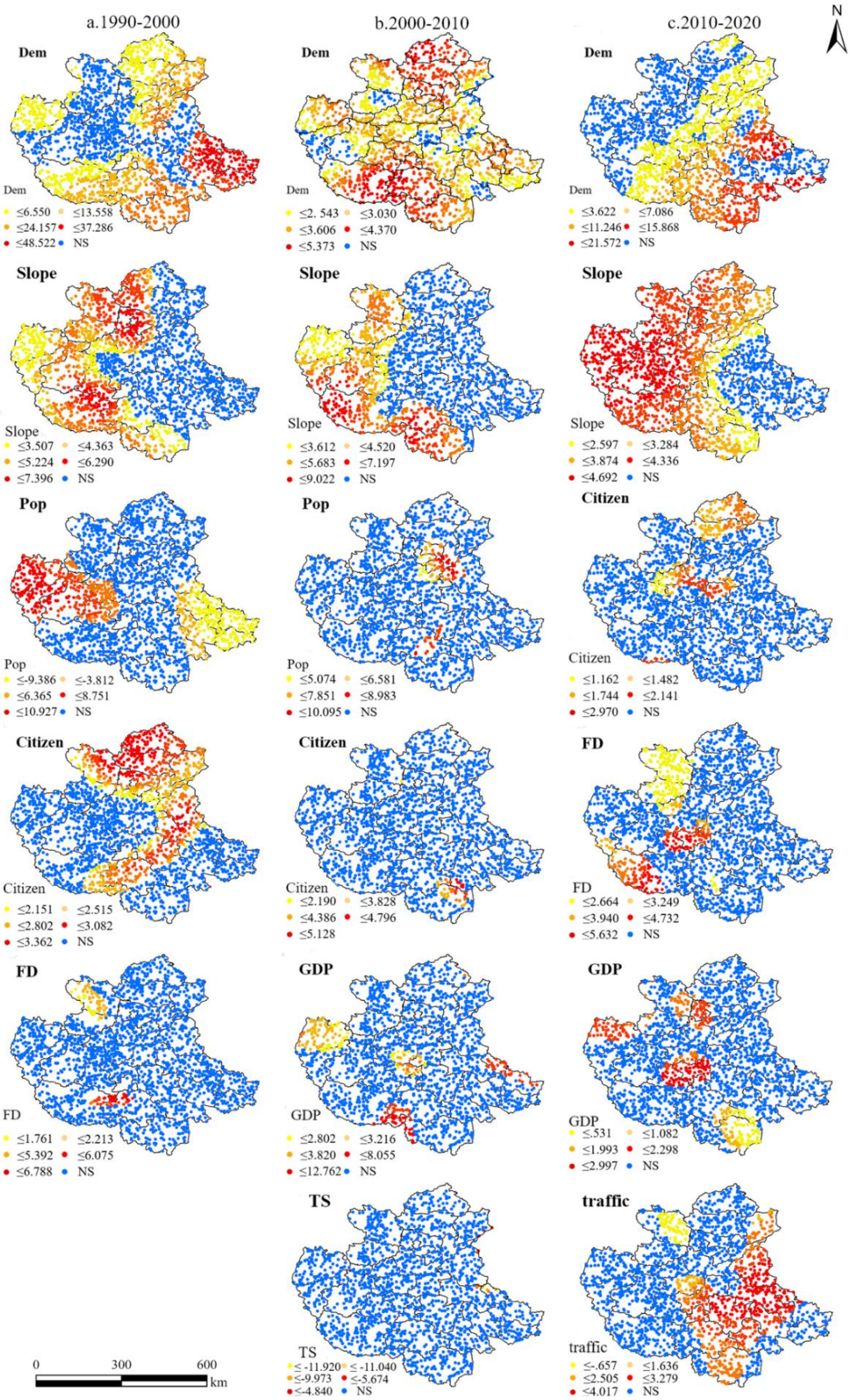

Figure 13. *Spatial patterns of coefficients in the GWLR*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

