Pol. J. Environ. Stud. Vol. XX, No. X (XXXX), 1-18
DOI: *10.15244/pjoes/203352* ONLINE PUBLICATION DATE: 2025-06-11

Original Research

Analysis of Multi-Scale Land Use/Cover Changes and Driving Forces in the Yellow River Basin of Henan Province, China

Yateng He[1], Xinchuang Wang[1], Runbo Chen[1], Xuejie Liu[1], Liting Fan[1], Jundang Jiao[2]*

[1]School of Surveying and Land Information Engineering, Henan Polytechnic University, Jiaozuo 454000, China
[2]Henan Institute of Land and Resourees Surveying and Planning, China

Received: 18 January 2025
Accepted: 25 March 2025

Abstract

A nuanced grasp of land use/cover changes, along with their drivers, is essential for effective land use management and ecological restoration. A new perspective on land use/cover changes analysis was proposed, which involves analyzing land use/cover changes and their driving forces at scales such as regional, geomorphological (plains, hilly area and mountainous area), and territorial spatial planning (core area and expansion collaborative area) scales based on the 2000, 2010, and 2020 land use/cover data in the Yellow River Basin of Henan Province. The land use/cover changes were scrutinized by employing the degree of land use/cover dynamics, transfer matrix, and change mapping model. The key drivers at each scale were unearthed by utilizing a geo-detector. The results show that: 1) The distribution characteristics of land types under different scale areas in the Henan section of the Yellow River Basin have obvious differences in that farmland is gathered in the plains, woodland in the mountains, and water in the core area. 2) From the dynamic attitude, it can be seen that the land use pattern of the plains and the core fluctuates sharply between 2000 and 2020, and the fluctuation of the mountain area is smaller, but the construction land in the mountain area has the most drastic change, the forest in the plains shrinks most obviously, and the core area has a large fluctuation of agricultural land. Compared with 2000-2010, the fluctuation amplitude between 2010 and 2020 is significantly reduced. 3) The dominant type of land change at all scales is the flow of agricultural land into construction land, while construction land also encroaches heavily on forest land. In the whole region, the plains and the core area, farmland also flows mainly into wetlands and waters, in the mountainous area, farmland flows heavily into forests and grasslands, and construction land continues to encroach on shrublands, and in the expansion and collaboration area, farmland encroaches heavily on grasslands. 4) Areas of intense land use change at all scales are concentrated in and around built-up areas. 5) The drivers of GDP and population dominate in the whole region, plains, core and extended collaboration areas, population and slope have the greatest influence in the hilly areas, slope and temperature play a major role in the mountainous areas, and the interactions of all factors show

*e-mail: jjd54321@163.com

an increasing trend. The results of the study show that there are differences in land changes and their drivers at different scales in the Yellow River Basin of Henan, so the overall or local ecological restoration measures concerning the Yellow River Basin should be formulated with attention to problem orientation, comprehensiveness of the measures, and pertinence. The spatial layout of ecological, production, and living areas should be rationally planned according to local conditions and the rationalization of resource utilization.

Keywords: multi-scale, land use/cover change, geo-detector, drivers

Introduction

Land use/cover change (LUCC) stands as a pivotal force in understanding the intricate interplay between human activities and the natural world, serving as a principal driver of global environmental transformation [1, 2]. Tracing back to the 1990s, a surge of interest emerged in LUCC, spurred by the International Geosphere and Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP) [3-5]. This research has evolved, underscoring LUCC's profound impact on climate functions [6, 7], the carbon cycle [8-10], water resources [11, 12], biodiversity [13, 14], and ecological services [15, 16] – elements crucial for effective land spatial planning and regional sustainability.

The Yellow River Basin, often hailed as the "cradle" of Chinese civilization, has historically been a nucleus of economic and cultural development. However, it faces acute challenges in watershed management due to a dramatic shift in land-use patterns [17-19]. Factors such as rampant population growth and urban sprawl have exacerbated ecological degradation, leading to severe soil erosion and the contraction of wetlands [20, 21]. This underscores the necessity of delving into LUCC and its drivers within the basin, aiming to enhance ecological management and promote a sustainable harmony between human activity and nature. Cui et al. [22] identified elevation, slope, and soil type as pivotal drivers of LUCC in Shandong's segment of the Yellow River Basin. Rong et al. [23] further examined the economic contribution coefficient (ECC) and ecological support coefficient (ESC) for the basin in 1995, alongside exploring CO_2 emissions and their causes due to land use/cover changes from 1995 to 2018. Zhou et al. [24] analyzed the efficiency of cultivated land use/cover and its drivers within the basin. However, current research on LUCC and its drivers within the Yellow River Basin predominantly relies on administrative or watershed boundaries as research units. This approach often limits the analysis to a singular scale [25-27], overlooking the nuanced interactions between various zones. Given that the Yellow River Basin flows through fewer areas in some provinces, using administrative boundaries alone can introduce redundancies, skewing results and creating discrepancies between findings and real-world conditions. Moreover, focusing solely on basin boundaries fails to capture the full spectrum of the Basin's role and its influence on surrounding areas, and it is a limitation of not being able to explain the differences and linkages between the different regions in the study area at a single scale [28]. Meanwhile, Jiao et al.'s [29] multiscale analysis based on the effect of land pattern on water quality in the Dongjiang River Basin, Jia et al.'s [30] multiscale analysis and simulation of land cover change in Nepal, and Zhao et al.'s [31] study of the drivers of multiscale land use/cover change have shown that multiscale is more responsive to the real situation and thus meets the needs of coordinated development in the region. However, the related multi-scale studies neglected the influence of geomorphology on land use/cover change. Subsequently, we observe the provinces through which the Yellow River Basin flows, among which Henan Province has obvious geomorphological polarization, and as a major grain-producing area, it is significantly affected by the radiation effect of the Yellow River Basin. At the same time, human-land relations, resource development, and environmental protection are particularly tense [32], and there is an urgent need to carry out relevant multi-scale studies as the basis for ecological restoration policies. Existing studies have shown that land use changes gradually with elevation [33, 34], and the distribution of land use types in Henan Province is closely related to geomorphological types, so it is reasonable to assume that there are differences in land use changes in different geomorphological types in Henan Province. For example, the fluctuation of farmland and construction land is more intense in the plain area, while the fluctuation of forest land is more intense in the mountain area. Meanwhile, the major economic cities in Henan Province are mainly located in the core area and the relevant policies in the core area are more intense than those in the expansion and collaboration area, so the rate of urban expansion and the decline of forest and farmland in the core area may be greater than that of the expansion and collaboration area, and the fluctuation of wetlands and waters in the core area may be more intense as well.

This paper, therefore, focuses on the core and expansion collaborative area defined by the Land Spatial Planning of the Yellow River Basin in Henan Province, based on the existing research, the stable and widely used methods such as land use/cover dynamic attitude, transfer matrix, and change mapping [35-37] were selected. It considers geomorphological influences on land-use distributions and assesses LUCC trends across various scales – entire regions, geomorphological types (plains, hilly, and mountainous areas), and land spatial planning zones (core and expansion collaborative area). It also introduces geo-probes to analyze the drivers of land use change at different scales. From a multi-scale perspective, to explore the direction, rate and trend of change of different land use types under different scales, to identify the differences in land use change under different regions, to combine geo-detectors to excavate the main driving factors in different regions, to elucidate the idiosyncrasies of different regions, and to carry out the sub-regional implementation of watershed ecological management to achieve the following when we know the main trend of change in different regions as well as the main driving factors multi-region hierarchical management and synergistic development. This study aims to provide a scientific basis for land resource planning and ecological protection in the Yellow River Basin of Henan Province and to provide a new perspective for land use change analysis.

Study Area and Data Sources

Study Area

Nestled within Henan Province, the Yellow River Basin sprawls across the middle and lower reaches of the great Yellow River (Fig. 1). Stretching an impressive 711 km through Henan, this river is not merely a geographical feature but a cornerstone of the region's natural landscape. The Basin itself is an intricate tapestry, subdivided into three distinct areas based on their roles and positions: the core, the extended, and the radiative areas, collectively known as the Yellow River Basin of Henan Province. This extensive region envelops 14 municipalities – Zhengzhou, Kaifeng, Luoyang, Hebi, Anyang, Jiaozuo, Jiyuan, Puyang, Xinxiang, Zhoukou, Shangqiu, Xuchang, Pingdingshan, and Sanmenxia – spanning the central, western, eastern, and northern parts of Henan. Geographically, this Basin is situated between latitudes 33°N and 36°N and longitudes 111°E and 117°E. The topography of the region exhibits a dramatic gradient, with elevations soaring from -95 m to a towering 5,073 m. The region's climatic character reflects a transitional continental monsoon climate, bridging the northern subtropical and warm temperate zones. Dominated by the westerly wind belt's atmospheric circulation, the climate shifts notably from the flat plains in the east to the rugged hills and mountains in the west. Average temperatures oscillate between 12.8ºC and 15.5ºC, while annual rainfall ranges from 600 to 950 mm. Urbanization within the Basin remains relatively modest. The majority of the population clusters in the plains of the central and eastern regions,

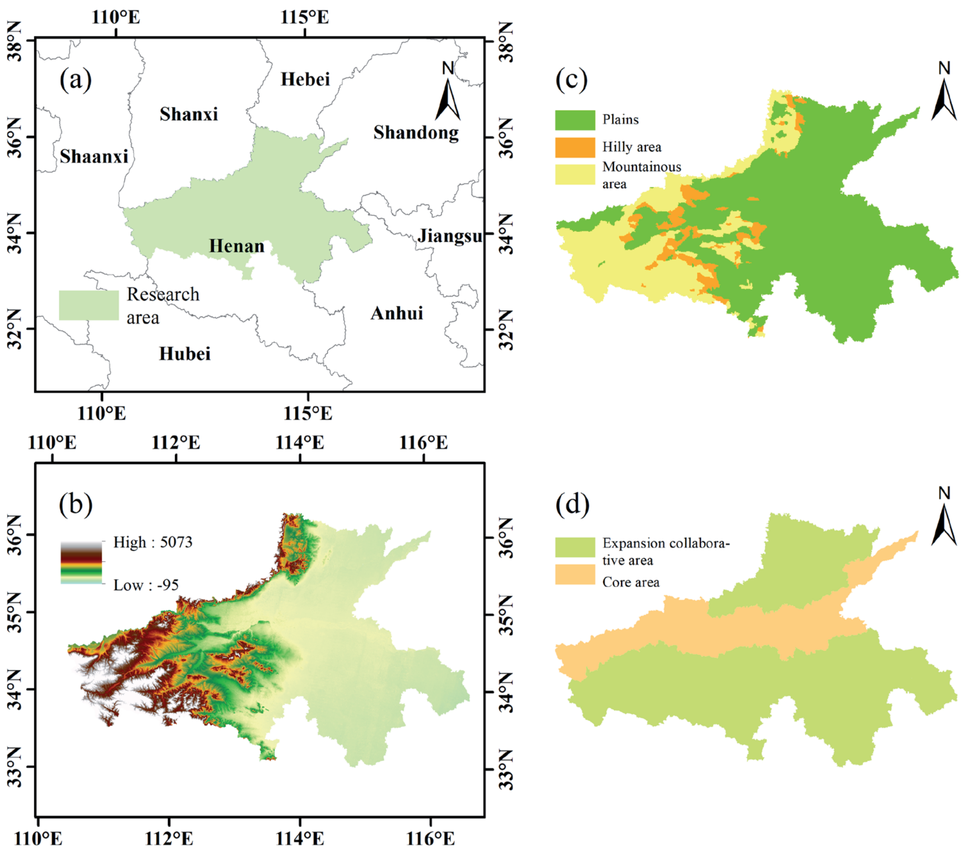

Fig. 1. a) Location of the study area; b) DEM and the regional scale; c) The geomorphological scale; d) The territorial spatial planning scale.

while the northwestern mountainous areas remain sparsely populated. Economically, the area's foundation rests firmly on agriculture and animal husbandry, with industry playing a secondary role. However, recent years have witnessed a surge in economic activity and human intervention, intensifying the clash between regional development and environmental preservation. Consequently, studying LUCC within this region has become crucial for balancing growth with ecological stewardship.

