Analysis and Forecast of Land Use Based on Patch-generating Land Usage Simulation (PLUS) Model: A Case of Shaanxi Province in China

Yunqiu Wang*

School of geography and tourism, Shaanxi Normal University, Xi'an, 710119, China

*Corresponding author: rachel_wang@snnu.edu.cn

Abstract. China has witnessed a substantial number of land-use type shifts and broken land-use distribution patterns as a result of massive irrational exploitation, which has led to problems like a significant loss of environmental habitability and declining ecosystem functioning. Investigating the origins and mechanisms of land-use change is essential. The results show that earlier land-use models, which also lacked simulation studies and projections of land-use changes in Shaanxi Province over a 20-year timeframe, find it difficult to integrate quantitative and spatial pattern forecasts. This paper uses the patch-generating land usage simulation (PLUS) model to assess Shaanxi Province's land use patterns between 2000 and 2020 and predict land usage for the year 2025.Farmland, woodlands, and grassland are the three main land types that make up most of the Shaanxi Province's total area. Forests make up most of the land that will be transferred between 2000 and 2020, while agriculture makes up most of the land that will be transferred. Most of the elements influencing the spread of all land use types were rainfall and Normalized Difference Vegetation Index (NDVI). The central and southern regions of Shaanxi province will primarily experience changes in land use by 2025.This research offering a resource for Shaanxi Province's science of land use structure and efficient land resource allocation.

Keywords: Land use, shaanxi province, PLUS model, driving factor, simulation.

1. Introduction

Land is the material basis and the environmental foundation for human survival and development [1]. Usually, changes in land type can bring about different degrees of impact on development [2]. For the study of global environmental change and sustainable development, it is essential to depict human-nature interactions through changes in land-use or cover [3, 4]. a crucial component of research on environmental change and sustainable development. Due to extensive irrational exploitation, China has experienced a significant number of land-use type shifts and broken land-use distribution patterns, which has resulted in issues like a significant loss of environmental habitability and diminishing ecosystem functioning. Investigating the process of land use change and its motivating elements is crucial for this reason.

Common models used for land use change studies are System Dynamics (SD), Markov, Cellular Automata (CA), Future Land Use Simulation (FLUS) and Geographical Simulation and Optimization System (GeoSOS). According to some studies, combining the benefits of both spatial pattern prediction and quantitative prediction in the models is challenging. And based on past land use change without considering demographic and economic factors and spatial simulation of future land use changes may result in differences between simulation results and actual results [5-9]. The PLUS model combines a CA model based on various seeds of randomly placed plots with a method for tracking the expansion of the land. The components of PLUS The model simplifies the analysis of land use changes while maintaining the capability to simulate the expansion of various land use types more accurately in patches and model a variety of complex changes in land use, producing simulation results that are more consistent with the actual results to aid in decision-making [10].

Using data on land use, this paper explores how the distribution and pattern changes of land use in Shaanxi Province from 2000 to 2020. The PLUS model is then used to investigate the driving forces behind each form of land use expansion in the Shaanxi province using the data that is currently

available. The two models are combined to project Shaanxi Province's land use in 2025. The results serve as a standard for the ideal distribution of land resources in the Shaanxi province and the science of land use structure.

2. Research Methods

2.1. Analysis of Spatial and Temporal Patterns of Land Use

2.1.1 Land-use transfer matrix

The land use transfer matrix represents the quantitative relationship between two forms of land cover through time as a matrix, which may accurately depict the importance and direction of transfer of various types of land cover within an area. The common form is shown in Table 1.

Table 1. Land-use transfer matrix.

T_L \ T_N	C_1	C_2	…	C_n
C_1	S_{11}	S_{12}	…	S_{1n}
C_2	S_{21}	S_{22}	…	S_{2n}
…	…	…	…	…
C_n	S_{n1}	S_{n2}	…	S_{nn}

where, Cn (n=1, 2, …, n) represents land type; S_{ij}(i, j=1,2, …, n) represents amount of converted area; T_L represents last time phase, T_N represents next time phase.

2.2. Patch-generating Land Use Simulation Model

The PLUS model originated from the FLUS model, a patch-scale meta-cellular automata model for land use change that is based on raster data. The PLUS model incorporates both the Land Expansion Analysis Strategy (LEAS) and CA based on Multiple Random Seeds. It can examine the contributing factors to each change in land use type and model changes at the parcel level for a variety of land use kinds.

