International Journal of Multidisciplinary Research and Analysis
ISSN(print): 2643-9840, ISSN(online): 2643-9875
Volume 05 Issue 11 November 2022
DOI: 10.47191/ijmra/v5-i11-09, Impact Factor: 6.261
Page No. 3021-3028

GIS-Based Prediction of Dynamic Land Use Change and its Structure in Bengbu City

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ABSTRACT: In this paper, Bengbu City, Anhui Province, China, was selected as the study area, based on three phases of multispectral image data in 2000, 2010 2020, to reflect the dynamic land use change characteristics of Bengbu City in the last decade in detail, used ArcGIS software for data processing, through the transfer matrix, land use dynamic attitude, land use change amplitude, respectively, the land use characteristics in the study area and its overall change trend were quantitatively assessed, and the future land use evolution of Bengbu City was predicted by simulation using Markov model. The results show that the overall change of land use structure in Bengbu City during the 20 years is mainly the decrease of cultivated land and the increase of man-made surface, and although the transfer out of cultivated land is greater than the transfer in, cultivated land is still the most dominant land use type in Bengbu City during the study period, accounting for more than 70% of the total land area, and it is predicted that the overall change of land use in Bengbu City in the future is still mainly the decrease of cultivated land, while the area of man-made surface continues to show an increasing trend year by year. the trend of the increasing year by year.

KEYWORDS: remote sensing; dynamic land use change; Markov model; Bengbu City

1. INTRODUCTION

As the carrier of all human activities, the land is closely related to human production and life, and land resource allocation, as the mainstream resource allocation method in today's society, becomes an urgent problem to be solved according to the regional geographical location and economic level for reasonable land resource allocation. Land use refers to the land resource utilization activities carried out by human beings to obtain the required products or services, which is the way of using the natural properties of land and the utilization status of human beings, and contains the purpose and intention of human beings to use land, and land use can be used as a coupling of land use demand and land supply type[1]. The natural resource conditions of the region as well as the regional economic development status also depend on the land use structure and status of the region to a certain extent. Only by fully understanding and studying the land use status and its spatial and temporal changes in the region can we reasonably plan the layout and formulate the land policy for regional development planning. As a once important industrial city in Anhui Province and one of the important transportation hubs in China, Bengbu City is currently experiencing a slowdown in economic growth and an increasingly prominent contradiction between land supply and demand. Therefore, it is of great practical significance to study the land use status and its structure in Bengbu city to promote regional economic development, reasonably plan the city's land use structure and make full use of land resources.

2. DATA SOURCES AND RESEARCH METHODOLOGY

2.1 Overview of the study area

Bengbu is located in the northeastern part of Anhui Province, in the middle reaches of the Huai River, with latitude 32°43′ to 33°30′ north and longitude 116°45′ to 118°04 4′ east. The city has three administrative counties, Wuhe, Guzhen, and Huaiyuan counties, four administrative districts, namely Longzihu, Bingshan, Yuyi, and Huaishang, and two functional districts, Bengbu High-Tech Industrial Development Zone and Bengbu Economic Development Zone, with a total area of 5,951km2. As of the end of 2020, the resident population was 3,296,400, accounting for 5.4% of the people of Anhui Province, with the urban population accounting for 55.08%, rural population 44.92%; Bengbu city's GDP in 2020 is 208.27 billion yuan, per capita GDP 63,209 yuan, slightly lower than Anhui Province per capita GDP 63,209 yuan, the primary, secondary and tertiary industries account for 12.2%, 40.1%, and 47.7% respectively, the leading industries are secondary and tertiary.

2.2 Data sources and pre-processing

The data used in this paper are surface coverage data provided by the global geographic information public product GlobeLand30, which is derived from TM5, ETM+, OLI multispectral imagery from the US Land Resources Satellite (Landsat), and multispectral imagery from the Chinese Environmental Disaster Reduction Satellite (HJ-1)[2]. The data remote sensing image data including three phases of 2000, 2010, and 2020 were pre-processed by ArcGIS tools for mask extraction, raster to the surface, fusion, intersection, and pivot table in Excel.