Data Sources

The dataset for this study encompasses a variety of elements, including land use/cover data, Geomorphological type distribution data, spatial extent definition data of the Yellow River basin in Henan Province, digital elevation model (DEM), meteorological information, and socio-economic development statistics. Among them, the land use cover data were obtained from the GLC-2020 dataset by vector data cropping at the study area boundary (https://data.casearth.cn). GLC-2020 is a global land cover product created by a research group in China with a resolution of 30 m and an overall accuracy of the dataset of 85.72% [38]. For analysis, data from 2000, 2010, and 2020 were meticulously selected and reclassified into 8 land categories – farmland, forests, shrubland, grassland, construction land, bare land, wetland, and waters – reflecting actual land-use distribution and research needs. The data on the distribution of landform types were obtained from the Resource and Environment Data Centre of the Chinese Academy of Sciences (http://www.resdc.cn/), and the data on the definition of the spatial extent of the Yellow River Basin in Henan Province were obtained from the Land Spatial Planning of the Yellow River Basin of Henan Province (2021-2035) organized and prepared by the Department of Natural Resources of Henan Province. The DEM data were sourced from the Geospatial Data Cloud (http://www.gscloud.cn/) and feature a spatial resolution of 30 m. Meteorological and socio-economic development data were acquired from the Resource and Environment Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/), with a spatial resolution of 1 km.

For the land use classification data and DEM data of different years, based on the GEE platform, remote sensing images of the core change areas of the corresponding years were acquired, and the validation samples were selected by the visual interpretation method to verify the consistency of the data of different years. As for the socio-economic data, the consistency between the distribution range of urban built-up areas and the high-value areas of GDP and population based on the land use classification data was cross-validated.

Research Framework

The idea of the study is shown in Fig. 2, initially, the distribution of different land classes in the study area is analyzed and the LUCC transfer matrix at different scales is calculated, this analysis helps to determine

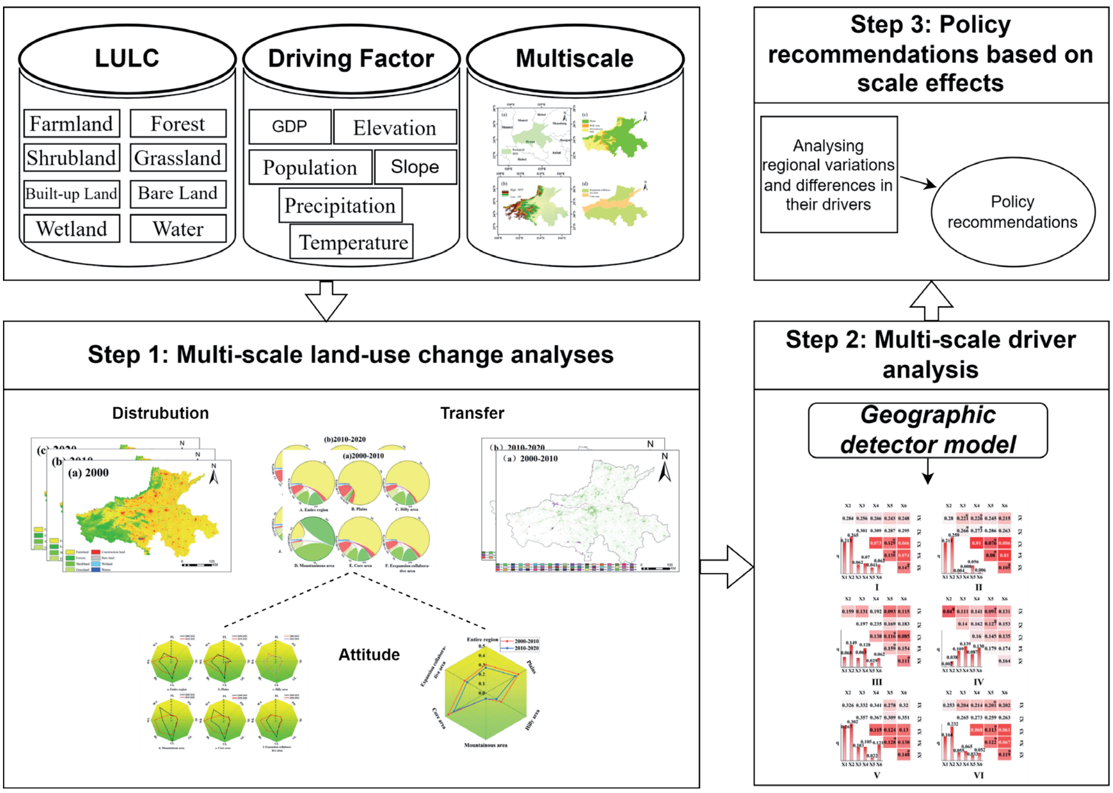

Fig. 2. Research framework.

the direction of change and transfer of land classes under different scale regions, subsequently, the main drivers and their interactions within different regions are identified based on the geo-detector model, so as to determine the regional specificity at different scales, and to provide a multi-scale policy formulation The results will provide a basis for policy formulation at multiple scales.

Materials and Methods

Land Use/Cover Dynamics

The land use/cover dynamics is a multifaceted concept that reveals not only the intensity of land use/cover changes but also the regional disparities in these changes. This attitude can be divided into two main categories: single land use/cover dynamics and comprehensive land use/cover dynamics [36, 39].

The single land use/cover dynamics sheds light on how a specific land use/cover type evolves over a designated period within the study area [40]. The formula used to quantify this attitude is:

$$\mathrm{U} = \frac{S_b - S_a}{S_a} \times \frac{1}{T} \times 100\%, \tag{1}$$

Here, U signifies the movement attitude of a particular land use/cover type during the study period. S_a and S_b denote the quantity of the land use/cover type at the start and end of the period, respectively, while T represents the duration of the study. If T is expressed in years, U will reflect the annual rate of change for that land use/cover type. For example, the overall scale of the 2000 farmland area is 71480.97 km^2, the 2010 farmland area is 68469.41 km^2, then the momentum of the 2000-2010 farmland attitude is $\mathrm{U} = \frac{68469.41 - 71480.97}{71480.97} \times \frac{1}{10} \times 100\%$.

On the other hand, the comprehensive land use/cover dynamics encapsulates the overall pattern of land use/cover transfers within the study area over the specified timeframe [41]. This is captured by the following formula:

$$LC = [\frac{\sum_{i-1}^{n} \Delta LU_{i-j}}{2\sum_{i-1}^{n} LU_i}] \times \frac{1}{T} \times 100\% \tag{2}$$

Here, LC represents the aggregate rate of land use/cover changes over the study period. LU_i indicates the area of land use/cover type i at the initial period, while ΔLU_{i-j} denotes the absolute change in area for land use/cover type i converted to other types during the study period. n is the number of land use/cover types. When T is measured in years, LC will convey the annual rate of change across all land types within the study area. Example, $\sum_{i-1}^{n} \Delta LU_{i-j}$ on behalf of the sum of the absolute value of the area of the land category of change, $2\sum_{i-1}^{n} LU_i$ is the total area of all land categories 2 times, in 2000-2010 the overall region as an example, known as the area of each category in 2000 and 2010, respectively, to do the difference to take the absolute value and then add the sum, the value of 6159.1 km^2, the total area of the various categories of 10,2505.36 km^2, then the 2000-2010 $LC = \left[\frac{6159.1}{2\times102505.36}\right] \times \frac{1}{10} \times 100\%$.

Land-Use Transfer Matrix

The land-use transfer matrix offers a multifaceted and detailed depiction of how land use/cover evolves over time and space within the study area. It serves as a powerful tool for unraveling the intricate patterns and directional shifts in land use/cover, revealing both spatial and temporal dynamics [42, 43]. This matrix is mathematically expressed as:

$$S_{ij} = \begin{vmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{vmatrix} \tag{3}$$

Here, S denotes the area of interest, and n represents the land use/cover type. The indices i and j are used to indicate the specific land use/cover types at the beginning and the conclusion of the study period, respectively.

The land-use transfer matrix still has some limitations at the same time, such as the lack of spatial details to reflect the distribution and pattern of spatial changes and a high dependence on the accuracy of the land-use classification data. In addition, the temporal resolution is also insufficient, as it can only represent the transformed state of the start event and its end time. Meanwhile, only static analyses are a major drawback, which cannot reflect the dynamic process, so the accuracy of the raw data of land classification is crucial, and relevant methods should be selected according to the research needs to make up for its limitations.

Land-Use Mapping Model

To investigate land use/cover changes, the spatial base data for the study area were meticulously selected for three distinct periods. Time series mapping units were then established for the intervals spanning 2000-2010 and 2010-2020. Utilizing the advanced capabilities of ArcGIS 10.6 software, the raster calculator function was employed to perform statistical analyses on the data, yielding insightful results post-processing. In this analysis, land use/cover data from consecutive periods were cross-referenced. By intersecting these datasets, the coded values representing land use/cover types from the earlier period were compared to those from the later period [37]. The transformation of these codes into a new three-digit land use/cover code value follows the formula:

$$P = 10M + N \quad (4)$$

Here, P signifies the newly generated four-digit land use/cover code. M represents the land use/cover type code from the earlier period, while N corresponds to the land use/cover type code from the later period.