2.2.1 Land Expansion Analysis Strategy

The technique modifies the interconversion of land classes in a binary categorization, extracts the expansion portion in which to sample, and uses the random forest algorithm (RFA) to mine each land use class for the reasons causing the expansion of the land classes. The RFA can effectively resolve the multicollinearity among components and spatial autocorrelation. The contribution of drivers and the likelihood of each type of terrain developing can then be determined.

Every time a data set is chosen at random with put-back and some features are randomly selected as input, the RFA combines many decision trees. The algorithm can do the classification which means making predictions for discrete values. It can also do the regression, which means making prediction of continuous values. The approach collects random samples from the initial training dataset and builds an ensemble classifier based on decision trees from each sub-dataset. High-dimension data processing and coping with multicollinearity across variables are also capabilities of RFC algorithms, which ultimately output the growth probability.

The selection of factors should be done from different aspects. Six motivating variables were chosen from the socioeconomic and natural domains. Rainfall totals, Gross Domestic Product (GDP), and NDVI are shown as averages every five years.

2.2.2 CA Model based on Multi-type Random Patch Seeds (CARS)

Under the limitations of the development probability, the PLUS model, which employs a mechanism for the formation of plots based on a variety of random seed land uses, is able to

automatically generate future land use simulated plaques. The CA model gathers 'top-down' and 'bottom-up' effects, and it is a scenario-based simulation of land use that are widely used. The most important part in CARS is the overall probability of land development, the basic equation can be expressed as equation (1):

$$OP_{i,k}^{d=1,t} = P_{i,k}^{d=1} \times \Omega_{i,k}^{t} \times D_{k}^{t} \quad (1)$$

where, $P_{i,k}^{d=1}$ indicates the likelihood that land use type k will grow in cell i; $\Omega_{i,k}^{t}$ represents the effects of cell i's surroundings; D_{k}^{t} is the effect of the anticipated increase in land use type k. It depends on the discrepancy between the anticipated demand for land use k and the present availability of land at iteration t. This driving coefficient is self-adaptive [10].

According to previous studies, the neighborhood weight set as Table 2. The CARS module also needs the support of the land use scenario simulation use the Markov chain or the linear regression.

Table 2. The table of neighborhood weight.

Cropland	Forest	Shrub	Grassland	Water	Snow/ice	Barren	Impervious
0.7	0.4	0.3	0.3	0.2	0.1	0.1	0.9

2.2.3 Accuracy verification

The Kappa coefficient is selected as a reference indicator for model accuracy evaluation. The specific formula is as equation (2) and (3):

$$\text{Kappa}=\frac{P_0-P_e}{1-P_e} \quad (2)$$

$$P_e = \frac{a_1\times b_1+a_2\times b_2+\cdots+a_c\times b_c}{n\times n} \quad (3)$$

where, P_0 represents the correct percentage of raster counts while simulating, c represents the number of classes, The numbers a_1, a_2, a_3... ac indicate the genuine samples per class, while b_1, b_2, b_3... bc indicate the anticipated samples per class. N stands for the overall sample count.

The Kappa scale has a 0 to 1 range. In general, a Kappa value between 0.8 and 1 denotes a good simulation effect, a value between 0.6 and 0.8, a somewhat good simulation effect, a value between 0.4 and 0.6, a medium level simulation effect, a value between 0.2 and 0.4, and a value lower than 0.2, a bad simulation effect.

3. Results and Discussion

3.1. Analysis of Spacecraft and Time Patterns of Land Use Change

3.1.1 Spatial distribution attributes of land use

The land use distribution of Shaanxi province from 2000 to 2020 at five-year intervals, as shown in Fig. 1 and Table 3.

