Past and future of land use change in the Middle reaches of the Yellow River Basin in China

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Abstract

When looking at maps of land use land cover (LULC) change, often derived from satellite imagery, China's increasing urban construction and decreasing cultivated land area can be identified. Using the middle reaches of the Yellow River Basin in China as the case study, the present work focuses on (i) identifying historical LULC change in the period 1995–2020; (ii) estimating LULC in the next ten years, combining Geographical Information Systems (GIS) with Markov model. Landsat 5/8 images were combined with field evidence to map LULC in three reference years (1995, 2005, 2015and2020), while the Markov model was applied to forecast LULC in 2025, and 2030.The LULC of the middle reaches of the Yellow River Basin was classified into six classes: forest, grassland, wetland, cultivated land, construction land and unused land. The results show that over the past 25 years, cultivated land and forest land have decreased by 8,600 km^2 and 6,400 km^2, respectively, while construction land has increased by 7,500 km^2, mainly due to increased urbanization and industrialization. In fact, during the simulated 2020–2030 period, cultivated land and forest land will continue to decrease, while construction land and grassland will increase. It is worth noting that the reduction of forest land will lead to increased soil erosion, while the reduction of cultivated land will lead to food security problems. The study points out that there is an urgent need for response measures in the region to ensure the sustainability of people and nature.

1. Introduction

Land Use and Land Cover Changes (LULC) is the most closely related issue between man and nature, and it is a direct manifestation of the relationship between man and land [1]. The spatial pattern of the earth's surface features has been changed by humans, and this activity has been objectively recorded by LULC. Changes in LULC are closely related to the following factors: worldwide weather, species decline, the safety of the ecological environment and the continuity of life between humans and nature, etc. [2, 3]. Two major international organizations, IGBP (International Geosphere-Biosphere Program) and IHDP (Global Change Human Factors Program) jointly proposed the "Land Use/Cover Change" (LULC) scientific research program in 1995, and positioned this research as a global key content of change [4]. Taking this as an opportunity, in order to emphasize the ensemble and simulation research of human and environmental coupling on land, GLP (Global Land Program) was launched in 2005, further making LULC research a core field and hotspot of global change research and land science research subject [5–7]. Previous LULC studies in many representative areas can help us understand the changing characteristics of LULC, so as to more scientifically explain the relationship between human activities on LULC and the mutual influence between LULC and nature [8].

The use of long time series is very important for land use change research and forecasting for future land management, and long time series is often used as a study of human impacts on land use change [9, 10]. Trend analysis of land-use change is helpful for land-use modeling, as past land-use changes often represent human impacts on land [10, 11]. In order to predict the future land use change more accurately and scientifically, the establishment of the model needs to be calibrated and verified. The following techniques are used in this paper: Radiometric Correction, Geometric correction, Image Fusion, Mosaicking, Gram-Schmidt Pan Sharpening(GS), FLUS-Markov,ect.

The rational use of land is a prerequisite for ensuring that human beings can carry out normal production and life. The purpose of LULC is to more thoroughly understand the continuous variation of LULC in the region, and its essence is to explain the interaction between people and the environment. In some developing countries and

Africa, there are few studies on comprehensive evaluation of the driving force analysis and results of land use change [12, 13]. Research in recent years has mainly focused on some underdeveloped areas in Asia and Africa, and the results have shown that land cover has decreased due to population growth, economic development, and globalized human activities [14–20]. Until recently, some scholars have begun to try to link land use change with related functions such as ecological services, in order to provide some policy services [21–23]. Combined with previous scholars' research on land use change and prediction in the Yellow River Basin, the research in this paper can provide some scientific basis for land use change in the middle reaches of the Yellow River Basin.

In fact, the LULC intensity and rate in the middle reaches of the Yellow River Basin continue to change dynamically and are closely related to the overexploitation of natural resources, which is influenced by climate, soil characteristics, vegetation, precipitation and natural disasters [24–27]. LULC changes have accelerated considerably over the past few decades due to increased human demand for natural resources. In the middle reaches of the Yellow River Basin, the change of LULC is continuous, and its agricultural development and urban construction are dominant [28, 29].

Focusing on the middle reaches of the Yellow River Basin in China, this paper aims to: (i) understand the changes in land use in the region in the past 25 years (1995–2020); (ii) predict the possible land use in the next ten years (2020–2030). The paper mainly uses satellite images and model establishment to study the research area, and at the same time supports the reliability of the research through field investigation and other evidence. The study area and method used will be described in Section 2, and the results are presented in Section 3. In Section 4, mainly discusses the impact of existing policies on land use, and the direction of possible future land use changes. Section 5 summarizes the main outcomes of the study and its limitations.

2. Materials And Methods

2.1Study Area

The middle reaches of the Yellow River Basin are located between Hekou Town in Inner Mongolia Autonomous Region and Huayuankou in Zhengzhou City (Fig. 1). The dimensions are from 32° to 42° north latitude and 104° to 113° east longitude. The total length of the river reaches 1206.4km, and the basin area is 363,000km2 and covers about 46% of the total area of the Yellow River Basin. The terrain of the middle Yellow River Basin is generally high in the northwest and low in the southeast. This area belongs to the semi-arid region of the middle temperate zone and warm temperate zone. The precipitation is mainly concentrated in summer and mainly in the form of heavy rain. The average annual precipitation varies from 320mm in the northwest to 840mm in the southwest [30], of which 6–9 The monthly precipitation accounts for about 70% of the annual precipitation, and the heaviest precipitation from July to August can account for more than 40% of the total annual precipitation.

2.2Datast

The data used in the study are free satellite imagery and Digital Elevation Models (DEMs) at 30m resolution.Landsat-5TM(L5,for the years 1995 and 2005)and Landsat-8OLI (L8, for the years 2015and2020) data were downloaded from the Geospatial Data Cloud Platform(http://www.gscloud.cn). The image selection is concentrated in the months of June to September, when the local vegetation is lush, which is convenient for different types of land use. Since the precipitation is mainly concentrated in these months, the image has been atmospherically corrected. In order to cover whole area, a composite of Landsat images from different paths/rows was created, ensuring that the images refer to the same season (Table 1).

Table 1
Details of the Landsat images that were analyzed in the study

Satellite	Year	Acquisition Date	Path/Row	Spatial Resolution
Landsat5 TM	1995	June 29	130/35	30m
		June 8	127/35	30m
		June 26	125/35	30m
		June 1	126/34	30m
Landsat5 TM	2005	July 5	127/34	30m
		June 12	126/35	30m
		June 8	125/35	30m
Landsat 8 OIL	2015	August 13	124/35	30m
		July 6	130/36	30m
		July 15	129/36	30m
		July 24	128/36	30m
		July 1	127/36	30m
Landsat 8 OIL	2020	September 7	128/34	30m
		September 18	125/34	30m
		September 18	125/35	30m

2.3Land Use Land Cover Classification of Historical Data

To map LULC, satellite images should be classified, assigning predefined LULC classes to some pixels. In this phase could be affected by various factors such as classification methods, algorithms, collecting of training sites, and the correctness of the classification should be assessed via field evidence [31–33].

The study was performed by classifying four reference years (1995, 2005, 2015and 2020) and considering six LULC classes. The selection of these classes was performed based on past studies [34], based on this, the Middle of the Yellow River Basin was classified into six classes, namely forest, grassland, wetland, cultivated land, construction land, unused land (Table 2).