Driver Analysis Based on Geo-Detectors

Acquisition and Processing of Driving Factors

LUCC is the result of multiple factors, and studies have shown that socioeconomic factors always play an important role in it [44, 45]. And from the geomorphological scale, as the elevation increases, the anthropogenic perturbation gradually decreases while the natural factors start to play a role [33, 34], therefore, combining the real situation of the study area and the limitations of the available data, six driving factors were selected mainly from the socio-economic, topographic, and climatic factors, in order to quantify the driving factors of the land-use change in the Yellow River Basin of Henan Province, including GDP, population, elevation, slope, precipitation, and temperature. Since the geomorphological scale and the administrative district planning boundary do not match, this study follows the raster cell for driving force detection. The relevant data of 2000 and 2020 were selected, and different factors were resampled into a 2 km^2 grid to count the change values of each factor during the 20 years, and then the change values of the driving factors were discretized in ArcGIS by applying the natural discontinuity method according to the 2 km^2 grid, and the discretization results were taken as the independent variable X_i. The number and direction of changes of the pixels of various land use types in each 2 km^2 grid were counted by ArcGIS, and the change area of each class was calculated by applying formula (1-2) one by one. ArcGIS was used to count the number and direction of image changes of various land use types in each 2 km^2 grid, calculate the area of changes of each class, and calculate the integrated dynamic attitude of each grid one by one as the dependent variable Y by applying the formula (1-2). The selected factors are shown in Table 1.

Geographic Detector

The geo-detector is a sophisticated statistical tool designed to probe and quantify the spatial dissimilarities among factors. It operates on the premise that if two spatial distributions significantly influence a dependent variable, they will exhibit similarity in their patterns. This method is invaluable for uncovering the underlying forces that drive the relationships between independent variables and the dependent variable [46-48]. It is widely used and advantageous in the quantitative analysis of LUCC driving mechanisms [49, 50]. The geographic detector comprises four distinct detectors [51], among which the factor detector and the interaction detector are primarily employed in this study.

The factor detector is instrumental in examining how variations in attribute Y correlate with changes in factor X. The degree to which factor X elucidates variations in Y is quantified by the q-value. A higher q-value signifies a more robust explanatory power of factor X over Y. The value interval is 0-1, and it is usually considered that the detection factor X has some explanatory power for the spatial distribution of the Y phenomenon when q>0.1, and X has strong explanatory power for the spatial distribution of the Y phenomenon when q>0.5, and when q is close to the value of 1, it indicates that X explains the spatial distribution of the Y phenomenon almost completely. The formula to compute the q-value is:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SST}{SSW} \quad (5)$$

$$SSW = \sum_{h=1}^{L} N_h \sigma_h^2 , SST = N\sigma^2 \quad (6)$$

Here, h represents the stratification level, ranging from 1 to L, categorizing either the variable Y or factor X. The stratification details, including the values for N_h and N, are outlined in the accompanying table. σ_h^2 and σ^2 denote the variances of Y within the stratified layers and the overall region, respectively. SSW and SST represent the sum of intra-layer variances and the total variance across the entire region [52].

Furthermore, the influence of regional LUCC might stem from a confluence of multiple factors. To address

Table 1. Various types of drivers.

	Driving Factor	Unit	Variable
Socio-economic factors	GDP	Ten thousand yuan	X1
	Population density	People/km^2	X2
Topographical factors	Elevation	Meter	X3
	Slope	Degree	X4
Climatic factors	Mean annual precipitation	Millimeter	X5
	Mean annual temperature	Celsius degrees	X6

Table 2. Types of interactions between the two factors (X1 and X2) in the Geographic Detector.

Interaction	Judgment Criteria
Weakened, nonlinear	q (X1 ∩ X2) < Min(q(X1), q(X2))
Weakened, unique	Min(q(X1), q(X2)) < q (X1 ∩ X2) < Max(q(X1), q(X2))
Enhanced, bilinear	q (X1 ∩ X2) > Max(q(X1), q(X2))
Independent	q (X1 ∩ X2) = q(X1) + q(X2)
Enhanced, nonlinear	q (X1 ∩ X2) > q(X1) + q(X2)

this complexity, interaction detectors come into play. These detectors analyze whether combinations of different risk factors X_i either amplify or diminish the explanatory power of the dependent variable Y when considered together. The nature of these interactions is detailed in Table 2.

Results

Multi-Scale Land Use Cover Characterization

The land use/cover types in the Yellow River Basin of Henan from 2000 to 2020 are mainly divided into 8 categories: farmland, forests, shrub forests, grasslands, construction land, bare land, wetlands, and waters. From Fig. 3 and 4, it is obvious that the land use/cover situation shows that farmland, forests, shrub forests, and construction land are the main ones, and various other land types are interspersed. Among them, farmland is widely distributed in the plain area and accounts for the largest area (around 84%), followed by the hilly area, which accounts for about 70% of the area, while in the whole region, the core area and the expansion of the radiation area farmland accounts for an approximate proportion (around 66%), and the mountainous area accounts for the least amount of farmland (around 14%), which is mainly located in the central part of the region as well as in the part of mountainous and hilly areas bordering the region. Built-up land is scattered within all scales, with a higher proportion in the core and plains areas (around 11%), followed by the whole area and the extended collaboration area (around 8%), and the least proportion in the mountainous areas (around 1%). Forests (around 41%) and shrubs (around 36%) cover a very high percentage of the mountainous areas, and there is also a large amount of woodland in the hilly areas, the western part of the core area, and the northern and southern parts of the extended radiation area, while

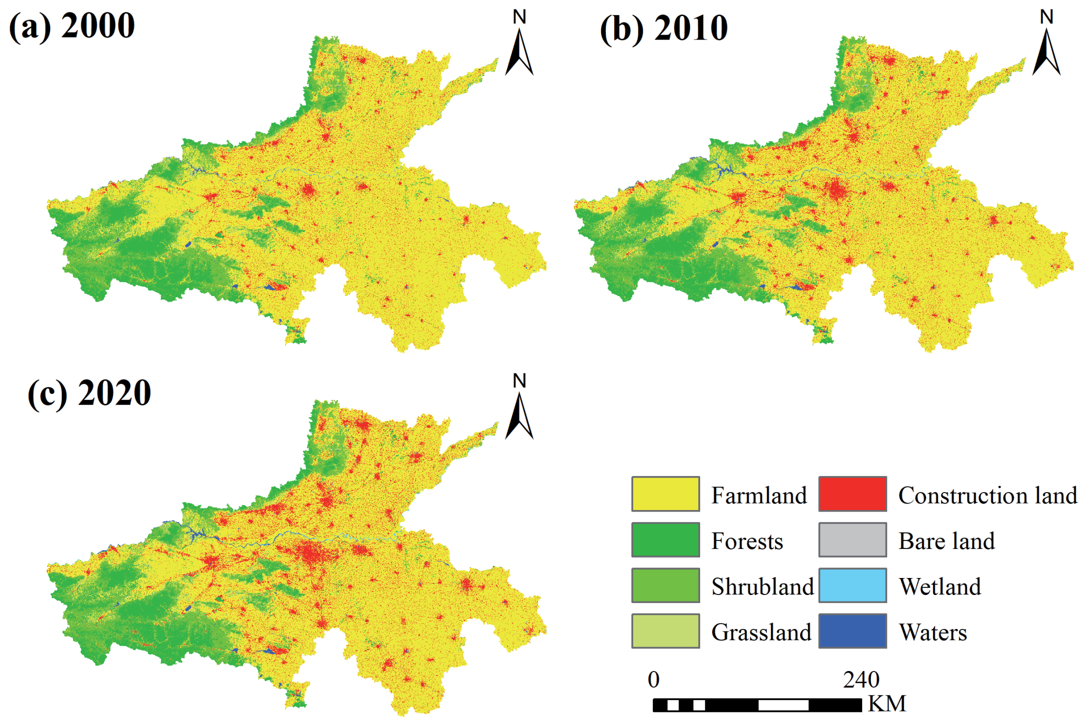

Fig. 3. a) Land use/cover in 2000; b) Land use/cover in 2010; ca) Land use/cover in 2020.

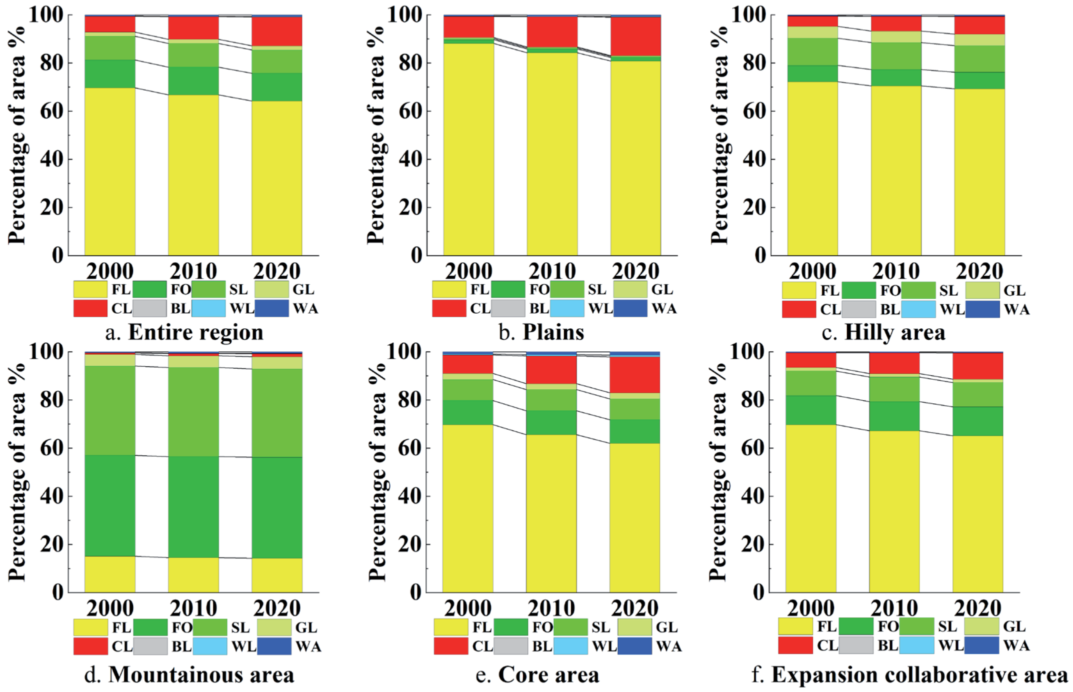

Fig. 4. a) Proportion of each land type in the whole area; b) Proportion of each land type in the plain area; c) Proportion of each land type in the hilly area; d) Percentage of each land type in the Hill District; e) Percentage of each land type in the core area; f) Percentage of each land type in the extended collaboration area.

forests (around 1.5%) and shrubs (around 0.5%) make up a very small percentage of the plains. Grassland is more predominant in the mountainous and hilly areas (around 5%), and wetlands and watersheds are distributed throughout the core area from west to east, with more than 79% of wetlands and 55% of watersheds distributed in the core area. In addition, more than 89% of bare ground is scattered throughout the Extension Collaboration Area.