2.3 Research methodology

2.3.1 Dynamic land use attitudes

The amount of change in the use pattern of a land use type over a certain period is known as the dynamic attitude of that land use type, which quantitatively describes the rate of land change over some time[3]. It quantifies the rate of land change over a while. The single land use dynamic attitude is used to characterize the dynamic change of a land use type in the study area during the study period, and this paper uses the single land use dynamic attitude to study the dynamic change of each land use type in Bengbu

City between 2000 and 2020, and its expression is:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\%$$

where K denotes the dynamic attitude of a single land use type in the selected study period, U_a and U_b are the numbers of a land use type at the beginning and end of the study, respectively, and T denotes the time interval between the two selected study periods, and if the unit is set to years, K denotes the annual rate of change of that land use type.

2.3.2 Magnitude of change

The magnitude of change is the amount of change in a land use type as a percentage of the total land area at the beginning of the study, and it characterizes the value of the change in a land use type relative to the land use pattern at the beginning of the study and is expressed as:

$$U = \frac{U_b - U_a}{S} \times 100\%$$

where U denotes the magnitude of change for a land use type, and U_a, U_b and S are the area of a land use type at the beginning of the study, the area of a land use type at the end of the study, and the total area of the study area, respectively.

2.3.3 Markov model (mathematics)

Land use change is an evolutionary process of a complex system, and it is difficult to make predictions with complex formulas[4]. However, Markov prediction models can make scientific and reasonable predictions on the land use structure of a region in the future based on the current state and changes in the dynamic system, to promote rational land planning and make full use of land resources. Markov model is a statistical model, in which the concept of the Markov process refers to a special stochastic process with "no posteriority (i.e. Markovianity)". The so-called "posteriority-free" means that the state at the moment T+1 of a stochastic process is only related to the state at the moment T, but not to the state before the moment T. That is, the state transfer probability is only related to the state at the time of transfer, the number of transfer steps, and the state after the transfer, but not to the moment before the transfer[5]. Under certain conditions, the dynamic evolution of land use has the nature of the Markov process, while the interconversion of land use types is difficult to describe by an accurate function, it is possible to apply the Markov prediction model to dynamically simulate the future land use structure in the study area.

The key to applying the Markov model is the identification of transfer probabilities, and the transfer matrix can effectively account for the interconversion of different land use types, with the transfer matrix expression being.

$$P_{ij} = \begin{bmatrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ P_{n1} & P_{n2} & \cdots & P_{nn} \end{bmatrix}$$

where P_{ij} is the transfer probability of conversion from land use type i to land use type

j. The elements of the matrix should satisfy the condition

$$\sum_{j=1}^{n} P_{ij} = 1(i, j = 1,2,3, \cdots, n); 0 \leqslant P_{ij} \leqslant 1$$

Let the probability of the initial state n = 0 in the land use system be.

$$A^{(0)} = \left[A_1^{(0)} \quad A_2^{(0)} \quad A_3^{(0)} \quad \cdots \quad A_n^{(0)}\right]$$

Then, according to the Markov prediction principle, the probability of land use after n transfers is

$$A^{(n)} = \left[A_1^{(n)} \quad A_2^{(n)} \quad A_3^{(n)} \quad \cdots \quad A_n^{(n)}\right] = A^{(0)} \cdot P^{(n)}$$

where $P^{(n)}$ denotes the transfer matrix after n steps of transfer. Since the state probability at any moment in the land use system prediction system is determined only by the initial state probability and the transfer probability. The transfer step in the prediction model is the time between two land use periods when the transfer matrix is established, and to ensure the accuracy of the prediction model and the availability of data, the initial year is chosen to be 2020 and the transfer step is chosen to be 10, then only the land use after 2020 can be predicted $10n(n = 1,2,3, \ldots, n)$ year land use state.