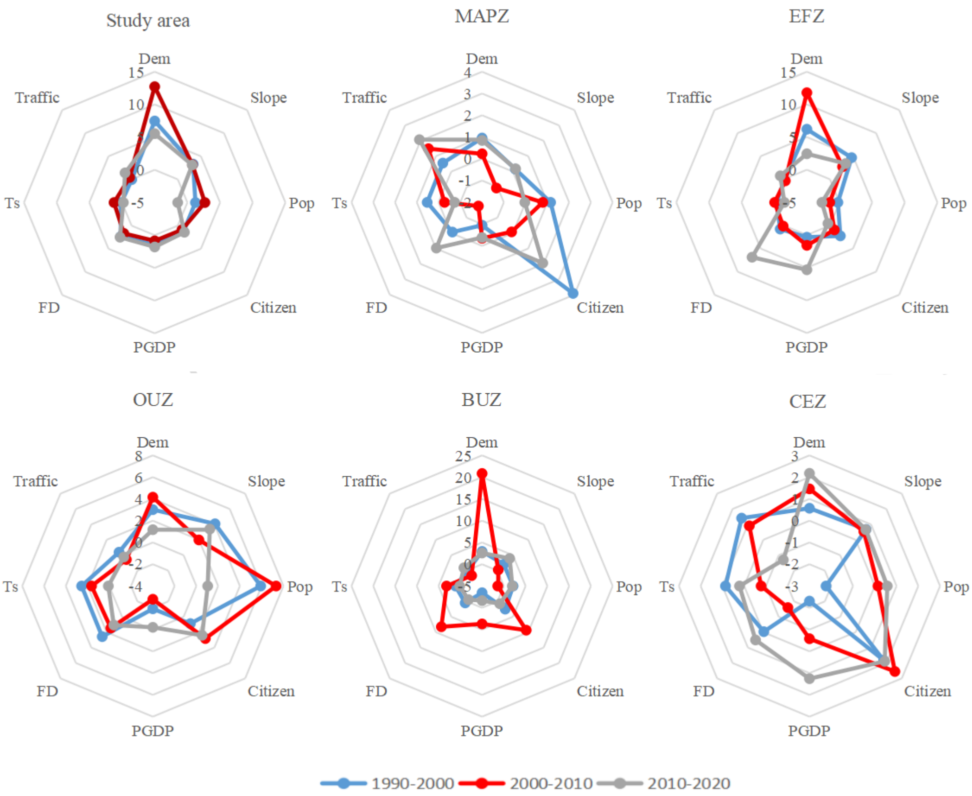

Figure 14. *Radar chart of the contribution rate of different factors to the impact of cultivated land in differentiated functional zones*

Analysis of construction land drivers

The driving factors and intensity of construction land changes vary across different periods (*Figure 15*). Over the past 30 years, the growth of construction land has been influenced by natural factors, with the distribution of elevation and slope coefficients showing clear east-west differences. High-value areas tend to shift toward the central and western regions. Between 1990 and 2000, and again from 2010 to 2020, population density inhibited the growth of construction land, with significant effects observed in the central and eastern parts of the study area. Between 1990 and 2010, the growth rate of fixed investment significantly contributed to construction land expansion, though its influence gradually diminished, particularly in the eastern region. From 1990 to 2000, total industrial output in the southern part of the study area had a significant positive effect on construction land change. After 2010, this positive impact extended across the entire study area, with higher industrial output increasing the likelihood of construction land change. Location is another key factor influencing the transfer of construction land, and it generally shows a negative correlation.

The growth rates of construction land in different land functional zones vary significantly (*Figure 16*). From 1990 to 2000, the expansion of construction land in the main agricultural production zone was primarily driven by the growth of fixed asset investment and industrial output value, however, from 2000 to 2010, the growth in industrial output had a negative impact on construction land expansion. The increase in population density between 2000 and 2010 intensified construction land expansion.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