It is worth noting that over the 20-year period, at different scales, the dominant land class in all regions except the mountainous areas is farmland, especially in the plains, where the share of farmland peaks, depending on the nature of Henan as a large agricultural province. The rest of the land classes show greater variability with scale.

Analysis of Land-Use Dynamics

The dynamic attitude can clearly reflect the land use/cover pattern and the degree of fluctuation of various land types in the study area, and Fig. 5 and 6 show the single dynamic attitude and the comprehensive dynamic attitude at multiple scales. From the dynamic attitude, we can learn that the construction land is expanding drastically while the farmland is shrinking seriously in all scales. The most drastic fluctuation of construction land is in the mountainous area, while farmland shrinks most seriously in the core area. The land use/cover pattern fluctuates most dramatically in the plains and the core area, and the land pattern fluctuates least in the mountain area. Forests remain stable in the mountain areas, but shrinkage gradually worsens in the plains and core areas. Grasslands increase in the mountain region and gradually shrink at the remaining scales. Wetlands and watersheds grow significantly in the Core Area. Overall, farmland in the study area from 2000 to 2020 continued to decline, built-up land continued to expand, wetlands and waters grew gradually, and forests and grasslands remained stable in the mountainous areas while shrinking significantly in the built-up agglomerations.

Through the dynamic attitude, we can clearly observe that compared with 2000-2010, the fluctuation of land pattern, urban expansion and shrinkage of farmland have gradually slowed down in 2010-2020, while the gradual growth of wetland and watershed reflects the gradual improvement of the strategy of ecological protection of the Yellow River Basin and its high-quality development as well as the policy of provincial ecological protection and watershed management. However, at the same time, the deterioration of forests, shrublands, and grasslands at multiple scales shows the limitations of the relevant policies and the necessity of regional characteristic management.

Analysis of Changes in Volume Structure

From the dynamic attitude, it is learnt that the land use/cover pattern in the Yellow River Basin of Henan Province has changed significantly during the past 20 years, and then we will look at the dynamic

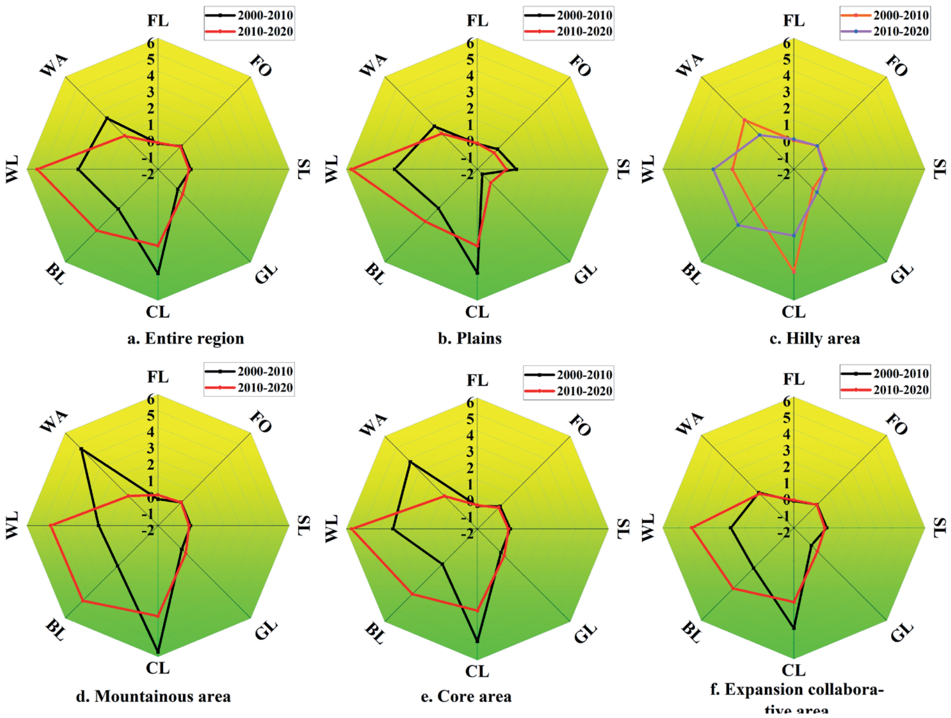

Fig. 5. Single-movement attitudes of land types at various scales a) Whole area; b) Plains area; c) Hilly area; d) Hilly area; e) Core area; f) Expansion collaborative area.

conversion between land classes to understand the details of the change more clearly. The change of land use/cover categories is mainly reflected in the transfer of farmland to other land types, and the increase of construction land, water, bare land, and wetland is mostly reflected in the transfer of farmland, while forests and grasslands are also transferred to farmland and construction land. The transfer out of farmland is obvious at all scales, and mainly to construction land, and the change area is concentrated around towns and cities, as can be seen from Fig. 7, 8, and 9.

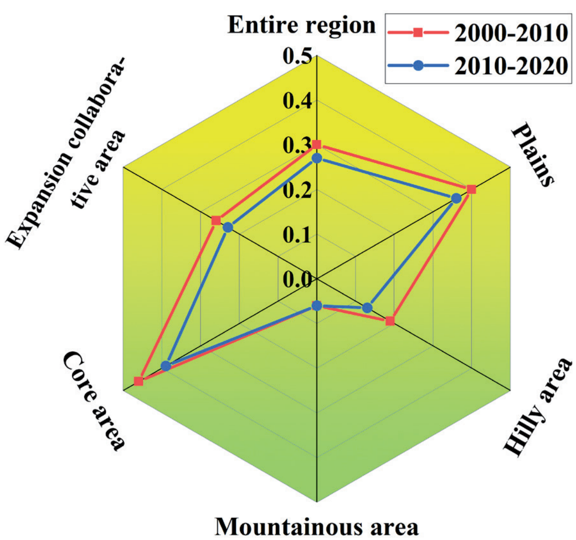

Fig. 6. comprehensive land use/cover dynamics at all scales.

At the global scale, from 2000 to 2010, 3,143.64 km^2 of agricultural land was transferred out of the study area, of which 2,829.14 km^2 was transferred to construction land, and the remaining was mainly transferred to forests (73.52 km^2) and waters (126.03 km^2). Agricultural land was transferred to 132.08 km^2, 25% from forests and 53% from grasslands, with the area of transfer concentrated in the southwestern part of the study area. In addition, construction land also encroaches heavily on forests (40.43 km^2) and grasslands (42.76 km^2), and the increase in the area of bare land and wetlands is mainly transferred from farmland and grasslands. 2,719.30 km^2 of farmland will be transferred out of the study area in the period from 2010 to 2020, of which 91% will be transferred to construction land, and the rest will be mainly transferred to watersheds (87.22 km^2), grasslands (54.52 km^2), and wetlands (73.57 km^2), and the change patches were concentrated in the central area. Agricultural land was transferred to 144.96 km^2, mainly from forests, shrub forests and grasslands; forests were transferred out of 126.76 km^2, 49.89 km^2 to agricultural land and 58.93 km^2 to construction land; shrub forests were transferred out of 115 km^2, 32.76 km^2 to agricultural land, 30.34 km^2 to forests and 27.08 km^2 to construction land; and forests and grasslands were the main remaining areas. The remaining is mainly transferred to forests and grasslands. The difference between the two yearly intervals is obvious, with a decrease in the area of farmland attenuation velocity from 2010 to 2020 compared to 2000-2010, but

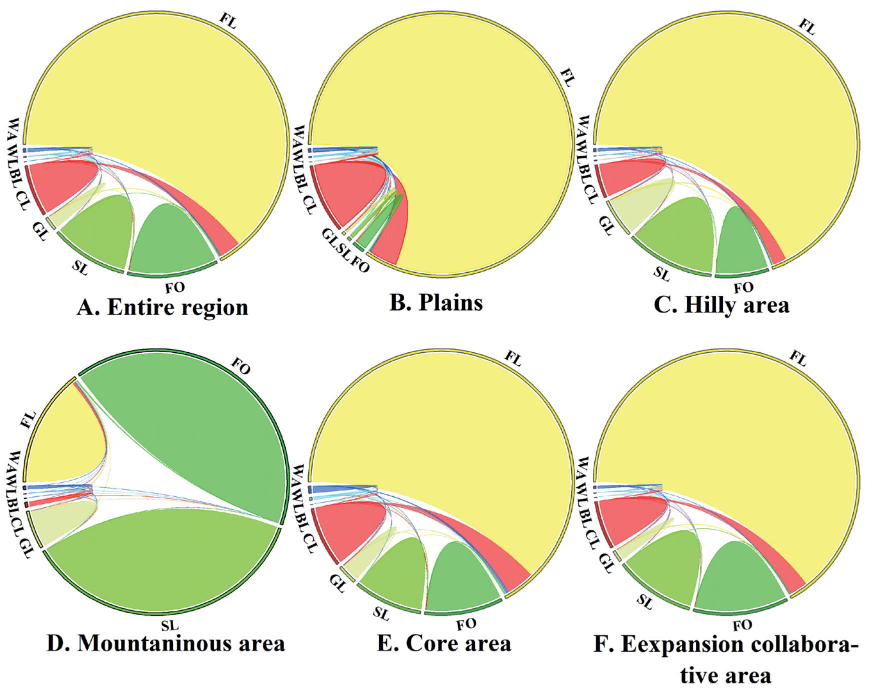

Fig. 7. Land use/cover transfer chords by scale, 2000-2010 a) Whole area; b) Plains area; c) Hilly area; d) Hilly area; e) Core area; f) Expansion collaborative area; where FL, FO, SL, GL, CL, BL, WL, WA stand for Farmland, Forest, Shrubland, Grassland, Built-up Land, Bare Land, Wetland, and Water, respectively.

a large increase in the area of forest land converted to building land.