3. RESEARCH FINDINGS AND ANALYSIS

3.1 Basic land use characteristics

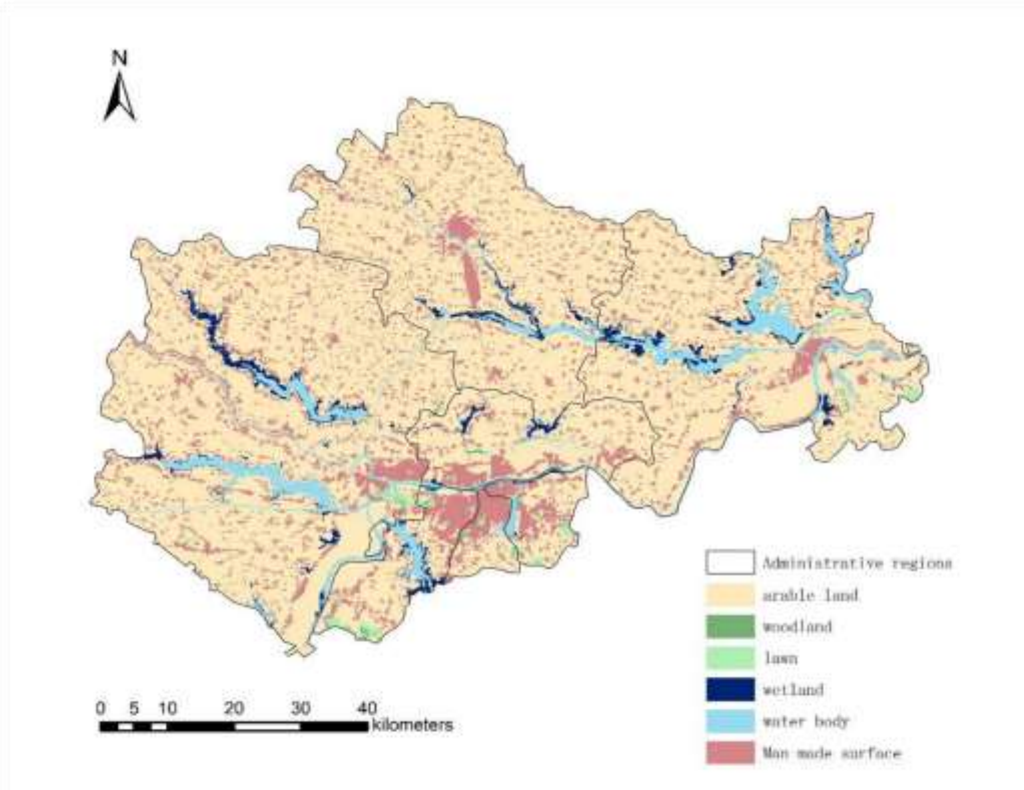

Figure 2-1 Distribution of land use types in Bengbu City in 2020

land category	2000 Area/hm²	2000 Area share	2020 Area/hm²	2020 Area share
arable land	467765.73	78.63%	446883.39	75.12%
woodland	838.44	0.14%	1496.07	0.25%
lawn	7064.46	1.19%	6866.28	1.15%
wetland	4301.91	0.72%	14384.79	2.42%
water body	49315.23	8.29%	35383.86	5.95%
Man-made surface	65576.61	11.02%	89847.99	15.10%

Table 2-1 Bengbu Land Use Distribution Table

According to Figure 2-1 and Table 2-1, because of the remarkable monsoon and mild climate in Bengbu city, the soil is mainly loamy and sandy soil, which is suitable for all kinds of crops, so the land use type in the whole territory of Bengbu city is mainly arable land, the arable land area in Bengbu city in 2000 is 467,765.73 hm², accounting for 78.63% of the total area, and the arable land area in Bengbu city in 2020 is
446,883.39 hm², accounting for 75.12% of the total area, the arable land area is more than 3/4 of the total land area. Bengbu city is located in the temperate semi-humid monsoon climate zone, the average annual precipitation is abundant, and the area of water in the territory is more widely distributed, so in the distribution of land types in 2000 wetlands and water bodies accounted for 0.72% and 8.29% of the total land area, a total of 9.01%, in 2020 wetlands and water bodies respectively accounted for 2.42% and 5.95%, for a total of 8.37%. As Bengbu City vigorously promotes the construction of the central city during the 13th Five-Year Plan period, focusing on promoting the synergistic development of new urban areas and old urban areas. To create a modern city with a beautiful environment and comfortable living features, Bengbu City vigorously promotes and improves infrastructure construction, including road construction, drainage facilities, and sewage treatment facilities, as well as the construction of supporting service facilities, further optimizes the layout of administrative areas, to accommodate the continuous influx of urban population, to adjust the administrative planning and expand the city limits promptly to face the steadily increasing level of the urban rate, Due to the above reasons, the man-made surface[6] (including surfaces formed by artificial construction activities, including towns and other types of residential land, industrial and mining, transportation facilities, etc.) also occupy a larger share in the land use structure of Bengbu City, with the area of man-made surfaces accounting for 11.02% and 15.10% of the total land area in 2000 and 2020, respectively.