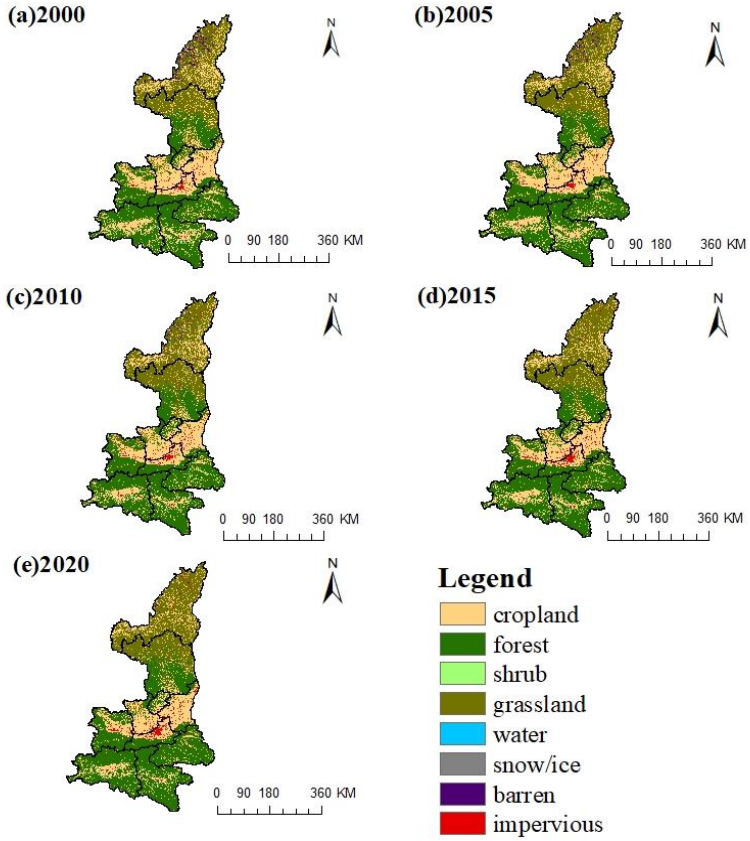


Fig. 1 distribution of land use in Shaanxi from 2000 to 2020. (Picture credit: Original)

Table 3. The area of each land-use type in Shaanxi from 2000 to 2020.

year	Land Use Type	cropland	forest	shrub	grassland	water	barren	impervious
2000	Area/km^2	60900.8	83558.59	1074.43	54942	544.476	2530.71	2511.35
	Proportion/%	0.295545	0.405501	0.005214	0.26662803	0.002642	0.012281	0.01218733
2005	Area/km^2	58377.13	85672.5	915.4791	55733.75	602.4141	1664.234	3096.699
	Proportion/%	0.283299	0.41576	0.004443	0.27047051	0.002923	0.008076	0.015027981
2010	Area/km^2	55533.32	88927.58	575.6022	55928.57	630.8244	680.9931	3785.189
	Proportion/%	0.269498	0.431557	0.002793	0.27141612	0.003061	0.003305	0.018369168
2015	Area/km^2	52403.9	91434.7	359.857	56315.7	635.397	212.818	4699.87
	Proportion/%	0.254311	0.443724	0.001746	0.27329461	0.003084	0.001033	0.022808012
2020	Area/km^2	50627.8	93766.6	255.548	55220.5	669.098	188.482	5334.35
	Proportion/%	0.245692	0.45504	0.00124	0.26797953	0.003247	0.000915	0.025887064

Mountains, plateaus, and basins are just a few of the several types of scenery found in Shaanxi Province. The Loess Plateau is in the northern part of Shaanxi province, the plain is in the middle, and the mountains and hills are in the southern part of the province. Shaanxi Province can be divided into three regions based on its topography: the Loess Plateau in the north, the Guanzhong Plain, and the Qinba Mountains in the south. The cities of Yulin and Yanan are located on the Loess Plateau in Northern Shaanxi. Baoji City, Xianyang City, Xi'an City, Tongchuang City, and Weinan City are all located on the Guanzhong Plain. Southern Shaanxi's Qinba Mountains are home to the cities of Hanzhong, Ankang, and Shangluo.

There are considerable differences by land type in Shaanxi Province based on the distribution and area of land use. Forest, agricultural, and grassland lands make up the majority of the land use types. Approximately 96% of the research region's total area is made up of the three areas. The area of cropland is approximately 28% and is decreasing. It is primarily distributed in Weinan, the northern half of Xi'an, the majority of Xianyang, and Hanzhong cities. The forest covers over 42% of the

province of Shaanxi and is growing. It is predominantly distributed in the southern region, particularly in the Qinling Mountains and along the Daba Mountains. Less than 0.01% of the shrub's proportion is present. The grassland is about 27%, mainly located in the northern Shaanxi, specifically the northern Yanan city and the southern Yulin city and part of the Hanzhong and Ankang city has grassland. The water and the barren has a very small percentage too. The impervious is about 1% to 2%, and there is a clear upward trend because of the level of social economy and the level of urbanization has increased. The Guanzhong Plain has the greatest concentration of impermeable surfaces, and Xi'an has the greatest area of urban residential land. Farmland, wooded areas, and grasslands continue to be the primary land uses despite the area's substantial changes.