The land use pattern of different landforms in the landform type zoning is obviously different, and there are obvious differences in LUCC. The main types of changes in the plains area are farmland, forest, construction land, and grassland, which are shown as the flow of farmland to construction land, wetland, and water, and the area is concentrated in the north-central part of the plains area. From 2000 to 2010, 2824.02 km^2 of farmland was transferred out, of which 2648.75 km^2, 34.34 km^2, and 75.76 km^2 were transferred to construction land, wetland and water respectively, and in addition, construction land still encroached on a large amount of forests (34.43 km^2) and grasslands (34.04 km^2), and in addition, a large amount of forests (21.30 km^2) and grasslands (32 km^2) flowed into farmland, and the change of other land categories was relatively minor. Between 2010 and 2020, 2503.16 km^2 of agricultural land was transferred to construction land (2341.83 km^2), wetlands (69.22 km^2) and waters (73.97 km^2), 68.60 km^2 of forests was transferred to 20.63 km^2 of agricultural land and 45.25 km^2 of construction land, and 32.96 km^2 of grasslands was transferred to 13.63 km^2 of agricultural land and 17.83 km^2 of construction land. It can be seen that in 2010-2020, the intensity of returning farmland to forests may be weakened, the encroachment of construction land into forest land will be intensified, and the encroachment of farmland and construction land into grassland will be significantly smaller than that in 2000-2010. The land use pattern in the hilly area is relatively stable, and the main types of changes are farmland and grassland. 129.26 km^2 of farmland was transferred out of the hilly area from 2000 to 2010, and 108.38 km^2 of farmland, 6.25 km^2 of forests, and 5.68 km^2 of watersheds were transferred to construction land, while 20.08 km^2 of grassland was transferred out of the hilly area, and the main areas were transferred to farmland (16.31 km^2) and construction land (2.95 km^2). From 2010 to 2020, 89.21 km^2 of agricultural land was transferred to construction land, forests, grasslands, and waters, and 9.63 km^2 of grasslands was transferred to agricultural land and construction land. In the mountainous areas, this is mainly manifested in the conversion of farmland, construction land, forests, shrublands, and grasslands. From 2000 to 2010, 180.07 km^2 of farmland was transferred out of the area, mainly into forests (33.27 km^2), grasslands (35.01 km^2), construction land (68.85 km^2) and waters (40.11 km^2) Construction land encroached heavily on forests (4.68 km^2) The land used for construction encroaches heavily on forests (4.68 km^2), shrub forests (5.37 km^2) and grasslands (5.74 km^2). From 2010 to 2020, 119.43 km^2 of agricultural land was transferred out of the country, and 70.73 km^2 was transferred in, of which 24% was transferred from grassland to agricultural land and 75% was transferred from forests and shrublands. Construction land was transferred to 82.04 km^2, of which 58% was transferred from agricultural land and 37% from forests and shrublands. Forests were transferred to 52.49 km^2, mainly from agricultural land (23.81 km^2) and shrubland (27.67 km^2).

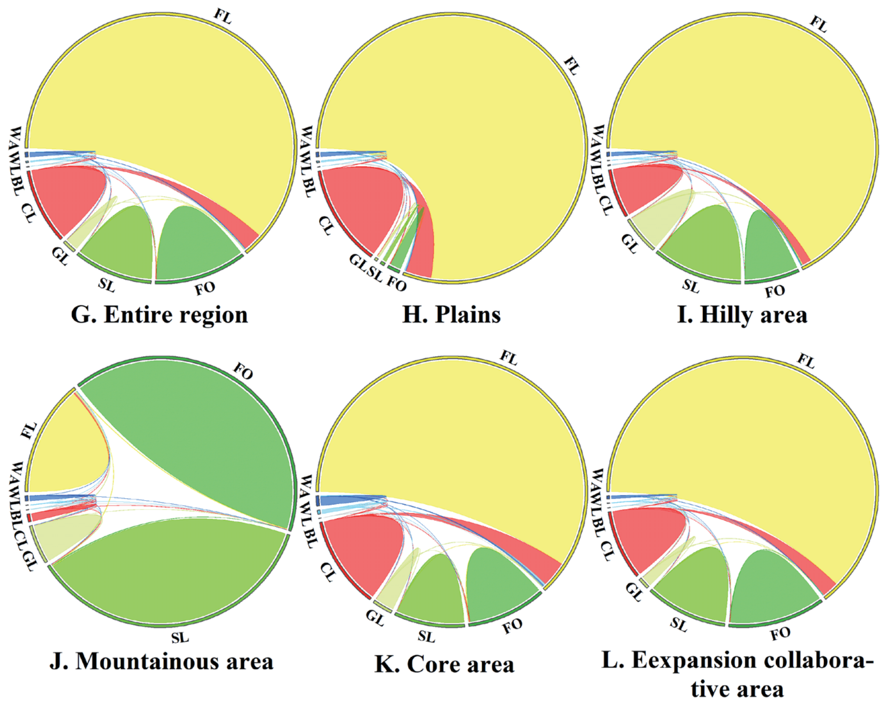

Fig. 8. Land use/cover transfer chords by scale, 2010-2020 a) Whole area; b) Plains area; c) Hilly area; d) Hilly area; e) Core area; f) Expansion collaborative area; where FL, FO, SL, GL, CL, BL, WL, WA stand for Farmland, Forest, Shrubland, Grassland, Built-up Land, Bare Land, Wetland, and Water, respectively.

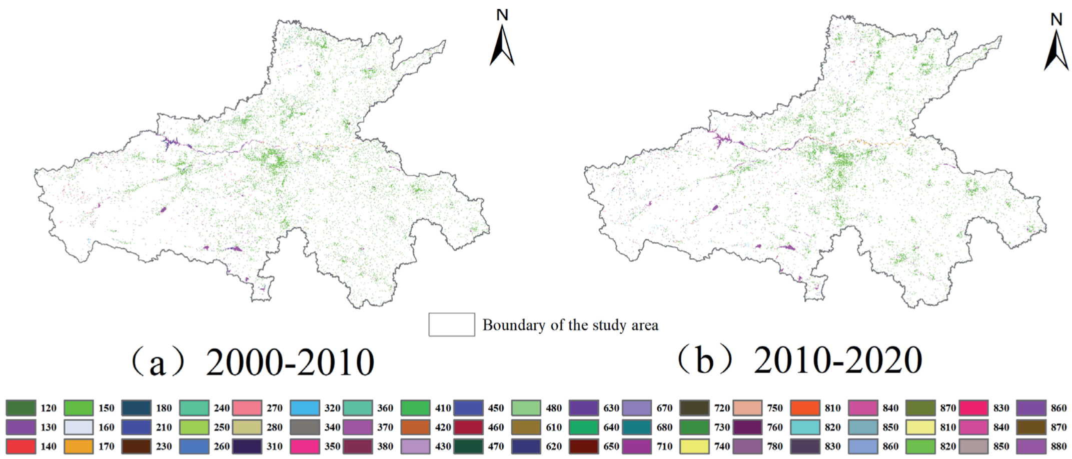

Fig. 9. Land-use mapping, a) 2000-2010; b) 2010-2020, where 10-80 represent the eight land categories from agricultural land to watersheds, respectively, and 120-880 represent the types of land-use change, with the example of 120 referring to the conversion of agricultural land to forests.

In the spatial planning zoning of land, the core area has obvious changes in the categories of farmland, construction land, forests, grassland, and waters. From 2000 to 2010, 1164.35 km^2 of farmland was transferred out of the core area, of which 26.86 km^2, 24.65 km^2, 981.81 km^2, 32.33 km^2, 98.31 km^2 were transferred to forests, grasslands, construction land and wetlands, but a total of 42.71 km^2 of other land types were transferred to farmland. 40.05 km^2 of forests were transferred out, mainly to farmland and construction land. From 2010 to 2020, 1030.64 km^2 of farmland was transferred to construction land, wetland, and water, with 882.38 km^2, 62.05 km^2, and 56.06 km^2 respectively. Forests flowed to farmland and construction land by 23.50 km^2 and 23.53 km^2, respectively, while waters flowed to farmland and wetlands by 16.55 km^2 and 12.35 km^2, respectively. The main types of changes in the extended collaborative area were farmland, forests, scrub forests, and grasslands.

Comparing the three scales, the main land use transition is from agricultural land to construction land and the encroachment of construction land into forest land, but the remaining land use changes vary greatly. From different years, regional economic development played an important role in the evolution of land use pattern during 2000-2010, with rapid urban expansion and encroachment of forest land in key economic zones in addition to the occupation of farmland, while urban expansion and shrinkage of farmland slowed down during 2010-2020, but the decline of forest land in key economic zones intensified, which proves that although the relevant policies played a certain role, the issue between economic development and ecological protection still needs to be addressed. This proves that although relevant policies have played a role, the issue between economic development and ecological protection still needs to be focused on.