Table 2
Land Use Land Cover classes and their description

LULC Classes	Description
forest	area to the land where trees, bamboos, and shrubs grow, and the land where mangroves grow along the coast
grassland	area to the land that grows mainly herbaceous plants
wetland	area to the land where the surface is too wet or often accumulates water and grows wetland organisms
cultivated land	area to the land on which crops are grown
construction land	area to the land on which buildings and structures are constructed
unused land	area to unused land

In the classification process, some plots with similar spectral characteristics are merged, so the accuracy of the results needs to be verified. Select 55 live points (10 forests, 10 grasslands, 10 wetlands, 10 cultivated land, 10 construction land, and 5 unused land) in the L8 image in 2020 for verification with the help of auxiliary tools (Google Earth, etc.), The points are evenly distributed over the study area to ensure their accuracy. To quantitatively assess the accuracy, statistical methods kappa value were applied[35, 36]. P_a is the ratio of the number of simulated correct grids to the total number, P_b is the ratio of the number of simulated correct grids to the total number in a random state, and 1 is the ratio of the number of simulated correct grids to the total number in an ideal state. Among them, when Kappa > 0.8, it means that the simulation effect is good and the degree of consistency is extremely high; when 0.6 < Kappa ≤ 0.8, it means that the simulation effect is good and the degree of consistency is good; when 0.4 < Kappa ≤ 0.6, it means that the simulation results are better Poor; when Kappa ≤ 0.2, it means the simulation effect is extremely poor[37].

$$Kappa = \frac{P_a - P_b}{1 - P_b}$$

2.4. Prediction of Future LULC

To map future LULC scenarios, the Markov model projection is performed by creating matrixes to estimate the transition probability and the area of each LULC class for future dates[38, 39].Markov model was applied to forecast the future LULC in two scenarios (2025 and 2030), via a few main steps: (i) analysis of historical LULC maps (1995, 2005, 2015and2020) and associated changes, (ii) creation of transition probability matrixes, (iii) model validation, (iv) prediction of future LULC maps, accounting for possible driving forces. In this work, we define the probability transitional matrix as a matrix showing the transfer direction of LULC types from one category to other categories in a given year [40].

To evaluate the capability of Markov model in predicting future LULC, a predicted map of 2015was created based on 1995 and 2005 LULC, and then compared with the actual 2015 map. To evaluate the quality of the 2015 predicted map against the 2015 reference map, the ANN model validation module was used [41], mimicking the approach proposed in similar studies [42]. In ANN model, two tools are available to assess the fit of the model to the sample data. First, the cross-validation tool iteratively removes a sample data point and interpolates a new value for the location. A table is produced to show the difference between the predicted attributes and the known attributes at those locations. Second, a variance image is produced that shows the spatial variation of uncertainty as a result of the fitted model. The variance image provides information to assist in identifying the problem areas where the relationship between the fitted model and the sample data points is poor.

3. Result

3.1. Historical LULC Maps

Four reference years (1995, 2005, 2015and 2020) were considered to evaluate historical LULC via a maximum likelihood supervised classification (Fig. 2). As reported in Table 3, forests, grasslands, wetlands, cultivated land, construction land and unused land in the middle reaches of the Yellow River showed the same quantitative distribution, which were cultivated land > grassland > forest land > construction land > wetland > unused land. Exactly, in 1995 most of the study area was covered by agriculture (38.8%), glass (36.9%)and forest (17.8%), with only a very minor part occupied by wetland (1.59%). Similar LULC was observed in 2005, with agriculture (38.4%), glass (34.7%)and forest (19.7%), being the most dominant LULC classes and just a small increase in the area covered by wetland (1.62%). In 2015 and 2020, the class distribution remained similar, with an increase the built-up area from 2.84–4.48%.

Table 3
Details of LULC area of the Middle reaches of the Yellow River Basin in the four reference years

LULC Type	1995		2005		2015		2020	
	[km^2]	[%]	[km^2]	[%]	[km^2]	[%]	[km^2]	[%]
forest	64512.25	17.76	71567.32	19.71	71855.36	19.78	71830.07	19.78
grassland	133957.09	36.88	125799.58	34.64	127892.23	35.21	127499.71	35.11
wetland	5774.89	1.59	5881.00	1.62	5041.98	1.39	5310.46	1.46
cultivated land	141136.05	38.86	139425.56	38.39	134666.17	37.08	132487.64	36.48
construction land	8725.67	2.40	10330.94	2.84	14587.39	4.02	16272.98	4.48
unused land	9078.44	2.50	10179.99	2.80	9141.26	2.52	9783.53	2.69
Total	363184.39	100.00	363184.39	100.00	363184.39	100.00	363184.39	100.00

To sum up, in the past, the main LULC in the study area were cultivated land and grassland, followed by forest land. In the past two decade, the construction land in the middle reaches of the Yellow River Basin has continued to increase, nearly doubling the amount, while the cultivated land has continued to decrease, decreasing by nearly 8,600km^2.

The results reported in Fig. 2 are in agreement with Xu et al. [43], who pointed out that the Middle reaches of the Yellow River Basin is characterized by an expansion of built-up LULC, resulting in a decline of natural vegetation and agriculture land.

3.2 Historical LULC Changes and Transition Probability Matrix

Comparing the four reference years, it is possible to observe a considerable reduction in the area covered by glass and cultivated during the observation period (Table 4). Specifically, about 258km^2 of grassland and 346 km^2 of agricultural land are converted to other types of LULC each year. The mutual transformation of various types of plots can be seen from Fig. 3:

Table 4
Historical LULC changes in the Middle reaches of the Yellow River Basin

LULC class	**1995–2005**			**2005–2015**		
	area(km^2)	**area(%)**	**change(km^2/year)**	**area(km2)**	**area(%)**	**change(km^2/year)**
forest	7055.07	0.11	705.51	288.04	0.00	28.80
grassland	-8157.51	-0.06	-815.75	2092.65	0.02	209.26
wetland	106.11	0.02	10.61	-839.02	-0.14	-83.90
cultivated land	-1710.49	-0.01	-171.05	-4759.39	-0.03	-475.94
construction land	1605.27	0.18	160.53	4256.45	0.41	425.65
unused land	1101.55	0.12	110.16	-1038.73	-0.10	-103.87
LULC class	2015–2020			1995–2020		
	area(km^2)	area(%)	change(km^2/year)	area(km2)	area(%)	change(km^2/year)
forest	-25.29	-0.00	-5.06	7317.82	0.11	292.71
grassland	-392.52	-0.00	-78.50	-6457.38	-0.05	-258.30
wetland	268.48	0.05	53.70	-464.43	-0.08	-18.58
cultivated land	-2178.53	-0.02	-435.71	-8648.41	-0.06	-345.94
construction land	1685.59	0.12	337.12	7547.31	0.86	301.89
unused land	642.27	0.07	128.45	705.09	0.08	28.20

During the period from 1995 to 2005, the decrease of grassland mainly turned to forest, cultivated land and unused land. The increase of grassland also came from forest, cultivated land and unused land, but the decrease was greater than the increase; the forest was mainly converted to grassland and cultivated land; Wetlands were mainly converted to cultivated land; during this period, construction land mainly came from cultivated land, and 2100 km² of cultivated land was converted into construction land, but only 800 km² of cultivated land was converted into construction land, and 100km² of unused land was converted into arable land;

From 2005 to 2015, the conversion of grassland to forest, wetland, cultivated land and unused land decreased, but the conversion of grassland to construction land increased, from 357 km² to 1140 km²; forest It was mainly converted to grassland and cultivated land, but the conversion rate decreased compared with 1995–2005; the reduction of wetland was mainly converted to construction land and cultivated land; as in 1995–2005, construction land mainly came from cultivated land in 2005–2015. During the period, 3700km² of cultivated land was converted into construction land, but only 1300 km² of construction land and unused land was converted into cultivated land;

From 2015 to 2020, the conversion of grassland to cultivated land decreased; the increase in construction land also mainly came from cultivated land. During this period, 2200 km² of cultivated land was converted into construction land, and 1400 km² of construction land and unused land was converted into cultivated land. Compensation is still unbalanced, but compared with 2005–2015, the unbalanced gap has decreased.

In conclusion, during the period from 1995 to 2020, the number of forests, grasslands, and construction land showed an upward trend, while the number of wetlands, cultivated land, and unused land showed a downward trend. The increase in the number of forests and grasslands mainly comes from three sources. One is the mutual transformation of the two. The second is the conversion of cultivated land to forest and grassland, and the third is the comprehensive improvement of part of the unused land; the increase of construction land is mainly from cultivated land and grassland; the decrease of wetland is mainly to cultivated land and grassland.

3.3 Model Validation

The LULC map of 2015, predicted from the 1995 and 2005 data, has been validated with the classified LULC map of the very same year (Table 5), showing that the Markov model can effectively forecast LULC changes.