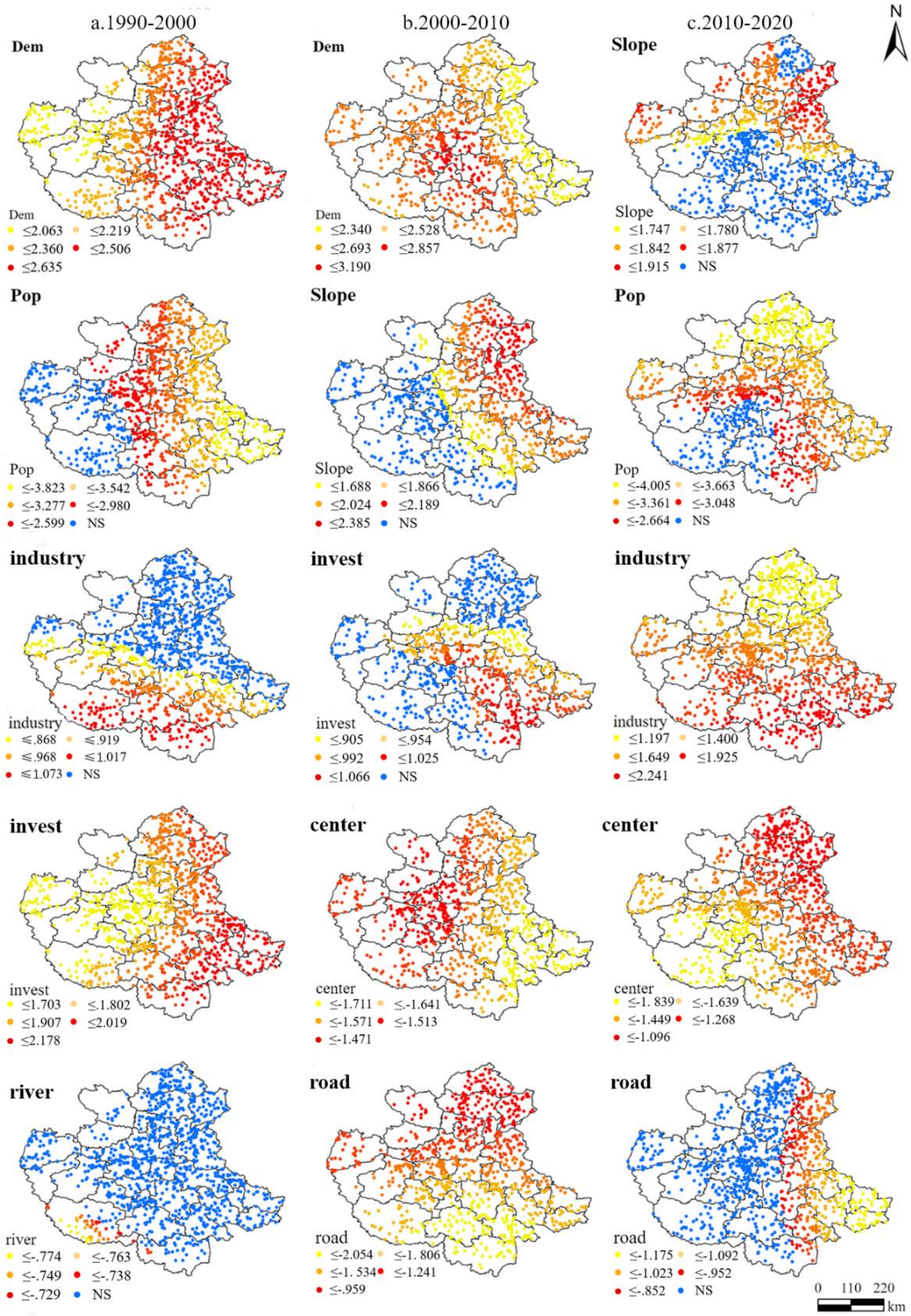

Figure15. *Spatial patterns of coefficients in the GWLR*

The terrain of the ecological functional zone is mainly mountainous, and the urban construction and development is greatly restricted by the terrain. Since 2000, the growth rate of fixed investment has played a crucial role in construction land changes. Between 1990 and 2000, the socioeconomic level of the belly of urban zone was moderate, with population being the primary factor driving changes in urban construction land. In the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

outer urban zone and core economic zone, socioeconomic development is relatively advanced, exerting a greater influence on the expansion of construction land. In addition, population density inhibits the expansion of construction land from 2010 to 2020.