LUCC Driver Analysis by Scale

In analyzing the diverse factors influencing LUCC,

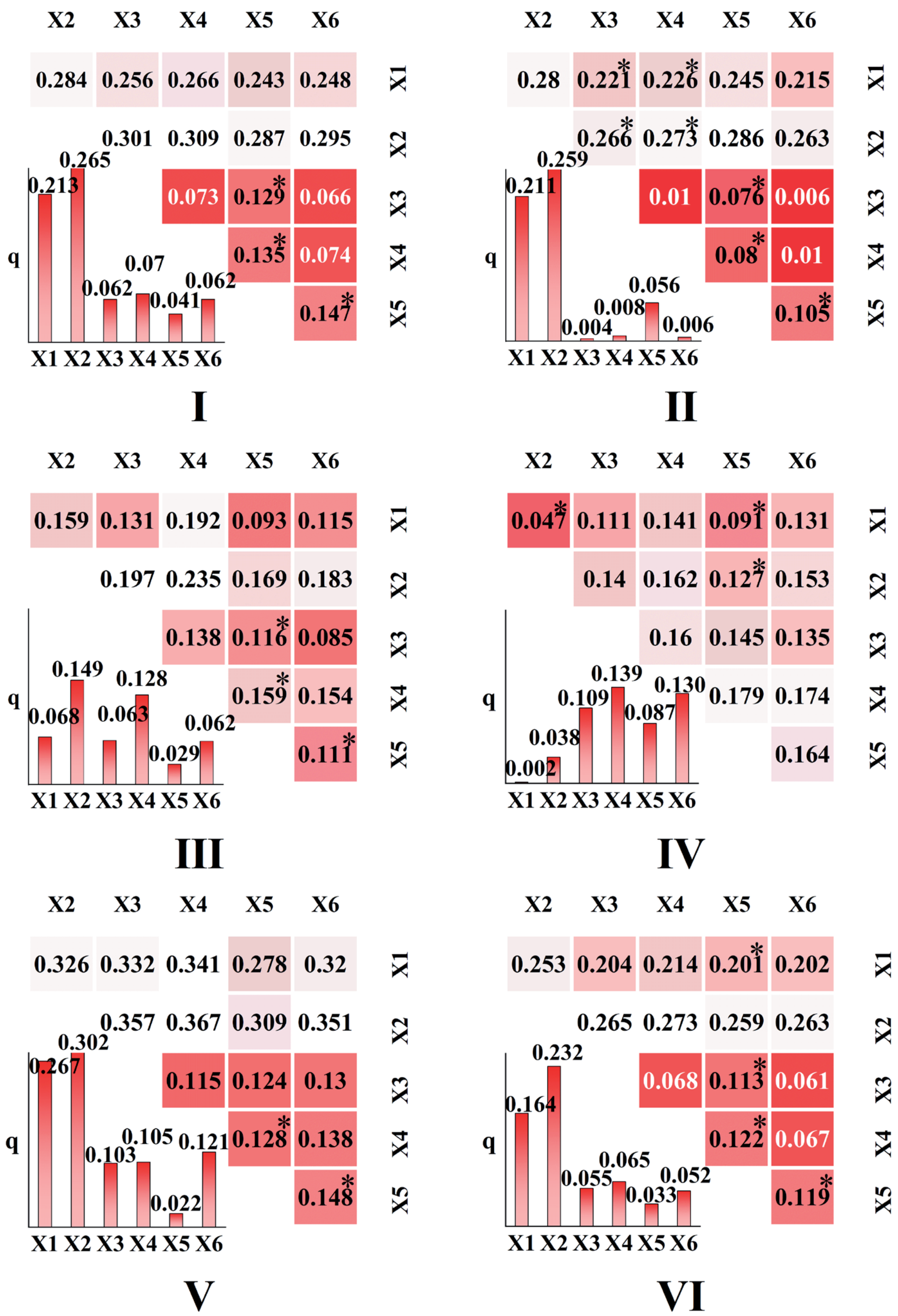

Fig. 10. The results of factor detection and interaction detection at each scale, (I) whole area, (II) plain area, (III) hilly area, (IV) mountain area, (V) core area, and (VI) extended collaboration area. Those marked with '*' represent nonlinear enhancement, and the rest are two-factor enhancement. Where X1-X6 represent GDP, population, elevation, slope, precipitation, and temperature, in that order.

we employed geo-detectors to examine their effects across three distinct scales. The results were unequivocal (Fig. 10): each factor exerted a statistically significant influence ($p<0.01$) across all scales considered. Notably, the q-values – indicative of the strength of these factors' impacts – varied significantly depending on the scale, underscoring substantial differences in their explanatory power. The examination of single-factor and interaction detections, as illustrated in Fig. 10, revealed a complex landscape of influence. Socio-economic factors consistently outperformed others in explaining LUCC across the entire region, the plains, the core area, and the expansion collaborative area. GDP and population consistently showed relatively high q-values (0.213 and 0.265, 0.211 and 0.259, 0.267 and 0.302, and 0.177 and 0.205, respectively). The predominance of construction land encroachment on the remaining land types in the above four regions indicates that population and economic development have a great impact on urban expansion. Therefore, balancing the relationship between population growth, economic surge, and urban expansion is the key to achieving benign land changes. The q-values of population and slope in the socio-economic factors in the hilly area are relatively high (0.149 and 0.128), and the q-value of precipitation is the lowest (0.029), which indicates that with the growth of population, the living space is tight, and part of the population has to be relocated to the hilly area, which leads to the intensification of landform change, but at the same time, it is still limited by the topography, which indicates that how to alleviate the pressure on the living space is of great importance. The q-value of slope for topographic factor and precipitation for climatic factor are relatively high (0.139 and 0.130), while the q-value of GDP and population are the lowest (0.009 and 0.006). Mountainous areas are less affected by human activities, and therefore, the focus should be on the prevention of extreme weather and events. At the same time, it is still necessary to raise the awareness of environmental protection among the citizens.

In addition, in terms of interaction detection results, the q-values of all factor interactions were greater than those of the two individual factors, demonstrating that the strength of LUCC was amplified by the interaction of the factors. The interaction of population and slope has the strongest explanatory power (q-value of 0.309) at the full domain scale, and the effects of both on land-use change come from multiple sources, with population growth driving the demand for land, especially for construction and agriculture; and slope determining the possibility of different types of land use. Flat areas are prioritized for urban construction and large-scale agriculture; while areas with larger slopes are commonly used for ecological protection, traditional agriculture or forestry due to topographical constraints, so the interaction between the two has a greater impact on land use change in densely populated and geomorphologically graded areas such as the Henan section of the Yellow River Basin. The explanatory power of population and precipitation is 0.286 in the plains area, where population growth drives land expansion and changes in the type of use, while changes in precipitation determine the pattern of agricultural production, the process of urbanization, and the use of water resources, so the two have a significant impact in the plains area, which is more livable and agriculturally developed. The interaction of population and slope is likewise most pronounced in the hilly areas. The interaction between slope and precipitation (q-value of 0.179) is most pronounced in the mountainous areas, where precipitation largely determines the change in forest land and the pattern of agricultural production, while the size of the slope determines the direction of land evolution into agricultural land, urban land, or ecological reserves. Finally, the interaction of population and slope remained the most influential within the core and expansion collaboration areas.

Discussion

Discussion of the Current Status of the Study Area

In order to study the evolutionary trend of LUCC in the Yellow River Basin in Henan, this paper uses three scales and explores the driving factors under multiple scales for the analysis. The results show that the land use/cover pattern fluctuates significantly in the study area from 2000 to 2020, with a serious reduction of farmland and a large increase of construction land in urban areas, which is consistent with the conclusions of existing studies [53, 54] and converges with the evolution of the land use/cover pattern of the Shandong section of the Yellow River Basin [22] as well as the middle and lower Yellow River Basin [55], proving that the land use/cover pattern changes occurring in the middle and lower Yellow River Basin, which is the main source of grain, have a certain homogeneity. Subsequently, from the information on the attitude of movement and its land use/cover transfer, comparing the changes from 2000-2010 to 2010-2020, it can be learnt that the urban expansion and farmland degradation gradually slowed down, the amount of woodland and grassland in the mountainous areas remained stable, and the waters and wetlands in the core area increased significantly. It proves that a series of policies actively launched by Henan Province, such as ecological protection zones, ecological corridors along the Yellow River, and comprehensive management of the beach area, have achieved certain results, but there are still shortcomings. For example, farmland has been decreasing, which may lead to a decline in agricultural production capacity and leave some farmers with no land to farm, thus affecting food security as well as social stability. At the same time, the built-up area and its surrounding agricultural land has been greatly reduced, and the woodland and grassland have intensified their decline, proving that the built-up area, as a concentration of socio-economic activities, and the urban and road construction associated with it, are the main factors leading to the degradation of agriculture and woodland, which may trigger an imbalance in the ecological balance, a conclusion that has been demonstrated in many studies [56-58]. Looking at LUCC, although a series of policies have made initial progress, the massive shrinkage of farmland and the intensified reduction of woodland and grassland indicate that the key to the problem is how to promote the return of farmland to forests and grassland in an orderly manner while adhering to the red line of arable land, and to maintain a balance of production, living and ecological space within the built-up area.

In terms of drivers, we clearly find that GDP and population are crucial to the impact of LUCC, as evidenced by Cheng et al.'s [35] study of the drivers of land use/cover in the Yellow River Basin and Kleemann et al.'s [59] study of the drivers of land use/cover in north-eastern Ghana, West Africa. Economic and population growth has pushed forward the process of urbanization, which has resulted in a large influx of people into the cities and an increase in the scale of land for construction, which in turn has compressed agricultural land and ecological resources. In mountainous areas rich in woodland, the main drivers are climate and topography, where temperature and precipitation affect the growth of green plants by influencing plant photosynthesis, transpiration, and water content. At the same time, topographic conditions are also crucial, and related studies have shown that elevation is the main reason for controlling land use/cover changes in local areas [60, 61], and the increase in elevation and slope will produce certain environmental resistance to human activities [62], so the changes in agricultural land and construction land are mainly concentrated in lower elevation and gentler slope areas, while the evolution of the ecological environment is mainly concentrated in higher elevation areas. The intricate driving force mechanism is the primary factor influencing decision makers to formulate strategies, so it is crucial to excavate the main influencing factors within different regions.

Policy Recommendations

In view of the opportunities and challenges facing the ecological protection of the Yellow River Basin, and based on the trends and characteristics of land use/cover changes in the Yellow River Basin of Henan over a period of 20 years at multiple scales, the high-quality development of the Yellow River Basin of Henan can be promoted in the following aspects:

1. In the case of the plains, which is a major concentration of farmland and population, in the face of the continuous encroachment of construction land on farmland and other land types brought about by the rapid growth of the population and the economy, it is necessary to adhere to the 'red line for farmland', clarify land use, improve the efficiency of agricultural production, promote intensive land management, carry out land reclamation and implement an ecological compensation mechanism, optimize urban space, enhance rural construction, and implement public education on land protection to raise policy acceptance and to strongly support green development and sustainable development of urban space, enhance rural construction, implement public education on land protection, enhance policy recognition, and strongly support green development and sustainable development.
2. In the hilly areas, where the problem of population migration has led to radical changes in land-use patterns, land planning should be clarified, ecological protection red lines should be established, development should be strictly controlled, and specialty agriculture should be developed, while the carrying capacity of the land should be assessed and land planning should be dynamically adjusted.
3. Mountainous areas are mainly subject to natural factors, so natural evolution should be accompanied by appropriate human intervention, such as water conservation, biodiversity protection, forest fire prevention, and other measures to improve the ecosystem's ability to cope with extreme weather and events. Indiscriminate logging and illegal encroachment on forest land are also prohibited.
4. The core area is the agglomeration zone of key economic development cities, and therefore construction land encroaches heavily on other construction land, especially farmland. Therefore, it is necessary to define the core functional areas of the city, rationalize the layout of residential, industrial and public facilities, promote the development of green industries, protect farmland and natural resources, and promote the green transformation of the city through cooperation between the government, enterprises and the society, as well as real-time monitoring of land use and flexibility in responding to external changes.
5. In expanding the scattered distribution of population and cities in the radiation zone, it is necessary to promote the development of urban agglomerations and regional centers, to facilitate the concentration and efficient flow of population and resources, to protect agricultural land and the ecological environment, to promote the concentration of agriculture and ecological restoration, to guide the rational distribution of industries, to provide incentives for the migration of population to industrial agglomerations, and to promote coordinated and sustainable development in the region in order to optimize the distribution of population and resources.
6. The ecological restoration of the Yellow River Basin in Henan should pay attention to the specificity of the problems and the pertinence of the measures, and in the process of overall or regional ecological management, ecological restoration planning should

be prepared and implemented under multi-sectoral synergies in accordance with regional specificities, so as to ensure the effective and orderly advancement of the ecological restoration of the Yellow River Basin in Henan as a whole and in the region.

It is expected that the implementation of these recommendations can effectively solve the problems that exist in the study area and, at the same time, provide some guidance for decision-makers and planning managers in related fields.