Table 5
LULC classes in 2015: projected vs classified values

LULC Type	Projected LULC		Classified LULC	
	area[km^2]	percentage[%]	area[km^2]	percentage[%]
forest	71002.55	19.55	71855.36	18.78
grassland	120431.94	33.16	127892.23	35.21
wetland	4285.58	1.18	5041.98	1.39
cultivated land	138409.57	38.11	134666.17	37.08
construction land	19357.73	5.33	14587.39	5.02
unused land	9697.02	2.67	9141.26	2.52
Total	363184.39	100.00	363184.39	100.00

Based on the real 2015 remote sensing interpretation data, the simulated LULC data in 2015 was compared and analyzed (Fig. 4). The results showed that the Kappa coefficient was 0.806, greater than 0.8, and the overall accuracy was 0.865, indicating that the model has high simulation accuracy and can be Conduct multi-scenario simulations of LULC in the middle reaches of the Yellow River in 2025 and 2030.

3.4. Future LULC

The multi-scenario simulation of LULC in the Middle reaches of the Yellow River is based on the remote sensing interpretation data in 2015 and 2020, and the Markov model is used to simulate the number of LULC in 2025 and 2035; On this basis, the FLUS model is used to conduct multi-scenario simulations of LULC in the middle reaches of the Yellow River in 2025 and 2035; Combined with the simulation results, the changes in the number of LULCs in the middle reaches of the Yellow River, the mutual transfer trend and spatial distribution of LULCs were analyzed.

By analyzing the data of the four reference years, predict the number of LUCCs in 2025 and 2030, and make a graph of changes in the number (Fig. 5); Using the FLUS model, the number of simulated LULCs is allocated under four different scenarios: production space priority, living space priority, ecological space priority, and comprehensive space optimization (Figs. 6 and 7); at the same time, ENVI was used to analyze the land type transfer of the LULC data in the middle reaches of the Yellow River under the comprehensive spatial optimization scenarios in 2020, 2025, and 2030, and the chord diagrams of the LULC transfer in the middle reaches of the Yellow River from 2020 to 2025 and 2025 to 2030 were obtained (Fig. 8).

To sum up, the increase of cultivated land and grassland in 2020–2025 is due to the decrease of each other, and the two are transformed into each other. The conversion of grassland is the same as that in 2020–2025. The increase in construction land still comes from the decrease in cultivated land, the difference is that a small amount of construction land is converted into cultivated land.

4. Discussion And Policy Implications

As suggested in the review carried out by Wang et al. [44], most of the studies of LULC in the Yellow River Basin are on a local scale, analyzing the soil salinization and water pollution a series of ecological and environmental problems, such as serious damage to wetland resources protection and threats to wetland resource protection. This is mainly due to the large scope of the middle reaches of the Yellow River Basin and the difficulty of LULC classification, which makes it difficult to conduct LULC research as a whole. So, very few works tried to forecast future LULC changes at the watershed scale, eventually providing new insights that can be useful for developing future basin-wide management strategies. This study was developed to fill this gap, estimating the Middle reaches of the Yellow River Basin LULC for the next decade (2025, and 2030) based on past information (LULC in 1995, 2005, 2015and 2020), to infer trends to be used in multiple ways. Markov model results point out that, in the coming decade, significant changes in LULC should be expected, mostly because of the ever-increasing pressure of humans in need of more land for construction. In fact, due to the rapid economic development and urbanization in China in recent years, a large amount of cultivated land and grassland has been lost in the middle reaches of the Yellow River [45].

The continuous reduction of cultivated land in the study area pointed out in this study is consistent with the results of previous studies [46–49]. This trend is an inevitable result of China's rapid industrialization and urbanization, such as the 2000 Western Development Strategy, etc. Artificial surfaces occupy a large amount of cultivated land and transform to other LULC types [50–52]. Due to the rapid pace of urbanization, people need more land to build residential sites, which leads to the shift of cultivated land in the study area to the type of construction land. With the continuous reduction of arable land, policy makers realized that in order to ensure food security, the first thing to do is to ensure that the area of arable land cannot be reduced, so they have launched a series of land remediation projects, such as the reclamation of abandoned industrial and mining areas, which can increase the area of arable land. At the same time, urban construction is also developing towards the direction of land intensification, which can effectively alleviate the contradiction between people and land.

For the process and causes of grassland degradation in the middle reaches of the Yellow River Basin, scholars at home and abroad have done a lot of research and analysis. Most scholars believe that natural and human factors are the main causes of grassland degradation. Among the natural factors, climatic factors have the greatest impact on grassland, and a large number of studies have shown that temperature, precipitation, and evaporation are important factors affecting grassland degradation in the middle reaches of the Yellow River [53]. The impact of rodents on the degradation of natural grasslands is mainly reflected in competition with livestock for food, especially when the sand, gravel and soil produced during burrowing and burrowing bury pastures. Erosion [54–57]. With the increase of the population in the study area, the one-sided pursuit of the number of livestock without considering the slaughter rate intensified, resulting in the number of livestock in the area exceeding the carrying capacity of the grassland, the quality of which was deteriorated, and the degradation degree of the degraded and desertified grassland was further aggravated.

The middle reaches of the Yellow River Basin have a large scope, spanning many provinces and cities, and the large differences in natural conditions and geographical locations make it have a greater impact on the changes of LULC in national policies. The land types and ecological environment of the Yellow River Basin are constantly being developed and used, resulting in increasingly tight resources and a sharp drop in ecological carrying capacity, which degrades the ecological environment and threatens ecological security. In addition, the provinces and cities in the Yellow River Basin have developed an extensive and solidified development model, which has caused irreversible damage and consumption to the ecology. This industrial development model has caused the ecological environment of the Yellow River Basin to degrade to a certain extent. In response to the deteriorating environment, China implemented the policy of returning farmland to forest in 1999, and promulgated the policy of soil and water conservation in 2012. In the previous paragraph, national leaders put forward the concept of promoting ecological protection and high-quality development in the Yellow River Basin. This series of policies or opinions aims to protect the ecological environment of the Yellow River Basin and enable LULC to achieve sustainable development.

5. Conclusions

The present study investigated the historical LULC (years 1995, 2005,2015 and 2019) in the middle reaches of the Yellow River Basin via a combination of satellite imagery and field support data. Based on such analysis, the Markov Model was applied to forecast LULC over the next decade (years 2015and 2030). The 2015 LULC map was used for validating the Markov Model (Fig. 4), comparing the forecast situation with the actual one derived from satellite images, indicating that the used Markov model has enough capability to predict future LULC.

In the middle reaches of the Yellow River, woodland, grassland, cultivated land, and wetlands have been transformed into each other. Most of the construction land is the transferee, and the occupation and compensation of cultivated land are not balanced. The transfer analysis of LULC in the middle reaches of the Yellow River from 1995 to 2030 found that there was mutual transformation among the four land types, namely forest land, grassland, cultivated land and wetland, and the transformation situation was relatively complex (Figs. 3 and 8). Among them, cultivated land and grassland were transformed into forests. The phenomenon is more obvious, and the forest will hardly transform to other LULC in the next ten years; among them, the conversion of cultivated land and grassland to forest is more obvious, and the forest will hardly be converted to other LULC in the next ten years; wetlands may be degraded into grassland and cultivated land in the next ten years; The cultivated land occupied by land use has not been fully supplemented, resulting in the phenomenon of unbalanced cultivated land occupation and compensation.

The change trend of forest and grassland in the middle reaches of the Yellow River takes 2005 as the node, and the wetland takes 2015 as the change node (Fig. 5). The trend of changes in the number of forests and grasslands takes 2005 as the node. Before 2005, there was a large increase or decrease. After 2005, the changes in the number of forests and grasslands were not significant; the change in the number of wetlands and unused land from 1995 to 2030. Consistent, the change nodes are all in 2015, and since 2015, the change trend of the two has turned to an upward trend.

The changes of LULC are jointly affected by social, economic, policy, natural and other factors. Population growth and economic development are inseparable from the expansion of construction land, and related policies such as land use control, ecological protection, and cultivated land red lines will control the occupation of construction land by other types of land, coupled with the constraints of natural factors such as topography, climate, and hydrology, the spatial distribution of various LULC in a region does not change much over time as a whole.