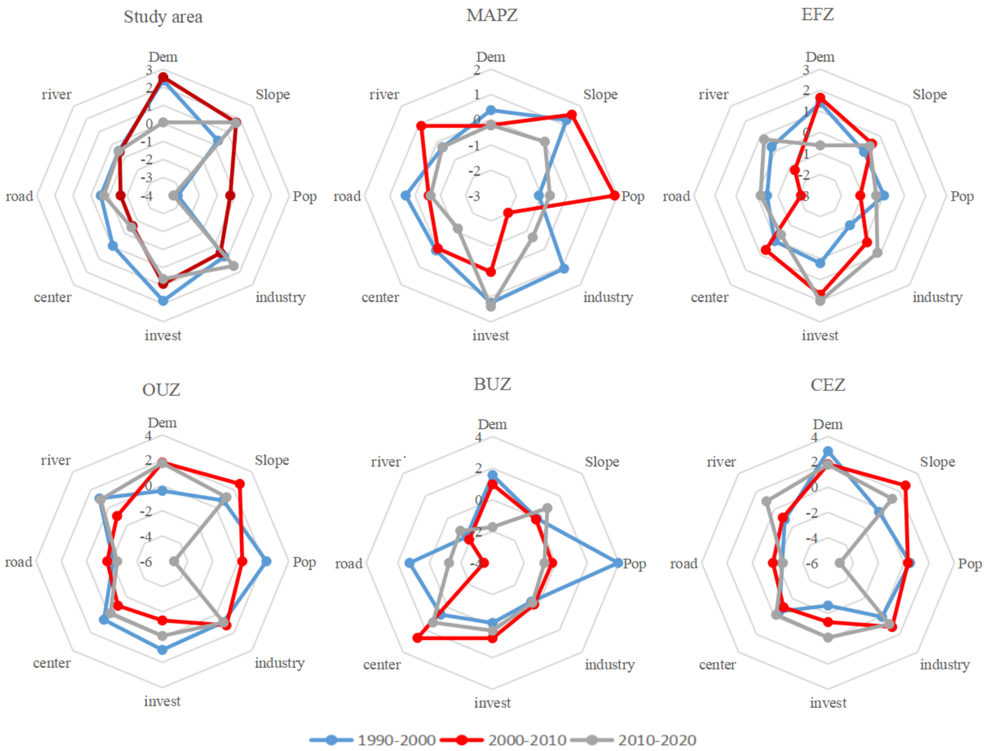

Figure 16. *Radar chart of the contribution rate of different factors to the impact of construction land in differentiated functional zones*

Discussion

Characteristics of different land functional areas

Comprehensive land use zoning reflects the spatial differentiation of land use functions and guides the direction of multifunctional expansion, existing research on urban agglomeration functional zoning focuses on the ‘three living’ functions, ecological restoration, and carbon neutrality (Tan et al., 2017; He et al., 2019; Cai et al., 2020), and did not form a more consistent hierarchical index system, and combined with the characteristics of the evolution of land use There is no consistent hierarchical index system, and less functional zoning is carried out by combining land use evolution characteristics. Land use/cover change, as an important representation of human-nature interaction, when combined with the spatial characteristics of traditional natural resources and socio-economic factors, can improve the appropriateness of regional land functional zoning.

The core economic zone is located in the central and northern regions of the urban agglomeration, and is the economic center of the urban agglomeration. The region has a high population density, with the maximum reaching 44313.84 people per square kilometer. The economic development is rapid, with prominent industrial and mining production conditions, and several national and provincial key development zones. The region is highly urbanized, and the contradiction between population and land is evident.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

The focus should be on reducing large-scale expansion, promoting transformation and upgrading, and fostering intensive land development. Priority development should guide and drive the growth of surrounding areas. Due to the influence of the radiation of the core economic zone, the highest regional per capita GDP can reach up to 121,748.01 yuan. As proposed in the "Zhengzhou Metropolitan Area Development Plan", the economic development of the surrounding regions of Zhengzhou will be further improved, and the development pattern of "Zhengzhou Metropolitan Area" will gradually take shape. Some areas in the outer urban zone, near the Funiu Mountain region, possess rich natural resources and offer great potential for land development. These areas can serve as key locations for industrial transfer in the Central Plains urban agglomeration and for promoting urbanization and industrialization. The natural resource carrying capacity in the urban hinterland is relatively weak and should be developed cautiously. The ecological development zone, located in the Funiu and Tongbai-Dabie Mountain regions, features rich ecological conditions, abundant vegetation, and tourism resources, with predominantly mountainous and hilly terrain and a strong forest industry base. The region has a good ecological environment, and should develop the economy appropriately while maintaining the ecological development service function. The main producing area of agricultural products is located in the Huang-Huai-hai Plain, with flat terrain, superior climate and light resources, and a number of national key agricultural development demonstration zones within the territory. This region should prioritize agricultural production while pursuing moderate industrialization and urbanization, using industry to support agriculture and enhancing land input-output efficiency.

Spatial and temporal differences of different land function zones

There are obvious differences in land use change among different land functional areas: main agricultural production zone and urban areas are located in the Huang-Huai-Hai Plain, where the natural conditions are not conducive to the formation of forest or grassland, so land type changes are mainly reflected in the expansion of new construction land. In the ecological functional area, the shrinking area of forest land decreased gradually, and the shrinking area of grassland increased significantly. In addition to the natural degradation of grasslands, afforestation and national land regulation have also contributed to the gradual conversion of grassland into woodland in some areas. The outer urban area contains both mountainous and plain regions and undertakes major water conservation tasks, such as the South-to-North Water Diversion Project and the Huaihe River Ecological Corridor. Woodland and grassland area increased rapidly. At the same time, affected by the radiation of Zhengzhou metropolitan area, the construction land has expanded rapidly. Rapid economic development and ongoing urbanization in the economic core areas have resulted in significant agricultural land being converted into construction land.