Inadequacies

Although the study analyzed the land use/cover changes and their potential driving forces in the Yellow River Basin over a period of 20 years from a multi-scale perspective, the study still has some shortcomings. The first one is the problem of data accuracy. Although the surface cover data have a high overall accuracy, the accuracy of the data under the small areas of the remaining scales has not been fully verified, which may affect the results of the study in the corresponding regions. For driver analysis, the selection of driver factors is not comprehensive enough due to the limitation of available data and the difficulty of quantifying some factors, such as government planning [35, 63]. The geo-detector only explains the interaction between the two factors but not the connection between more factors, which still has some limitations.

Conclusions

This paper quantifies the intensity of the fluctuation of each land use/cover type at different scales in the Yellow River Basin of Henan Province from 2000 to 2020 based on the attitude of land use/cover dynamics, land use/cover transfer matrix, land use/cover mapping and specifies the main change areas, and uses geo-detectors to reveal the degree of response of the LUCC to the selected factors at various scales, and draws the following conclusions:

1. The proportion of each category and its change trend within different scales from 2000 to 2020 show spatial analysis, and the degree of change of land use/cover pattern in 2000-2010 is higher than that in 2010-2020 within any scale, indicating that Henan Province has gradually realized the importance of balancing the land use/cover pattern.
2. Farmland and built-up land are most predominant in the plains, with the most serious areas of farmland decline in the core areas and dramatic fluctuations in built-up land in the mountainous areas. Forests, shrublands, and grasslands are mainly found in mountainous areas but fluctuate sharply in the plains. Bare land is predominantly found in the hills but fluctuates sharply in the mountains, and wetlands and waters are predominantly found in the core area.
3. The dominant land change type within all scales is the transfer of agricultural land to built-up land. In the whole area, the plains, the core area, and the extended radiation area farmland also flows in large quantities to wetlands and waters, and in the mountainous and hilly areas farmland also flows to forests and meadows. Land for construction in mountainous areas also encroaches heavily on forests, shrublands, and grasslands.
4. From 2000 to 2020, the land use/cover change areas in the Yellow River Basin of Henan Province were mainly concentrated in and around the urban agglomerations, and the degradation of forests and grasslands in the relevant areas became more and more serious.
5. Being more sensitive to socio-economic factors in areas where the dominant type of land conversion is from agricultural land to built-up land, such as the entire region, the plains, the core area, and the extended collaborative area. Hilly areas are mainly affected by population and slope. Mountainous areas depend mainly on topographic and climatic factors. At the same time, factor interactions enhance the evolution of land use/cover patterns at all scales.
6. The above study shows that starting from different landforms and their spatial planning zones, the land-use characteristics of different regions and their unique driving factors can be identified more precisely, avoiding the blurring of the overall scale. At the same time, it can provide local governments with a more specific policy basis so that they can formulate targeted land management and resource protection policies according to regional characteristics, making planning more adaptable and effectively improving resource use efficiency.

In this paper, the Yellow River Basin in Henan is examined at the scales of the whole area, geomorphology, and watershed radiation area, and this novel perspective can be extended to other basins as well. For example, the Yangtze River Basin in China [64], the Oder River Basin in Europe [65] and its Thames River Basin in the United Kingdom [66], all of which are ecologically sensitive areas. This perspective is important for ecological restoration under a multi-regional linkage system within a watershed. At the same time, however, there is still much room for improvement; for example, the multi-scale classification should be adapted to the characteristics of the study area and reflect the real situation in the study area. In the analysis of land use change, land use classification data with higher resolution and overall accuracy can be used if available. In terms of driving force analysis, more driving factors that are closely related to the study area can be selected, and at the same time, effective methods can be found to quantify factors such as government planning policies to reveal their potential impacts. In terms of driver analysis methods, multi-method analyses can be conducted to ensure the reliability of the results.

Acknowledgments

Department of Natural Resources of Henan Province Natural Resources Science and Technology Project [Yu Zhengcai (2) 20190450-7].

Conflict of Interest

The authors declare no conflict of interest.

References

1. EDWIN I.E., CHUKWUKA O., OCHEGE F.U., LING Q., CHEN B.J., NZABARINDA V., AJAERO C., HAMDI R., LUO G.P. Quantifying land change dynamics, resilience and feedback: A comparative analysis of the lake Chad basin in Africa and Aral Sea basin in Central Asia. Journal of Environmental Management. **361** (1), 121218, **2024**.
2. HU Y.F. DONG Y., BATU N. An automatic approach for land-change detection and land updates based on integrated NDVI timing analysis and the CVAPS method with GEE support. Isprs Journal of Photogrammetry and Remote Sensing. **146**, 347, **2018**.
3. HE C., ZHANG J., LIU Z., HUANG Q. Characteristics and progress of land use/cover change research during 1990-2018. Acta Geographica Sinica. **76** (11), 2730, **2021**.
4. NUNES C.E. Land use and land cover change implementation strategy. Stockholm, Sweden International Geosphere-Biosphere Programe, **1999**.
5. TURNER B.L., LAMBIN E.F., REENBERG A. The emergence of land change science for global environmental change and sustainability. Proceedings of the National Academy of Sciences of the United States of America. **104** (52), 20666, **2007**.
6. AHMED H.A., SINGH S.K., KUMAR M., MAINA M.S., DZWAIRO R., LAL D. Impact of urbanization and land cover change on urban climate: Case study of Nigeria. Urban Climate. **32**, 17, **2020**.
7. PANDE C.B., MOHARIR K.N., VARADE A.M., ABDO H.G., MULLA S., YASEEN Z.M. Intertwined impacts of urbanization and land cover change on urban climate and agriculture in Aurangabad city (MS), India using google earth engine platform. Journal of Cleaner Production. **422**, 18, **2023**.
8. PAN Y.S., ZHANG H.B., WANG CY., ZHOU Y.D. Impact of land use change on regional carbon sink capacity: Evidence from Sanmenxia, China. Ecological Indicators. **156**, 12, **2023**.
9. TANG X.J., WOODCOCK C.E., OLOFSSON P., HUTYRA L.R. Spatiotemporal assessment of land use/land cover change and associated carbon emissions and uptake in the Mekong River Basin. Remote Sensing of Environment. **256**, 13, **2021**.
10. WANG H.Y., WU L.S., YUE Y.S., JIN Y.Y., ZHANG B.B. Impacts of climate and land use change on terrestrial carbon storage: A multi-scenario case study in the Yellow River Basin (1992-2050)-2050). Science of the Total Environment. **930**, 12, **2024**.
11. BAO Z.X., ZHANG J.Y., WANG G.Q., CHEN Q.W., GUAN T.S., YAN X.L., LIU C.S., LIU J., WANG J. The impact of climate variability and land use/cover change on the water balance in the Middle Yellow River Basin, China. Journal of Hydrology. **577**, 13, **2019**.
12. NARANY T.S., ARIS A.Z., SEFIE A., KEESSTRA S. Detecting and predicting the impact of land use changes on groundwater quality, a case study in Northern Kelantan, Malaysia. Science of the Total Environment. **599**, 844, **2017**.
13. CAJAIBA R.L., PÉRICO E., DA SILVA W.B., VIEIRA T.B., DALZOCHIO M.S., BASTOS R., CABRAL J.A., SANTOS M. How informative is the response of Ground Beetles' (Coleoptera: Carabidae) assemblages to anthropogenic land use changes? Insights for ecological status assessments from a case study in the Neotropics. Science of The Total Environment. **636**, 1219, **2018**.
14. KOUFAKI T., BARBOUTIS C., THEODOROU K. Differential impact of climate and land use change on habitat suitability of migrant passerines according to habitat preferences. Anthropocene. **47**, 17, **2024**.
15. WU H.W., WU F., CAI Y.M., LI Z.H. Assessing the spatiotemporal impacts of land use change on ecological environmental quality using a regionalized territorial impact assessment framework. Sustainable Cities and Society. **112**, 13, **2024**.
16. ZHANG P., WANG Q., LIU Y., ZHANG J. Potential ecological risk assessment based on loss of ecosystem services due to land use and land cover change: A case study of Beijing-Tianjin-Hebei region. Applied Geography. **171**, 103389, **2024**.
17. JIANG W., YUAN L., WANG W., CAO R., ZHANG Y., SHEN W. Spatio-temporal analysis of vegetation variation in the Yellow River Basin. Ecological Indicators. **51**, 117, **2015**.
18. RU X.T., QIAO L.X., ZHANG H.P., BAI T.Q., MIN R.Q., WANG Y.B., WANG Q.F., SONG H.Q. Effects of land use and land cover change under shared socioeconomic pathways on future climate in the Yellow River basin, China. Urban Climate. **55**, 15, **2024**.
19. YANG S.T., LIU C.M., SUN R. The vegetation cover over last 20 years in Yellow River basin. Acta Geographica Sinica. **57** (6), 679, **2002**.
20. NIU H., XIU Z., XIAO D. Impact of land-use change on ecological vulnerability in the Yellow River Basin based on a complex network model. Ecological Indicators. **166**, 112212, **2024**.
21. ZHOU Z.C., GAN Z.T., SHANGGUAN Z.P., DONG Z.B. China's Grain for Green Program has reduced soil erosion in the upper reaches of the Yangtze River and the middle reaches of the Yellow River. International Journal of Sustainable Development and World Ecology. **16** (4), 234, **2009**.
22. CUI J., ZHU M.S., LIANG Y., QIN G.J., LI J., LIU Y.H. Land Use/Land Cover Change and Their Driving Factors in the Yellow River Basin of Shandong Province Based on Google Earth Engine from 2000 to 2020. Isprs International Journal of Geo-Information. **11** (3), 18, **2022**.
23. RONG T.Q., ZHANG P.Y., JING W.L., ZHANG Y., LI Y.Y., YANG D., YANG J.X., CHANG H., GE L.N. Carbon Dioxide Emissions and Their Driving Forces of Land Use Change Based on Economic Contributive Coefficient (ECC) and Ecological Support Coefficient (ESC) in the Lower Yellow River Region (1995-2018). Energies. **13** (10), 18, **2020**.
24. ZHOU X., WU D., LI J., LIANG J., ZHANG D., CHEN W. Cultivated land use efficiency and its driving factors in