Declarations

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References

1. Li, X.B.A review of the international researches on Land use/Land cover change. Acta geograohica sinica, 1996,51(6),553-558.
2. Kenea, U., Adeba, D., Regasa, M.S., Nones, M. Hydrological Responses to Land Use Land Cover Changes in the Fincha'a Watershed, Ethiopia. Land 2021, 10, 916.
3. Khan, T.U., Mannan, A., Hacker, C.E., Ahmad, S., Amir Siddique, M., Khan, B.U., Luan, X. Use of GIS and Remote Sensing Datato Understand the Impacts of Land Use/Land Cover Changes (LULCC) on Snow Leopard (Panthera uncia) Habitat in Pakistan. Sustainability 2021, 13, 3590.
4. Lambin, E. F., Baulies, X., Bockstael, N. Land-use and land-cover change (LUCC): Implementation strategy//A Core Project of the International Geospere-Biosphere Programme and the International Human Dimensions

Programme on Global Environmental Change. Stockholm: IGBP Report 48. IHDP Report 10. 1995.

5. McMahon, B.G., Benjamin, S. P., Clarke, K., Findley, J.E., Fisher, R.N., Graf, W.L., Gundersen, L.C., Jones, J.W., Loveland, T.R., Roth, K.S. Geography for a changing world: A science strategy for the geographic research of the U.S. Geological Survey, 2005-2015, Sioux Falls. SD: U.S. Geological Survey Circular,2005(1281):1-76.
6. Rindfuss, R.R., Walsh, S.J., Turner, B. L., Fox, J., Mishra, V. Developing a science of land change: Challenges and methodological issues. PNAS,2004(101): 13976-13981.
7. Turner, B. L., Robbins, R. Land-change science and political ecology: Similarities differences, and implications for sustainability science. Annual Review of Environment and Resources,2008(33): 295-316.
8. Zong, W. Research on Land use/Land cover Chang and driving forces mechanism in coastal zone in Shang, East China Normal University, SH, China,2012.
9. Opelele, O.M.,Fan, W.Y.,Yu,Y.,Kachaka,S.K. Analysis of Land use/Land cover change and its prediction in the Mambasa sector democratic pepublic of Congo. Applied ecology and environmental research. 2020,18(4), 5627-5644.
10. Han, H., Yang, C., Song, J. Scenario simulation and the prediction of land use and land cover change in Beijing, China. Sustainability2015, 7, 4260–4279.
11. Rahman, M.T.U., Tabassum, F., Rasheduzzaman, M., Saba, H., Sarkar, L., Ferdous, J., Islam, A.Z. Temporal dynamics of land use/land cover change and its prediction using CA-ANN model for southwestern coastal Bangladesh. Environ. Monit. Assess.2017, 189, 565.
12. Reid, R.S., Kruska, R.L., Muthui, N., Taye, A., Wotton, S., Wilson, C.J., Mulatu, W. Land-use and land-cover dynamics in responseto changes in climatic, biological and socio-political forces: The case of southwestern Ethiopia. Landsc. Ecol. 2000, 15, 339–355.
13. Govender, T., Dube, T., Shoko, C. Remote sensing of land use-land cover change and climate variability on hydrological processesin Sub-Saharan Africa: Key scientific strides and challenges. Geocarto Int. 2022, 1–25.
14. Li, Z., Wang, J., Bai, Z.K., Guo, Y.Q., Y.L. Land Use and Ecosystem Service Values and Their Grey Forecast in Guizhou Province. Progress in geography, 2012,31(05):577-583.
15. Li, Y.W., Li, C.L., Liu, J., Yin, S., Bao, Y.H., Alatengtuya. The dynamic change characteristic of land desertification in recent 20years taking Xilinguole League as case study. Soil and Fertilizer sciences in China, 2015,5,1-6.
16. Soffianian, A., Madanian, M. Monitoring land cover changes in Isfaha n Province, Iran using Landsat satellite data Environmental Monitoring and Assessment. Monit. Assess, 2015,187 (543),1-15.
17. Woldesenbet, T. A., Elagib,N.A., Ribbe, L., Heinrich, J. Catchment response to climate and land use changes in the Upper Blue Nile sub-basins, Ethiopia. Science of The Total Environment, 2018,644,193-206.
18. Wang, C.P. Analysis on Dynamic Change of Desertification Land and Driving Forces in the Middle Area of Kubuqi Desert. Forest resources management, 2018(01):63-71.
19. Nayak, S., Mandal, M. Impact of land use and land cover changes on temperature trends over India.Land Use Policy, 2019,89,104238.
20. Ji, Q.L., Liang, W., Fu, B.J., Lv, Y. H., Yan J.W., Zhang, W.B., Jin, Z., Lan, Z.Y. Land use/cover change in the Yellow River Basin based on Google Earth engine and complex network. Acta geograohica sinica, 2022,42(06):2122-2135.
21. Shiferaw, H., Bewket, W., Alamirew, T., Zeleke, G., Teketay, D., Bekele, K., Eckert, S. Implications of land use/land cover dynamicsand Prosopis invasion on ecosystem service values in Afar Region, Ethiopia. Sci. Total

Environ. 2019, 675, 354–366.

22. Biratu, A.A., Bedadi, B., Gebrehiwot, S.G., Melesse, A.M., Nebi, T.H., Abera, W., Egeru, A. Ecosystem Service Valuation alongLandscape Transformation in Central Ethiopia. Land 2022, 11, 500.
23. Sahle, M., Saito, O., Fürst, C., Demissew, S., Yeshitela, K. Future land use management effects on ecosystem services underdifferent scenarios in the Wabe River catchment of Gurage Mountain chain landscape, Ethiopia. Sustain. Sci. 2019, 14, 175–190.
24. Wang, W.S., Ma, Q.X., Zhang, J.C., Li, G.J. Spatial distribution of air pollutants in the middle reaches of the Yellow River Basin in winter 2015—2019. Bulletin of Surveying and Mapping, 2021(10):39-47.
25. Wang, G.Q., Li, T.J., Li, J.Y., Wei, J.H., Zhong, D.Y. Analysis of Sky Water Resources in the Source Region and the Upper-Middle Region of the Yellow River Basin. Yellow River, 2016,38(10):79-82.
26. Song, W.L., Gu, W., Liu, Y.J., Liu, C.Z. Characteristics of anomalous sign and prediction of Summer precipitation in the Middle reaches of Yellow River. Meteorological Monthly, 2013,39(09):1204-1209.
27. Luo, L., Wang, Z.J., Liu, X.Y., Zhang, X.C. Changes in characteristics of precipitation in flood season over five typical basins of middle reaches of the Yellow River in China. Journal of Hydraulic Engineering, 2013,44(07):848-855.
28. Shi, T. The Analysis of the Spatiotemporal Evolution and Driving Factors of Urban Resilience in Yellow River Basin. Regional Economic Review, 2022,01:139-149.
29. Zhou, Z.H., Wang, J.P., Han, Q.F., Jia, Z.K., Min, A.C. Analysis and Strategies for Response Climate Change in Agriculture of Ecologically Fragile Areas: a Case Study of Shanxi in the Middle Reaches of the Yellow River. Ecological Economy, 2012,02:246-250.
30. Zhao, G.J., Tian, P., Mu, X.M., Jiao, J.Y., Wang, F., Gao, P. Quantifying the impact of climate variability and human activities on streamflow in the middle reaches of the Yellow River basin, China. Journal of Hydrology. 2014, 519, 387–398.
31. Jemberie, M., Gebrie, T., Gebremariam, B. Evaluation of land use land cover change on stream flow: A case study of Dedissa Sub Basin, Abay Basin, South Western Ethiopia. Int. J. Innov. Eng. Res. Technol. 2016, 3, 2394–3696.
32. Kindu, M., Schneider, T., Teketay, D., Knoke, T. Land use/land cover change analysis using object-based classification approachin Munessa-Shashemene landscape of the Ethiopian highlands. Remote Sens. 2013, 5, 2411–2435.
33. Abijith, D., Saravanan, S. Assessment of land use and land cover change detection and prediction using remote sensing and CA Markov in the northern coastal districts of Tamil Nadu, India. Environ. Sci. Pollut. Res. 2021, 1–13.
34. Chen, B, Zhou, X. Explanation of Current Land Use Condition Classification for National Standar d of the People's Republic of China. Journal of Natural Resources, 2007(06):994-1003.
35. Rwanga, S.S., Ndambuki, J.M. Accuracy assessment of land use/land cover classification using remote sensing and GIS. Int. J. Geosci. 2017, 8, 611.
36. Aliani, H., Malmir, M., Sourodi, M., Kafaky, S.B. Change detection and prediction of urban land use changes by CA–Markov model (case study: Talesh County). Environ. Earth Sci. 2019, 78, 546.
37. Gidey, E., Dikinya, O., Sebego, R., Segosebe, E., Zenebe, A. Modeling the Spatio-temporal dynamics and evolution of land use and land cover (1984–2015) using remote sensing and GIS in Raya, Northern Ethiopia. Modeling Earth Syst. Environ. 2017, 3, 1285–1301.