3.1.2 Land use transfer analysis

During the 2000 and 2020, In general, the area of the land transfer out ordered from largest to smallest is cropland>grassland>barren>forest>water>shrub>impervious; the area of the land transfer in ordered from largest to smallest is forest>grassland>cropland>impervious>shrub>water>barren (Table 4).

Table 4. Shaanxi Province Land Use Devolution Matrix from 2000 to 2020 (km^2).

Indicators	cropland	forest	shrub	grassland	water	barren	impervious
Cropland	43717	6353	20	8095	138	8	2571
Forest	1441	81979	50	78	1	0	10
Shrub	40	808	103	124	0	0	0
Grassland	5195	4626	82	44676	35	72	256
Water	76	1	0	10	398	3	57
Barren	137	0	2237	8	0	106	42
impervious	23	0	0	1	90	0	2398

The transition from farmland to other land uses has resulted in a significant change in land use type. There is a large amount of the cropland shift to the forest and the grassland, the area is 6353 km^2 and 8095 km^2 separately, because of the returning farmland to forest and grass policy. The area of the grassland shift to the forest is 4626 km^2 and there are 5195 km^2 of grassland convert to the cropland. Although much area has been transferred to cropland, it is not enough to avoid the loss of the cropland. Besides, the area of the cropland shift to the impervious is also considerable, is about 2571 km^2. Mainly because the original impervious is not enough for human activities and the population increase, so the use of the cropland began to increase.

3.2. Analysis of the Drivers of Land Use Change Based on PLUS Model

The analysis shows that the largest change of land-use in Shaanxi Province from 2000 to 2020 is cropland, forest, grassland and impervious. Among them, NDVI and rainfall contributed more to the changes of all land types. The factor contribution of cropland land type expansion from largest to smallest is rainfall, NDVI, GDP, Digital Elevation Model (DEM), slope and distance to primary roads. The expansion of cropland mainly influenced by natural factors. The rainfall is higher, the expansion is greater. The contribution of rainfall to croplands increases from 2000 to 2010 and remains largely balanced from 2010 to 2020.The GDP contribution stay an up trend from 2000 to 2020. The contribution of NDVI increases from 2000 to 2010, then remain a fall trend during the 2010 to 2020. The contribution of DEM falls first at the first five years, then stay still for five years, at last five years, it increases. The change of contribution of slope is opposite of the contribution of DEM (Fig. 2).

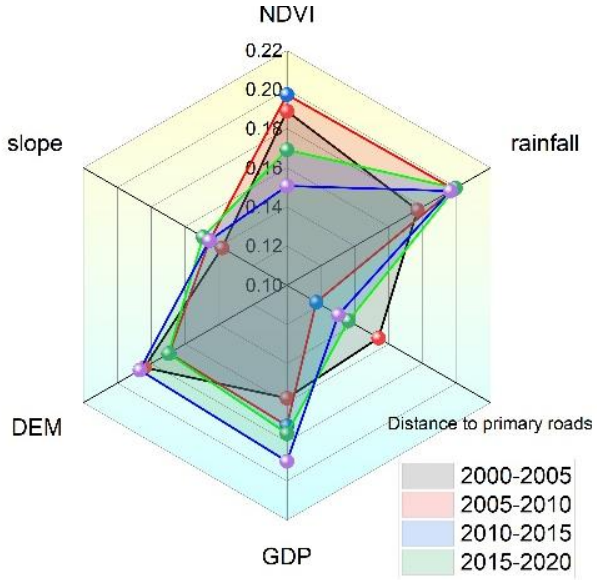


Fig. 2 The level of impact of each factor on farmland expansion. (Picture credit: Original)