Cultivated land drivers variability

On the whole, the fluctuation of cultivated land during 30 years was always greatly affected by natural factors, and there were obvious terrain differences, which was related to the southernmost location of Tongbai-Dabie Mountains in the study area. The urbanization rate and per capita GDP had an inhibitory effect on changes in cultivated land. The continued progress of urbanization and economic development increases the demand for construction land, making it more likely that cultivated land will be converted into other land categories. The proportion of fiscal expenditure and the added value of the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

tertiary industry showed a significant negative effect in some areas. The former is related to the fact that in some areas, the government will restrict urban expansion to maintain regional ecological or production functions. The latter is because the greater the added value of the tertiary industry, indicating that the tertiary industry such as technical services, financial services, and commercial services with relatively small demand for land continues to develop, the industrial structure continues to optimize, and the land type changes are relatively small. The significant improvement in regional transportation after 2010 may be attributed to the construction of the ‘one core, four axes, and four districts’ network spatial pattern, first proposed in the 2016 Development Plan of the Central Plains Urban Agglomeration, which has accelerated the integration of urban agglomeration and formed a modern transport network with efficient multi-path connections between regions. Since 2010, population density has promoted changes in cultivated land, which is related to cultivated land protection policies.

The influencing factors of cultivated land change in different land function zones were significantly different. The main agricultural production zone are flat and the cultivated land is less affected by natural processes. From 1990 to 2000, the change was mainly driven by the urbanization rate. After 2000, the influence of regional transportation on the transfer of cultivated land gradually increased. Since 2010, changes in cultivated land have been primarily influenced by fiscal expenditure. To ensure regional ecological service functions, local governments have promoted the policy of returning farmland to forest, leading to a reduction in cultivated land. Most outer urban zone are located in the Huang-Huai-Hai Plain, while some are in the southern Taihang Mountains. The overall terrain is low, and changes in cultivated land are mainly driven by socio-economic factors, with arable land use expected to increase. The core economic zone, as a high-value economic hub within the Central Plains city group, features flat terrain, developed transportation, and prominent industrial and mining production conditions. Therefore, GDP, population density, regional transportation and urbanization rate have been the main driving forces of regional cultivated land change.

Construction land drivers variability

In the past 30 years, the growth of construction land has been influenced by natural factors, with high-elevation and steep-slope areas showing a tendency to shift towards the central and western regions, which is related to the rise of the Central Plains urban agglomeration, the vigorous construction of Zhengzhou metropolitan area, and the strategy of intensifying the development of the central and western regions. Population density has inhibited the growth of construction land, particularly in the central and eastern parts of the study area. This is because the eastern region is dominated by agriculture, and the permanent population is often smaller than the registered population, resulting in a serious loss of urban human resources. In the central region, rapid urban land expansion driven by economic development and urbanization outpaces population growth, leading to a negative population density coefficient. From 1990 to 2010, the growth rate of fixed investment significantly impacted construction land expansion in the eastern region, with investment shifting from real estate and new district development to agriculture, forestry, animal husbandry, and fishery. On the whole, the more developed the total industrial output value of the region, the continuous progress of urbanization, so that the construction land change probability is greater. Location factors inhibit the transfer of construction land. The closer the existing urbanization projects are, the more restricted the urban expansion will be.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

The growth rate of construction land in different land function zones varies significantly and exhibits obvious regional characteristics. For example, the growth rate of industrial output value from 2000 to 2010 inhibited the expansion of construction land in the main agricultural production zone. This is due to the farming needs of main agricultural production zone, which restrict extensive industrialization and land space development; the more developed the industry, the more constrained the expansion of construction land in the region. The terrain in ecological functional zone is predominantly mountainous, which significantly restricts urban construction and development. After 2000, the regional investment in real estate and new district construction increased, which intensified the transfer of regional construction land. The social and economic level of the belly of urban zone is moderate, with population being the main factor driving changes in urban construction land. The level of social and economic development of outer urban zone and core economic zones is relatively high. From 2010 to 2020, population density has inhibited the expansion of construction land, possibly related to the rapid growth of urban land scale in the region.