38. Hasan, S., Shi, W., Zhu, X., Abbas, S., Khan, H.U.A. Future simulation of land use changes in rapidly urbanizing South China based on land change modeler and remote sensing data. Sustainability 2020, 12, 4350.
39. Khoshnood Motlagh, S., Sadoddin, A., Haghnegahdar, A., Razavi, S., Salmanmahiny, A., Ghorbani, K. Analysis and prediction of land cover changes using the land change modeler (LCM) in a semiarid river basin, Iran. Land Degrad. Dev. 2021, 32, 3092–3105.
40. Han, H., Yang, C., Song, J. Scenario simulation and the prediction of land use and land cover change in Beijing, China. Sustainability, 2015, 7, 4260–4279.
41. Zhang, G.Q., Patuwo, B.E., Hu, M.Y. Forecasting with artificial neural networks: The state of the art. International Journal of Forecasting,1998,14(1),35-62.
42. Nagel, K., Schreckenberg, M. A cellular automaton model for freeway traffic. Journal de Physique I, 1992,2(12), 2221-2229.
43. Xu, W.X., Xu, Z.X., Liu, C.J. Coupling analysis of land intensive use efficiency and ecological well-being performance of cities in the Yellow River Basin. Journal of Natural Resources, 2021,36(01):114-130.
44. Wang, H., Gong, P., Liu, G. H. The review and prospect on land use and land cover change research in Yellow River Delta. 2004,19(01):110-118.
45. Wang, F., An, L.Z., Dang, A.R., Han, J.Y., Miao, C.H., Wang, J., Zhang, G.H., Zhao, Y. Human-land coupling and sustainable human settlements in the Yellow River Basin. Geographical Research. 2020, 39, 1707–1724.
46. Wu, X., Liu, S.X., Zhao, L.Y., Gao, H.T., Li, J.S. Study on the improvement of farmland use efficiency in the Yellow River Basin from the perspective of high-quality development. Research of Agricultural Modernization, 2022,43(04):702-714.
47. Li, C.S., Yan, J.M. The relationship between cultivated land change and agricultural production, ecological environment in the Yellow River Basin under the background of grain for green program. Chinese Journal of Agricultural Resources and Regional Planning, 2022, :1-10.
48. Wei, X.D., Zhang, J., Wang, S.N., Lin, K.L., Wang, N., Liu, Y.P. The evolution and differentiation trend of ecological land pattern in the Yellow River Basin from 2000 to 2020. Chinese Journal of Ecology ,2021, 40(11) : 3424 3435.
49. Zhang, W.H., Lv, X., Shi, Y.Y., Sun, P.L., Zhang, Y.H. Graphic Characteristics of Land Use Transition in the Yellow River Basin. China Land Science, 2020, 34(08):80-88.
50. Ding, Y.L. Opinions about the relationship between protecting arable land and its services during the great development in West China. Resources and industries, 2003.5(2),24-25.
51. Wang, X.F., Hao, J.M., Bi, J.Y., Li, X.L. Cultivated Land Protection in Development of Western Regions of China. Bulletin of Soil and Water Conservation, 2003,23(01):12-15.
52. Liu, W.X. Cultivated Land Protection Policy in the Great Western Development. China Land Science, 2001,15(03):9-11.
53. Gu, X.X., Si,J.H., Lu,S.J., Gui, Z.J., Xie, D.J., Zhao, Z.Q., Li, S.S., Li, H.M., You, Q.M. Analysis on the characteristics of dry and wet changes in the source region of the Yellow River in historical period. Jiangsu Agricultural Sciences,2019,47(23),315-320.
54. Ren, C.H., Bai,C. Q., Ding, K. Investigation and research On rodents damage of effect and control in the Sanjiangyuan. Qinghai Prataculture,2020,29(2),35-40.
55. Ning, J. Problems and counter measures of grassland rodent control in Qinghai province. Animal Husbandry and Veterinary Today,2020,36(08),20.

56. Du, J.Z., Wang, G. X., Li,Y.S. Rate and causes of degradation of alpine grassland in the source regions of the Yangtze and Yellow Rivers during the last45years.Acta Prataculturae Sinica,2015,24(6),5-15.
57. Liu, Y. H., Wei,W. D., Yang, Y. W., Zhang Y. Redundancy analysis on relationships between grassland vegetation and soil factors on degraded alpine meadow. Acta Agriculturae Boreali-occidentalis Sinica, 2018,27(4):480-490.