As to the expansion of the forest, NDVI has the highest contribution and the distance to primary roads has the lowest contribution. Normalized Differential Vegetation Index, or NDVI, is one of the key metrics for assessing crop growth and nutritional data. It can capture the background impact of the plant canopy. That is why NDVI keeps a high contribution. During the 2005-2020, the NDVI contribution value keeps dropping, but still keeps the highest. The contribution of the distance to primary roads dropping at first five years, and on an upward trend from 2010 to 2020. The remaining four factors have complex trends (Fig. 3)

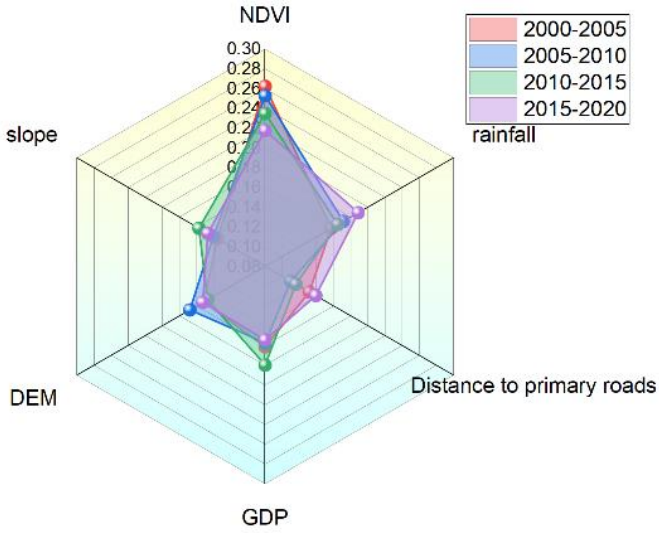


Fig. 3 The level of impact of each factor on forest expansion. (Picture credit: Original)

As to the expansion of the impervious, the factor has the highest contribution is rainfall and DEM and GDP. That's because the higher NDVI it has, means the less expansion of the impervious there will be. Additionally, socioeconomic considerations have an impact on the expansion of the impervious. As a result, when the GDP is larger, the impervious expands more. The distance to primary roads remains largely unchanged over 20 years. And the contribution of the rainfall has a drop trend during the first 5 years, then start to increase in the year 2010, at last it stay still during 2015 to 2020 (Fig. 4).

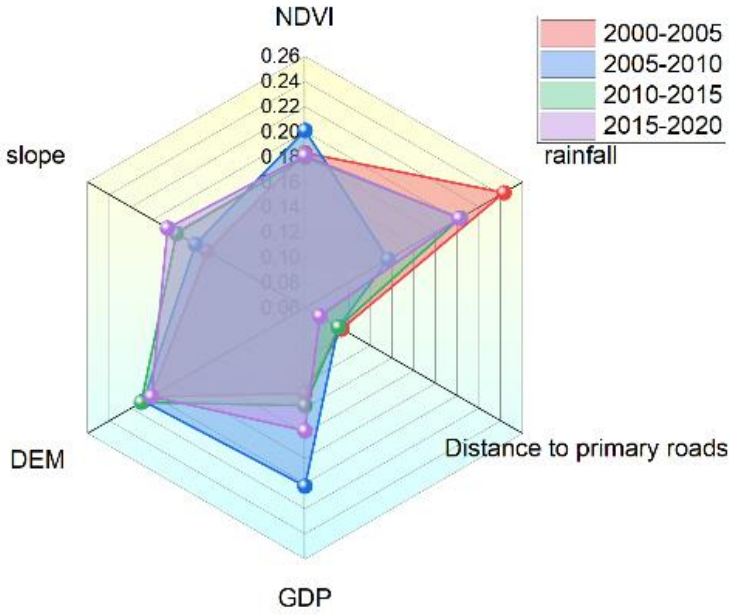


Fig. 4 The level of impact of each factor on impervious expansion. (Picture credit: Original)

3.3. Prediction and Accuracy Validation Vased on the PLUS Model

3.3.1 The accuracy validation

Cross-tabulation of simulation of land use with current land use in 2020, the simulation error can be get. In general , the accuracy is rather high, the average accuracy get 93.54%. overall, the simulation of forest and barren has a lower accuracy rate,50.49% and 49.37% separately. The other five land use simulations have high accuracy, all reaching 84% or more (Table 5).