Conclusion

Taking the Central Plains urban agglomeration as a case region, we divide different land functional areas and adopt geographic information mapping to portray the spatial and temporal land use evolutionary features of different land functional areas, then apply the GWLR method to research the key driving variables on land use change in each region. The following conclusions are drawn:

- The most prevalent land type in the study region is cultivated land, and the proportion of arable land exceeds 65% in all four periods. Arable land and grassland show a continuous trend of shrinkage, with average yearly change rates of -0.34% and -1.00%, respectively. The areas of construction land and forestland increase, with average yearly change rates of 3.11% and 0.34%, respectively.
- There are obvious differences in Tupu changes among different land function zones, with the most significant change of cultivated land and construction land in the core economic zone, frequent shift between cultivated land and forest and grassland in the ecological functional zone and outer urban zone, and rapid extension of construction land in outer urban zone. Due to the lack of natural forest and grass growing conditions in the belly of urban zone and the main agricultural production zone. Much of the shift in land type has also manifested itself in an increase in the extension of construction land.
- The motivating motives for cultivated land and construction land change in various eras and land use type zones differ significantly. On the whole, cultivated land is always influenced by natural factors, the change in arable land in the main agricultural production zone is most significantly driven by the urbanization rate, the cultivated land in the ecological functional zone and belly of urban zone is mainly influenced by elevation, population is the leading factor driving the change in cultivated land in the outer urban area, and the change in cultivated land in the core economic zone is mainly influenced by the urbanization rate. Population, socioeconomic elements and location elements all have an influence on the shift in construction land. The growth of construction land in the main agricultural production zone and ecological functional zone is significantly influenced by population and fixed investment growth rate, while the extension in construction

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_28692895

land in the belly of urban zone is mainly driven by population and location factors, and the change in construction land in the core economic zone and outer urban zone is significantly influenced by population and plays a negative driving role during 2010-2020, which is related to the fast regional urbanization development, which exceeds the population's pace of natural increase.

With the national urban agglomeration development policy being actively promoted, monitoring land use changes in the central and western urban agglomerations is essential to promote the coordinated advancement of urban agglomerations. The Central Plains urban agglomeration is the largest and densest populated urban group in the 500 km radius between Beijing, Wuhan, Jinan and Xi'an, with strong economic power, rapid industrialization, a high urbanization level and outstanding transportation location advantages. It is of profound significance for the prudent exploitation and development of land resources, ensuring regional ecological security and food safety and building ecological civilization. This paper couples the spatial characteristics of natural resources, socioeconomic and land use evolution hotspots, divides land use functional areas, and constructs land use arising and declining Tupu for three-time series units of each land use functional area, which comprehensively reflects the changes and differences in land use in urban clusters in spatial and time series. Finally, the GWLR model explores the spatial variation characteristics of natural factors, socioeconomic factors and location and traffic on land use changes in each region, aiming to give a theoretical foundation for regional territorial spatial planning and sustainable exploitation of land resource use. Due to space limitations, the study of future trends of land use is not carried out in this paper but will be continued in future studies.

Acknowledgements. This research was funded by the [Open Fund of Key Laboratory of Urban Land Resources Monitoring and Simulation, Ministry of Natural Resources], grant number [KF-2022-07-019], the [Key scientific and technological projects in Henan Province], grant number [242102210017], the [Key Scientific Research Projects of Colleges in Henan Province], grant number [23A520001,21A420007].

REFERENCES

[1] Bosch, M., Jaligot, R., Chenal, J. (2020): Spatiotemporal patterns of urbanization in three Swiss urban agglomerations: insights from landscape metrics, growth modes and fractal analysis. – Landscape Ecology 35: 879-891. doi: 10.1007/s10980-020-00985-y.
[2] Cai, H. S., Chen, Y., Zha, D. P., Zeng, H., Shao, H., Hong, T. (2020): Principle and method for ecological restoration zoning of territorial space based on the dominant function. – Transactions of the CSAE 36(15): 261-270.
[3] Dutta, I., Das, A. (2019): Exploring the dynamics of urban sprawl using geo-spatial indices: a study of English Bazar Urban Agglomeration, West Bengal. – Applied Geomatics 11: 259-276. doi: 10.1007/s12518-019-00257-8.
[4] Hailu, A., Mammo, S., Kidane, M. (2020): Dynamics of land use, land cover change trend and its drivers in Jimma Geneti District, Western Ethiopia. – Land Use Policy 99: 105011. doi: 10.1016/j.landusepol.2020.105011.
[5] Han, H. Q., Wang, X. H., Niu, L. Z., Liang, X. J., Jiang, X. H., Tan, Z. T. (2021): The land-use and land-cover change characteristics and driving forces of cultivated land in Central Asian countries from 1992 to 2015. – Chinese Journal of Eco-Agriculture 29(2): 325-339. doi: 10.13930/j.cnki.cjea.200406.
[6] He, Q., Zeng, C., Xie, P., Tan, S., Wu, J. (2019): Comparison of urban growth patterns and changes between three urban agglomerations in China and three metropolises in the USA

from 1995 to 2015. – Sustainable Cities and Society 50: 101649. https://doi.org/10.1016/j.scs.2019.101649.