Figures

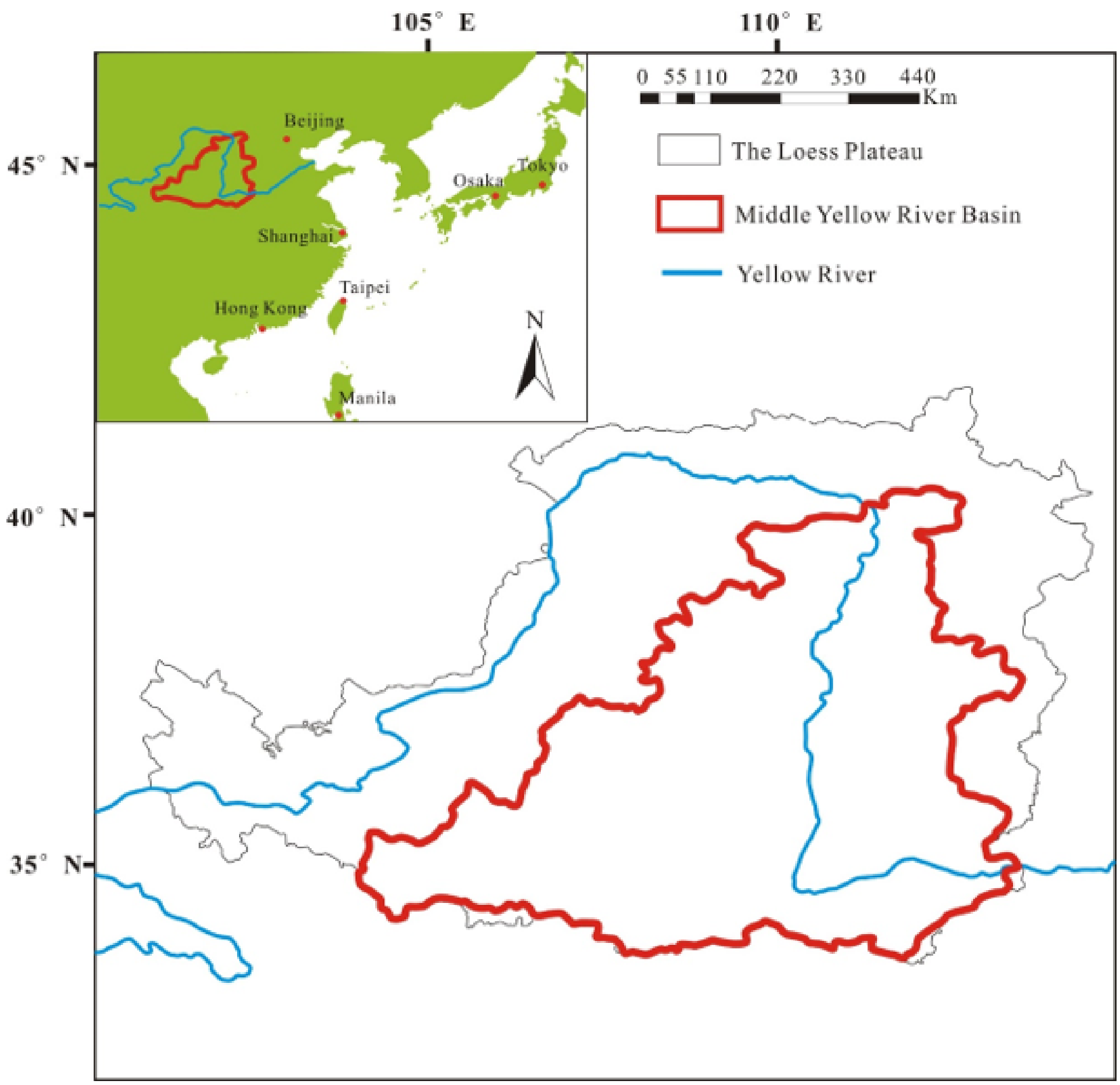

Figure 1

Map of the middle reaches of the Yellow River Basin

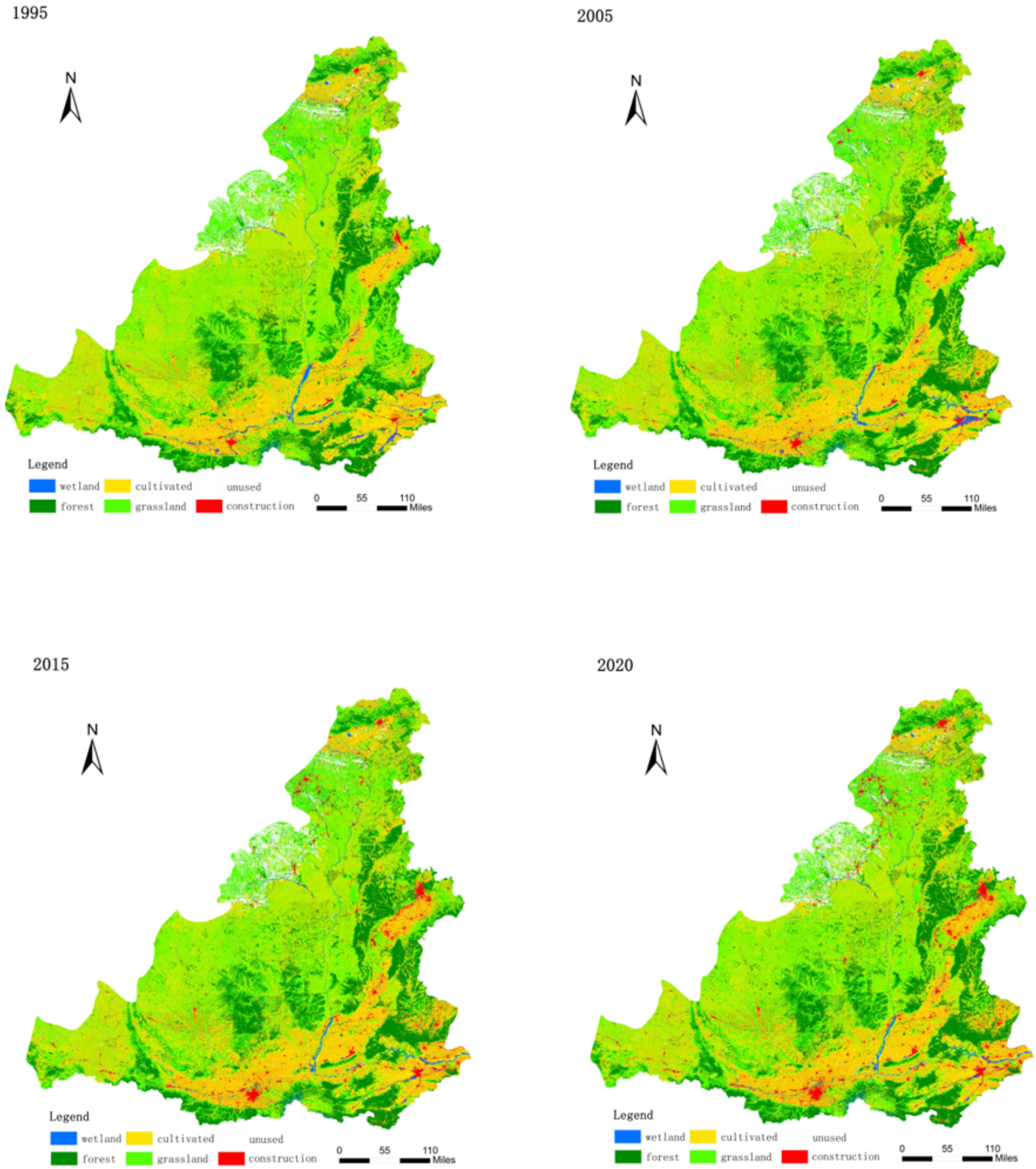

Figure 2

LULC maps of the middle reaches of the Yellow River Basin in the four reference years

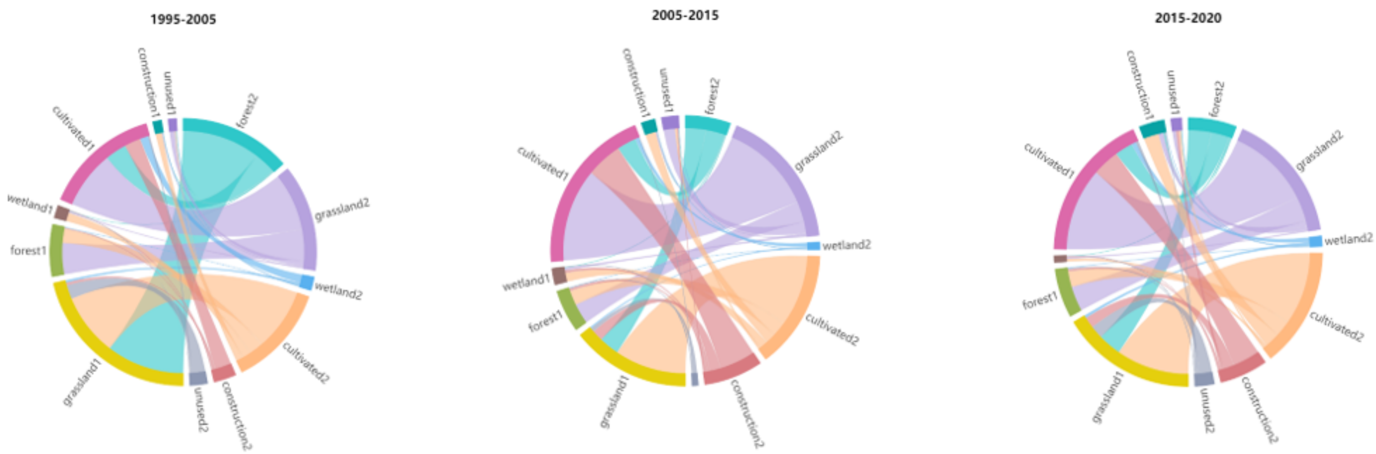

Figure 3

The chord diagram of the transfer of LULC in the middle reaches of the Yellow River from 1995 to 2020 (land type 1 is the previous year, and land type 2 is the next year)