Table 5. The accuracy validation

cropland	Forest	shurb	grassland	water	barren	impervious
0.8793	0.9703	0.5049	0.9370	0.8459	0.4937	0.8943

3.3.2 Simulation of land use analysis in Shaanxi Province in 2025

Choosing 2015 to 2020 as the base period, setting the inertia development scenario, combined with Markov chain quantity prediction, the predicted results are shown in the Fig. 5.

The amounts of the cropland, shurb, grassland, barren will decrease and the amounts of the forest ,water and impervious will increase. Most of the shift happen in the middle and the southern part of Shaanxi province. Converting forest into grassland mainly locate in Yanan city, Shangluo city and the northern of Baoji and Xianyang city. The conversion from impervious to cropland mostly locate in the Baoji, Xi'an and Weinan city. Conversion of forests to cultivated land occurs primarily in the south of Shaanxi province. The reason for this may be that the study period is relatively short and land use is influenced by human activities, slowly converting towards building land. The adequacy of land use should be ensured, ecological-economic corridors should be delineated, and the coordination of land use and ecological functions should be improved.

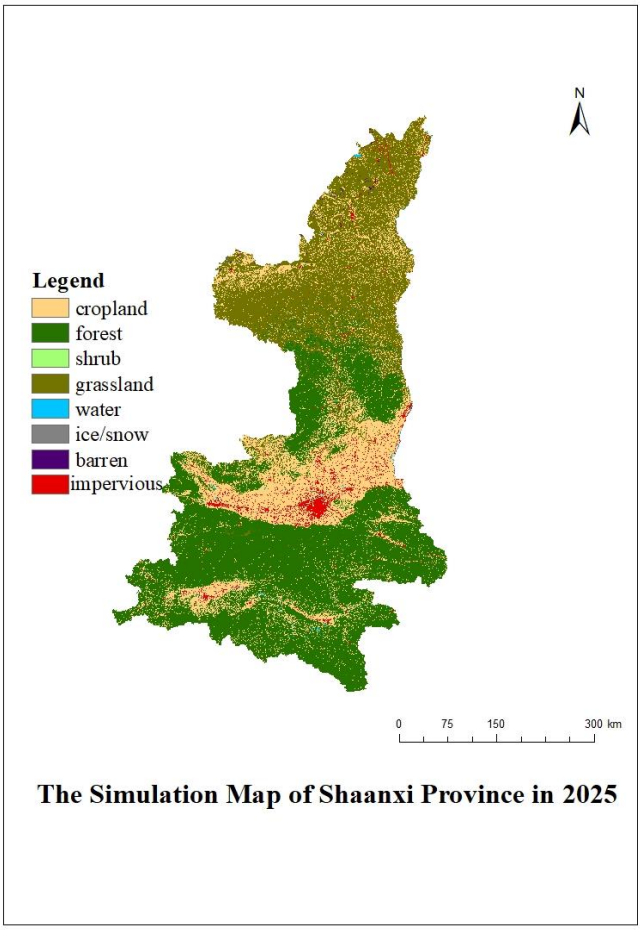


Fig. 5 Simulation of land use in Shaanxi Province in 2025. (Picture credit: Original)

4. Conclusion

Shaanxi Province has a pivotal position in the northwest China, with complex landscape types, large diversities in the degree of land use in different regions, and prominent conflicts between urban and rural areas, ecological construction and economic development, etc. Land use conversion and prediction still require in-depth research. This paper studies the distribution and land use changes within Shaanxi Province from 2000 to 2020 with a 5-year cut-off. The three types of land that account for the largest proportion in Shaanxi is cropland, forest and grassland. During the 2000 and 2020, the largest land transfer out is cropland; the smallest land transfer in is forest. As for analysis of the land use change factors of Shaanxi Province shows that NDVI and rainfall contributed more to the changes of all land types. The factor contribution largest of cropland land type expansion is rainfall. As to the expansion of the forest, NDVI has the highest contribution and the distance to primary roads has the lowest contribution. As to the expansion of the impervious, the factor has the highest contribution is rainfall and DEM and GDP. According to the predict of the 2025 simulation, the changes will occur primarily in the central and southern portion of Shaanxi province. There is still a lot of room for development in the application of PLUS model. This research offering a resource for Shaanxi Province's science of land use structure and efficient land resource allocation.

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