[7] He, Q. S., Wang, B. (2022): Spatial Mismatch between External Urban Morphological Compactness and Internal Urban Development Levels of Urban Agglomerations in China from a Multiscale Perspective. – China Land Science 36(08): 85-97.

[8] Huang, B., Wu, B., Barry, M. (2010): Geographically and temporally weighted regression for modeling spatio-temporal variation in house prices. – International Journal of Geographical Information Science 24(3): 383-401. doi:10.1080/13658810802672469.

[9] Jin, L., Xu, Q., Yi, J., Zhong, X. (2022): Integrating CVOR-GWLR-Circuit model into construction of ecological security pattern in Yunnan Province, China. – Environmental Science and Pollution Research 29(54): 81520-81545. doi: 10.1007/s11356-022-21421-5.

[10] Ju, H. R., Zhang, S. R., Yan, Y. C. (2022): Spatial pattern changes of urban expansion and multi-dimensional analysis of driving forces in the Guangdong-Hong Kong-Macao Greater BayArea in 1980-2020. – Journal of Geographical Sciences 77(05): 1086-1101. doi:10.11821/dlxb202205004.

[11] Kamali, F. P., Borges, J. A. R., Meuwissen, M. P. M., de Boer, I. J. M., Oude Lansink, A. G. J. M. (2017): Sustainability assessment of agricultural systems: The validity of expert opinion and robustness of a multi-criteria analysis. – Agricultural Systems 157: 118-128. doi:10.1016/j.agsy.2017.07.013.

[12] Kong, D. Y., Chen, H. G., Wu, K. S. (2021): The evolution of “Production-Living-Ecological” space, eco-environmental effects and its influencing factors in China. – Journal of Natural Resources 36(05): 1116-1135. doi:10.31497/ZRZYXB.20210503.

[13] Li, J., Liu, Y., Yang, Y., Liu, J. (2018): Spatial-temporal characteristics and driving factors of urban construction land in Beijing-Tianjin-Hebei region during 1985–2015. – Geographical Research 37(1).

[14] Li, D. H., Shi, D. M., Xia, R., Ni, S. H., Zhang, J. L., Wang, R. H. (2022a): Evolution characteristics and driving mechanism for the spatiotemporal pattern of sloping farmland in Chongqing based on geodetector. – Transactions of the Chinese Society of Agricultural Engineering 38: 280-290. doi: 10.11975/j.issn.1002-6819.2022.12.032.

[15] Li, L., Ma, S., Zheng, Y., Xiao, X. (2022b): Integrated regional development: Comparison of urban agglomeration policies in China. – Land Use Policy 114: 105939. doi:10.1016/j.landusepol.2021.105939.

[16] Lin, Y., Chen, D. (2022): Functional Zoning and Path Selection of Land Comprehensive Consolidation Based on Grey Constellation Clustering: A Case Study of Dongying City, China. – International Journal of Environmental Research and Public Health 19(11): 6407. doi:10.3390/IJERPH19116407.

[17] Liu, Y., Long, H. (2016): Land use transitions and their dynamic mechanism: The case of the Huang-Huai-Hai Plain. – Journal of Geographical Sciences 26: 515-530. doi:10.1007/s11442-016-1283-2.

[18] Lu, Z. D., Zhang, Z. F. (2022): Research on Regional Variability in the Evolution of Territorial Space Pattern and Its Driving Factors in Beijing-Tianjin-Hebei Region. – China Land Science 36(10): 42-52.

[19] Miao, C. H., Zhang, B. F. (2021): Regulation Strategy of Zoning-Gradation-Classification for High-quality Development in the Yellow River Basin. – Journal of Economic Geography 41(10): 143-153. doi: 10.15957 / j.carol carroll nki JJDL. 2021.10.016.

[20] Niu, X., Liao, F., Liu, Z., Wu, G. (2022): Spatial-temporal characteristics and driving mechanisms of land–use transition from the perspective of urban–rural transformation development: A case study of the Yangtze River Delta. – Land 11(5): 631. doi:10.3390/land11050631.

[21] Tan, X., Yu, S., Chen, W., Ouyang, Q., He, Y., Zhou, G. (2017): Evaluation of rural function and spatial division in Chang-Zhu-Tan urban agglomerations. – Scientia Geographica Sinica 37(8): 1203-1210.