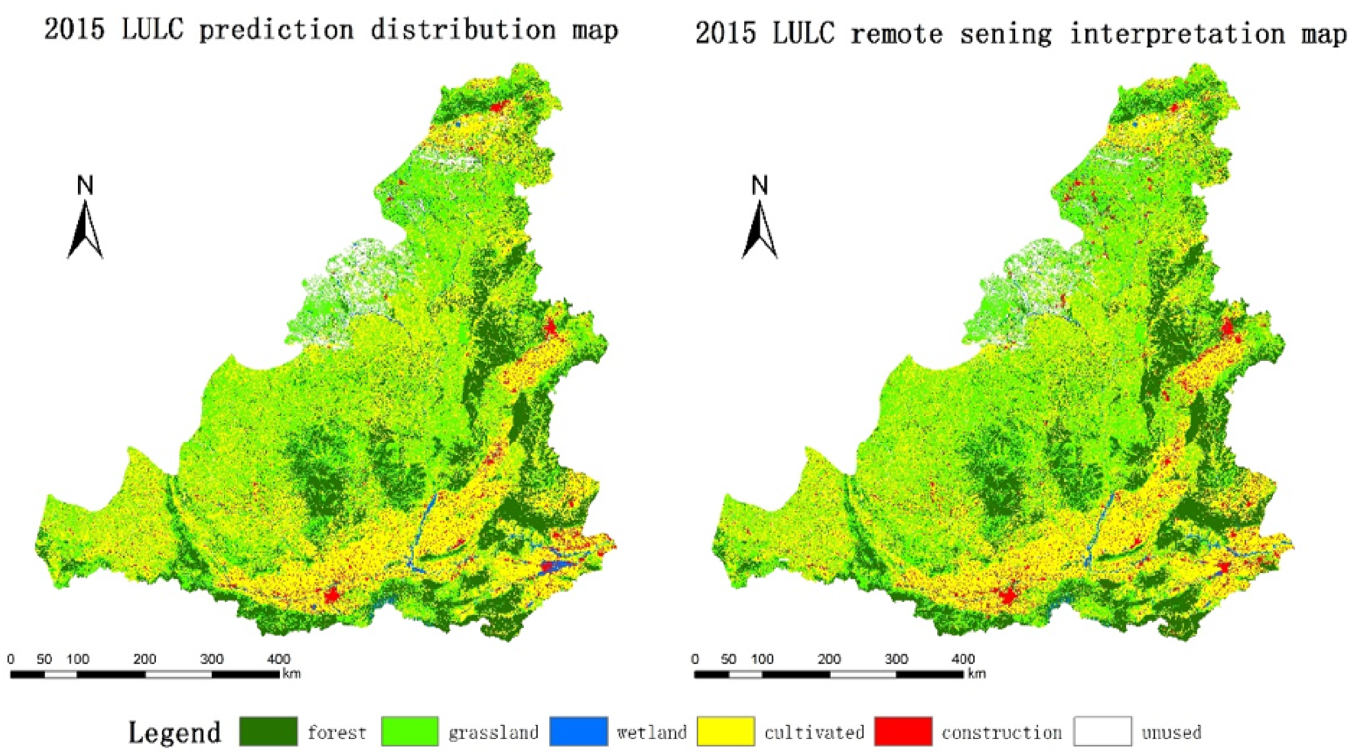

Figure 4

2015 LULC remote sensing interpretation and prediction map

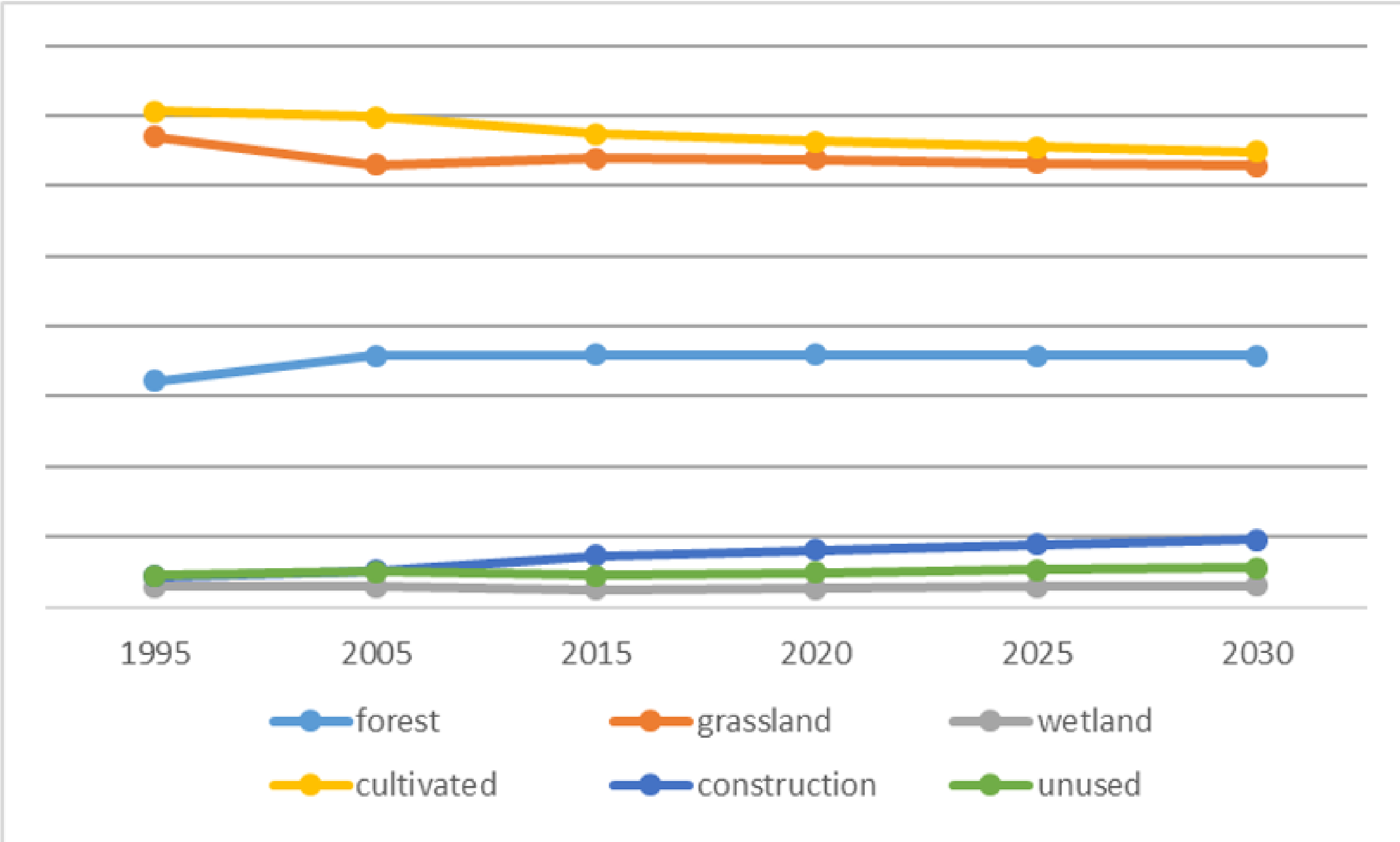

Figure 5

Variation trend of LULC quantity in the middle reaches of the Yellow River from 1995 to 2030