the Yellow River Basin, China. Ecological Indicators. **144**, 109411, **2022**.
25. CHE X.C., JIAO L., QIN H.J., WU J.J. Impacts of Climate and Land Use/Cover Change on Water Yield Services in the Upper Yellow River Basin in Maqu County. Sustainability. **14** (16), 21, **2022**.
26. DU L.D., DONG C., KANG X.C., QIAN X.L., GU L.X. Spatiotemporal evolution of land cover changes and landscape ecological risk assessment in the Yellow River Basin, 2015-2020. Journal of Environmental Management. **332**, 16, **2023**.
27. QU Y.B., ZONG H.N., SU D.S., PING Z.L., GUAN M. Land Use Change and Its Impact on Landscape Ecological Risk in Typical Areas of the Yellow River Basin in China. International Journal of Environmental Research and Public Health. **18** (21), 26, **2021**.
28. REN S.M., ZHAO H., ZHANG H.L., WANG F.Q., YANG H. Influence of Natural and Social Economic Factors on Landscape Pattern Indices-The Case of the Yellow River Basin in Henan Province. Water. **15** (23), 25, **2023**.
29. DING J., JIANG Y., LIU Q., HOU Z.J., LIAO J.Y., FU L., PENG Q.Z. Influences of the land use pattern on water quality in low-order streams of the Dongjiang River basin, China: A multi-scale analysis. Science of the Total Environment. **551**, 205, **2016**.
30. JIA W.Q., GU X.F., MI X.F., YANG J., ZANG W.Q., LIU P.Z., YAN J., ZHU H., ZHANG X., ZHANG Z. Multi-Scale Spatiotemporal Pattern Analysis and Simulation (MSPAS) Model with Driving Factors for Land Cover Change and Sustainable Development Goals: A Case Study of Nepal. Remote Sensing. **14** (24), 25, **2022**.
31. ZHAO J.S., YUAN L., ZHANG M. A study of the system dynamics coupling model of the driving factors for multi-scale land use change. Environmental Earth Sciences. **75** (6), 13, **2016**.
32. BAI S., ZHANG Y., CHEN Y., ZHOU D. Exploration and Analysis of Ecological Restoration Planning Establishment at Provincial Level Territorial Space:A Case of Henan Province. Areal Research and Development. **42** (1), 38, **2023**.
33. RUAN X.F., QIU F., DYCK M. The effects of environmental and socioeconomic factors on land-use changes: a study of Alberta, Canada. Environmental Monitoring and Assessment. **188** (8), 31, **2016**.
34. ZHU Z.Q., LIU L.M., CHEN Z.T., ZHANG J.L., VERBURG P.H. Land-use change simulation and assessment of driving factors in the loess hilly region-a case study as Pengyang County. Environmental Monitoring and Assessment. **164** (1-4), 133, **2010**.
35. CHENG Y., CHEN Y. Spatial and Temporal Characteristics of Land Use Changes in the Yellow River Basin from 1990 to 2021 and Future Predictions. Land. **13** (9), 1510, **2024**.
36. ZHANG H., DENG W., WANG Y. Analyses on the spatio-temporal evolution and driving factors of land use in India during 2000-2020. World Regional Studies. **31** (4), 786, **2022**.
37. ZHANG W., LV X., SHI Y., SUN P., ZHANG Y. Graphic Characteristics of Land Use Transition in the Yellow River Basin. China Land Science. **34** (8), 80, **2020**.
38. ZHANG X., LIU L., CHEN X., GAO Y., XIE S., MI J. GLC_FCS30: global land-cover product with fine classification system at 30 m using time-series Landsat imagery. Earth System Science Data. **13** (6), 2753, **2021**.
39. LI J., DONG S., LI Y., YANG Y., TAMIR B. The pattern and driving factors of land use change in the China-Mongolia-Russia economic corridor. Geographical Research. **40** (11), 3073, **2021**.
40. ZHANG R., WANG Y., CHANG J., LI Y. Response of land use change to human activities in the Yellow River Basin based on water resources division. Journal of Natural Resources. **34** (2), 274, **2019**.
41. CHEN W., LI J., RAN D. On the Spatial elationship Between Land Use Transition and Urbanization in the Middle Yangtze River Urban Cluster. Resources and Environment in the Yangtze Basin. **28** (5), 1036, **2019**.
42. LI J.Y., ZHENG X.Q., ZHANG C.X., CHEN Y.M. Impact of Land-Use and Land-Cover Change on Meteorology in the Beijing-Tianjin-Hebei Region from 1990 to 2010. Sustainability. **10** (1), 22, **2018**.
43. WEI X., YANG J., LUO P., LIN L., LIN K., GUAN J. Assessment of the variation and influencing factors of vegetation NPP and carbon sink capacity under different natural conditions. Ecological Indicators. **138**, 108834, **2022**.
44. LI Z., LIU W., ZHENG F. The land use changes and its relationship with topographic factors in the Jing river catchment on the Loess Plateau of China. SpringerPlus. **2** (1), S3, **2013**.
45. PETERS M.K., HEMP A., APPELHANS T., BECKER J.N., BEHLER C., CLASSEN A., DETSCH F., ENSSLIN A., FERGER S.W., FREDERIKSEN S.B., GEBERT F., GERSCHLAUER F., GÜTLEIN A., HELBIG-BONITZ M., HEMP C., KINDEKETA W.J., KÜHNEL A., MAYR A.V., MWANGOMO E., NGEREZA C., NJOVU H.K., OTTE I., PABST H., RENNER M., RÖDER J., RUTTEN G., SCHELLENBERGER COSTA D., SIERRA-CORNEJO N., VOLLSTÄDT M.G.R., DULLE H.I., EARDLEY C.D., HOWELL K.M., KELLER A., PETERS R.S., SSYMANK A., KAKENGI V., ZHANG J., BOGNER C., BÖHNING-GAESE K., BRANDL R., HERTEL D., HUWE B., KIESE R., KLEYER M., KUZYAKOV Y., NAUSS T., SCHLEUNING M., TSCHAPKA M., FISCHER M., STEFFAN-DEWENTER I. Climate–land-use interactions shape tropical mountain biodiversity and ecosystem functions. Nature. **568** (7750), 88, **2019**.
46. GUO Y.J., CHENG L.R., DING A.Z., YUAN Y.M., LI Z.Y., HOU Y.Z., REN L.S., ZHANG S.R. Geodetector model-based quantitative analysis of vegetation change characteristics and driving forces: A case study in the Yongding River basin in China. International Journal of Applied Earth Observation and Geoinformation. **132**, 15, **2024**.
47. WANG J.F., XU C. Geodetector: Principle and prospective. Acta Geographica Sinica. **72** (1), 116, **2017**.
48. ZHU M., YU X., CHEN K., TAN H., YUAN J. Spatiotemporal characteristics and driving factors of chemical oxygen demand emissions in China's wastewater: An analysis based on spatial autocorrelation and geodetector. Ecological Indicators. **166**, 112308, **2024**.
49. DU Z., YU L., CHEN X., GAO B., YANG J., FU H., GONG P. Land use/cover and land degradation across the Eurasian steppe: Dynamics, patterns and driving factors. Science of The Total Environment. **909**, 168593, **2024**.
50. RAN Q.W., HAO Y.B., XIA A.Q., LIU W.J., HU R.H., CUI X.Y., XUE K., SONG X. N., XU C., DING B.Y., WANG Y.F. Quantitative Assessment of the Impact of Physical and Anthropogenic Factors on Vegetation Spatial-Temporal Variation in Northern Tibet. Remote Sensing. **11** (10), 22, **2019**.

51. WANG J.F., HU Y. Environmental health risk detection with GeogDetector. Environmental Modelling & Software. **33**, 114, **2012**.
52. WANG J.F., LI X.H., CHRISTAKOS G., LIAO Y.L., ZHANG T., GU X., ZHENG X.Y. Geographical Detectors-Based Health Risk Assessment and its Application in the Neural Tube Defects Study of the Heshun Region, China. International Journal of Geographical Information Science. **24** (1), 107, **2010**.
53. GUO P., ZHANG F., WANG H. The response of ecosystem service value to land use change in the middle and lower Yellow River: A case study of the Henan section. Ecological Indicators. **140**, 109019, **2022**.
54. NIU H.P., ZHAO X.M., XIAO D.Y., LIU M.M., AN R., FAN L.X. Evolution and Influencing Factors of Landscape Pattern in the Yellow River Basin (Henan Section) Due to Land Use Changes. Water. **14** (23), 27, **2022**.
55. WANG X.W., CHENG H. Dynamic changes of cultivated land use and grain production in the lower reaches of the Yellow River based on GlobeLand30. Frontiers in Environmental Science. **10**, 17, **2022**.
56. SEN G., BAYRAMOGLU M.M., TOKSOY D. Spatiotemporal changes of land use patterns in high mountain areas of Northeast Turkey: a case study in Macka. Environmental Monitoring and Assessment. **187** (8), 14, **2015**.
57. UPTON V., O'DONOGHUE C., RYAN M. The physical, economic and policy drivers of land conversion to forestry in Ireland. Journal of Environmental Management. **132**, 79, **2014**.
58. XIE H.L., LIU Z.F., WANG P., LIU G.Y., LU F.C. Exploring the Mechanisms of Ecological Land Change Based on the Spatial Autoregressive Model: A Case Study of the Poyang Lake Eco-Economic Zone, China. International Journal of Environmental Research and Public Health. **11** (1), 583, **2014**.
59. KLEEMANN J., BAYSAL G., BULLEY H.N.N., FURST C. Assessing driving forces of land use and land cover change by a mixed-method approach in north-eastern Ghana, West Africa. Journal of Environmental Management. **196**, 411, **2017**.
60. DI X.H., HOU X.Y., WANG Y.D., WU L. Spatial-temporal Characteristics of Land Use Intensity of Coastal Zone in China During 2000-2010. Chinese Geographical Science. **25** (1), 51, **2015**.
61. LU L., GUO L., ZHAO S.T. Land use and land cover change on slope in Qiandongnan prefecture of Southwest China. Journal of Mountain Science. **11** (3), 762, **2014**.
62. SHUI W., XU G.W. Analysis of the influential factors for changes to land use in China's Xingwen Global Geopark against a tourism development background. Geocarto International. **31** (1), 22, **2016**.
63. LI H.Y., ZHU M.Y., WANG Z.J., HONG J.R., WANG Y. Synergy level of urban resilience and urban land use efficiency in the Yellow River Basin: Spatial-temporal evolution characteristics and driving factors. Heliyon. **10** (10), 15, **2024**.
64. YANG H.F., ZHOU H., DENG S.Q., ZHOU X., NIE S.A. Spatiotemporal Variation of Ecosystem Services Value and its Response to Land Use Change in the Yangtze River Basin, China. International Journal of Environmental Research. **18** (2), 21, **2024**.
65. DE ROO A., SCHMUCK G., PERDIGAO V., THIELEN J. The influence of historic land use changes and future planned land use scenarios on floods in the Oder catchment. Physics and Chemistry of the Earth. **28** (33-36), 1291, **2003**.
66. WHITEHEAD P.G., CROSSMAN J., BALANA B.B., FUTTER M.N., COMBER S., JIN L., SKURAS D., WADE A.J., BOWES M.J., READ D.S. A cost-effectiveness analysis of water security and water quality: impacts of climate and land-use change on the River Thames system. Philosophical Transactions of the Royal Society A-Mathematical Physical and Engineering Sciences. **371** (2002), 16, **2013**.