[22] Tang, C. C., Li, Y. P. (2020): Geo-information Tupu Process of Land Use/Cover Change in Polycentric Urban Agglomeration: A Case Study of Changsha-Zhuzhou-Xiangtan Urban Agglomeration. – Geographical Research 39(11): 2626-2641. doi:10.11821/dlyj020200207.

[23] Wang, F. J., Wei, X., Su, C. G., Liu, Y. Q., Lu, Z. Y., Yi, L. (2022): Research Hotspots and Prospect of Land Spatial Planning Zoning in China. – Journal of Economic Geography 42(02): 84-92. doi: 10.15957 / j.carol carroll nki JJDL. 2022.02.010.

[24] Wang, X. D., Liu, P. X., Geng, M. D., Wang, M., Lu, J. (2023): The key driving factors of land use patio-temporal change and its influence trend-A case study of Wuwei. – China Environmental Science 43(12): 6583-6591. doi: 10.19674 / j.carol carroll nki issn1000-6923.2023.0211.

[25] Wen, D., Li, X., Wang, X., Hong, M., Wen, Z., Xu, N. (2023): Evaluating the impact of multi scenario land use change simulation on carbon storage at different scales: a case study of Pearl River Delta Urban Agglomeration. – Frontiers in Ecology and Evolution 11: 1259369. doi:10.3389/fevo.2023.1259369.

[26] Xie, X., Li, X. (2021): Spatio-temporal evolution characteristics and influencing factors of "production-living-ecological" functions in Henan Province, China. – Transactions of the Chinese Society of Agricultural Engineering 37: 243-252. doi: 10.11975/j.issn.1002-6819.

[27] Yang, Y., Ren, Z. Y., Fan, X. S. (2017): Land use comprehensive evaluation and regionalization in Zhongyuan urban agglomeration. – Economic Geography 37(09): 177-184. doi:10.15957/j.cnki.jjdl.2017.09.022.

[28] Yang, A. M., Zhu, L., Chen, S. H., Jin, H., Xia, X. X. (2019): Geo-informatic spectrum analysis of land use change in the Manas River Basin, China during 1975-2015. – Ying yong sheng tai xue bao = The Journal of Applied Ecology 30(11): 3863-3874. doi:10.13287/j.1001-9332.

[29] Yang, H., Zhong, X., Deng, S., Nie, S. (2022a): Impact of LUCC on landscape pattern in the Yangtze River Basin during 2001–2019. – Ecological Informatics 69: 101631. doi:10.1016/j.ecoinf.2022.101631.

[30] Yang, L. P., Zhang, J., Gong, E. J., Liu, M., Ren, J., Wang, Y. (2022b): Analysis of spatio-temporal land-use patterns and the driving forces in Xi'an City using GEE and multi-source data. – Transactions of the Chinese Society of Agricultural Engineering 38(2): 279-288. doi: 10.11975/j.issn.1002-6819.2022.02.031.

[31] Zhang, Y., Long, H., Tu, S., Ge, D., Ma, L., Wang, L. (2019): Spatial identification of land use functions and their tradeoffs/synergies in China: Implications for sustainable land management. – Ecological Indicators 107: 105550. doi:10.1016/j.ecolind.2019.105550.

[32] Zhang, M., Du, H., Zhou, G., Mao, F., Li, X., Zhou, L., Zhu, D. E., Xu, Y. X., Huang, Z. (2022): Spatiotemporal Patterns and Driving Force of Urbanization and Its Impact on Urban Ecology. – Remote Sensing 14(5): 1160.doi:10.3390/rs14051160.

[33] Zhen, H. D., Ah, R., Ji, Q. Z., Tong, Z. J., Han, A., Zhi, F. (2022): Study on the Evolutionary Features and Driving Factors of Land-Use System in Xilingol, China. – Land 11(4): 526-526.

[34] Zhu, L., Yue, J. C., Chen, S. Y., Huang, Q., Yang, S. S. M., Liu, Z. W. (2019): Urban expansion in Beijing-Tianjin-Hebei urban agglomeration from 1992 to 2016: the process and driving forces. – Journal of Beijing Normal University: Natural Science Edition 55(2): 291-298. doi:10.16360/j.cnki.jbnuns.2019.02.017.

[35] Zhu, H., Ou, X., Yang, Z., Yang, Y., Ren, H., Tang, L. (2022): Spatiotemporal dynamics and driving forces of land urbanization in the Yangtze River Delta urban agglomeration. – Land 11(8): 1365. doi:10.3390/land11081365.