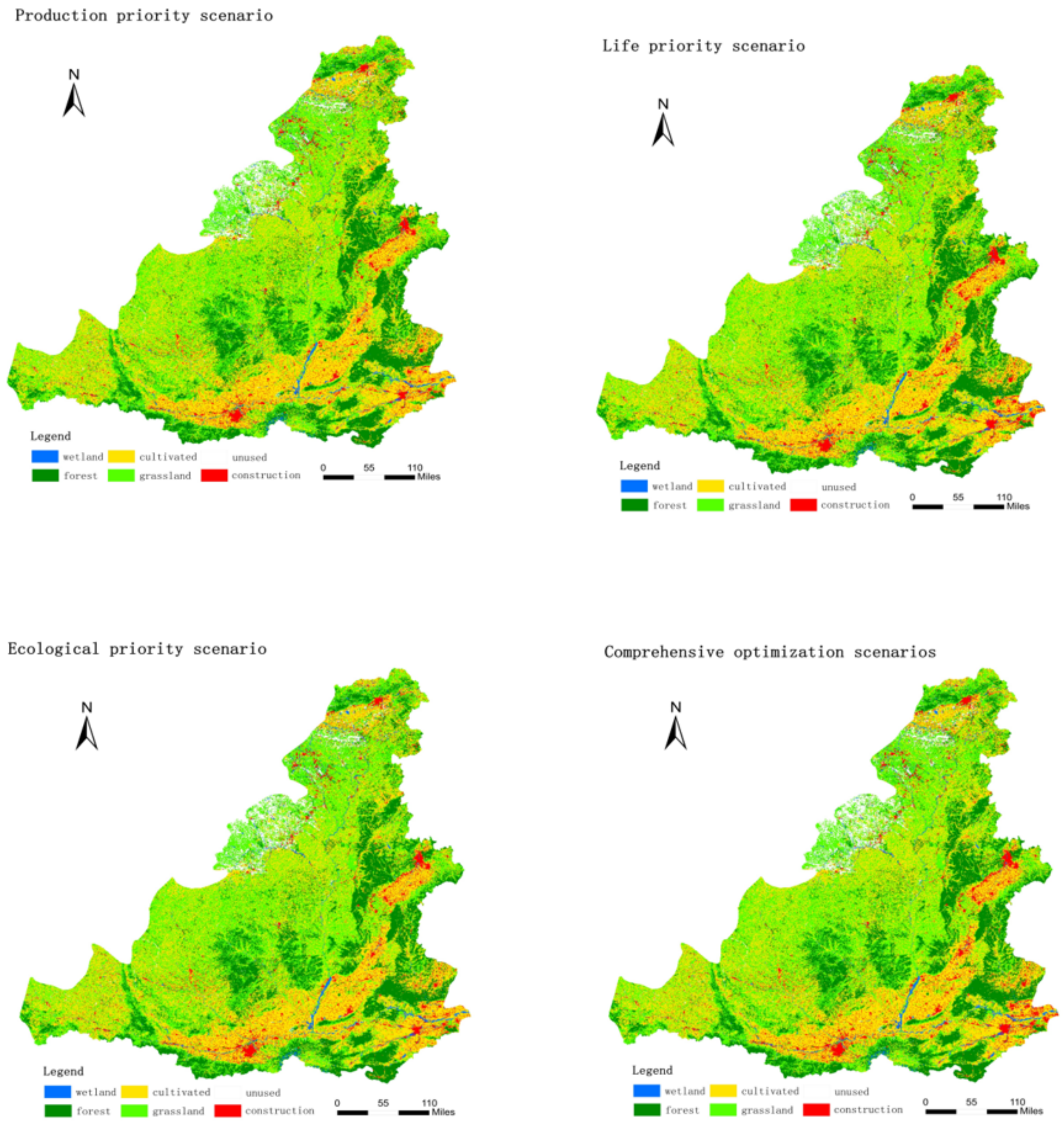

Figure 6

Prediction of multi-scenario spatial distribution of LULC in the middle reaches of the Yellow River in 2025

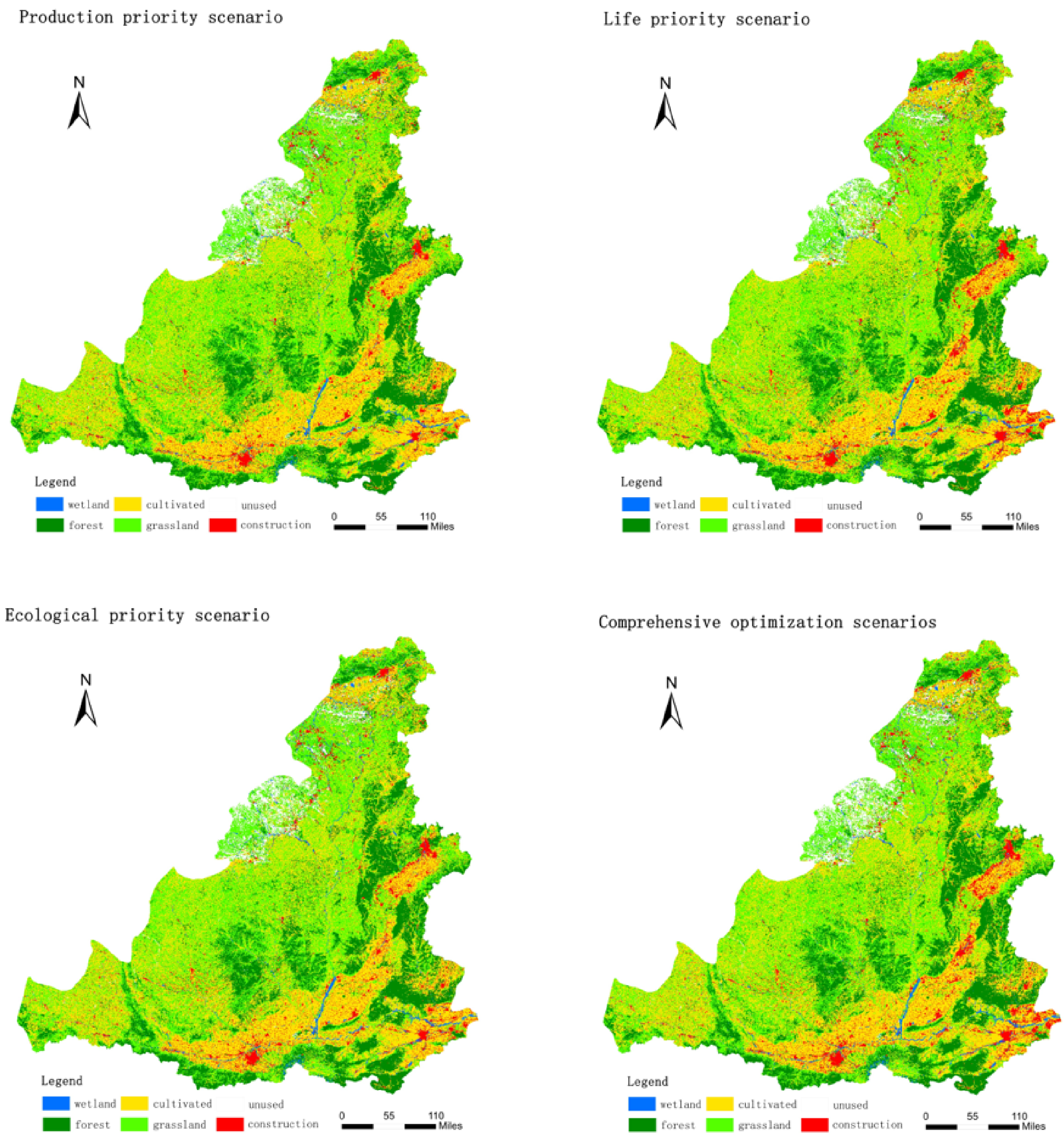

Figure 7

Prediction of multi-scenario spatial distribution of LULC in the middle reaches of the Yellow River in 2030

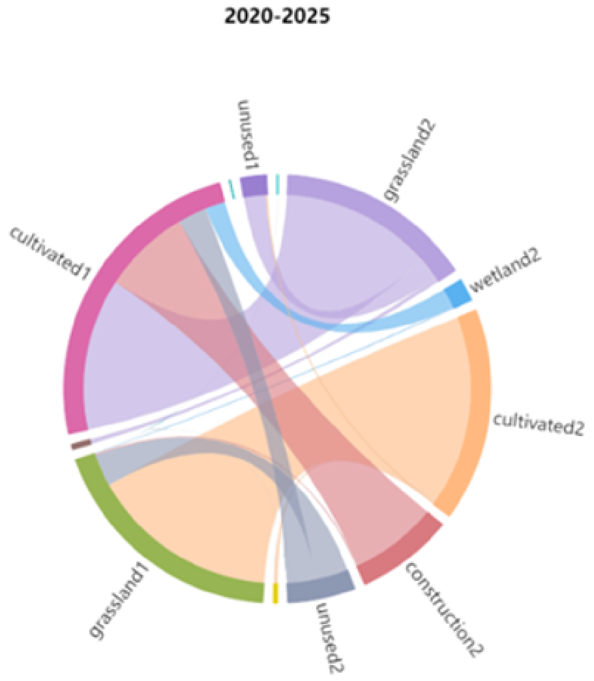

Figure 8

Prediction of LULC transfer chord diagram of the middle reaches of the Yellow River from 2020 to 2030 (land type 1 is the previous year, and land type 2 is the next year)