3.2 Overall land use change characteristics

2000 land category	Land category 2020						
	arable land	woodland	lawn	wetland	water body	Manmade surface	2000
arable land	418321	384.12	3412.89	3471.84	2570.22	39605.67	467765.7
woodland	83.34	531.27	190.08	7.47	7.11	19.17	838.44
lawn	895.23	153.54	2049.03	1471.32	554.94	1940.4	7064.46
wetland	747.27	178.47	237.78	2185.38	868.14	84.87	4301.91
water body	9541.44	165.33	546.84	7089.57	31313.16	658.89	49315.23
Man-made surface	17295.12	83.34	429.66	159.21	70.29	47538.99	65576.61
2020	446883.4	1496.07	6866.28	14384.79	35383.86	89847.99	

Note: Where all land use change areas are in hm^2.

Table 2-2 2000-2020 Bengbu City Land Use Transfer Matrix

According to the results in the land use transfer matrix in Table 2-2, Bengbu City mainly shows an increase in man-made surfaces and wetlands and a decrease in arable land and water terraces during the study period. Among them, the transfer out of cultivated land amounted to 49444.74 hm², with a net decrease of 20882.34 hm², of which the main transfer out was man-made surface, totaling 39605.67 hm², accounting for 80.1% of the total transferred area, followed by grassland and wetlands, accounting for 6.9% and 7.02% of the total transferred area, respectively, with a change of -3.51 (the change is less than zero, indicating that cultivated land is in a negative state, i.e., the amount of transfer out is greater than the amount of transfer in). The surface transfer of man-made land amounted to 42309 hm² with a net increase of 24271.38 hm², of which the main transfer came mainly from arable land with a total of 17295.12 hm², accounting for 93.61% of the total transfer. The decrease in arable land as well as the increase in the man-made land surface is mainly due to Bengbu City's policy of optimizing the structure and layout of urban and rural land and steadily promoting urbanization, increasing urban construction land and a decrease in rural arable land to meet the needs of urbanization in Bengbu City. At the same time, Bengbu City actively promotes the construction of transportation, water conservancy, and basic service facilities in its land planning to strengthen cross-regional exchanges and give full play to Bengbu City's geographical advantages, which is also the reason for the increase in man-made surface area.

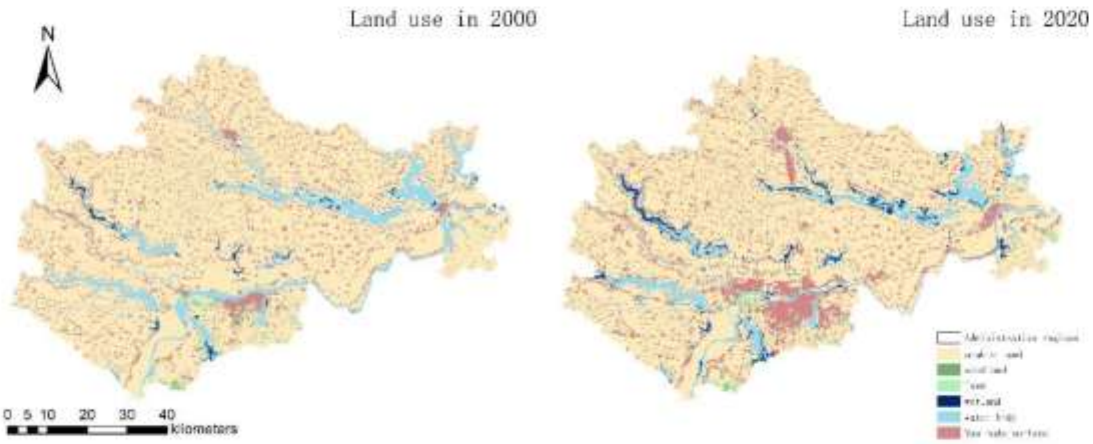

Figure 2-2 Bengbu City Land Use Map for 2000 and 2020

The changing characteristics of land use types in Bengbu City can be observed more visually from the land use maps in Figure 2-2 for the two study periods of 2000 and 2020, which are consistent with the results of the land use transfer matrix, where the transfer in of man-made surfaces is greater than the transfer out. The net increase is greater than zero, with a clear increase in the red area in the figure, which is also accompanied by a decrease in cultivated land, that is, the yellow area in the figure, and also the observation of wetland and mutual transfer in and out of water bodies, i.e., the dark blue and blue portions of the figure.

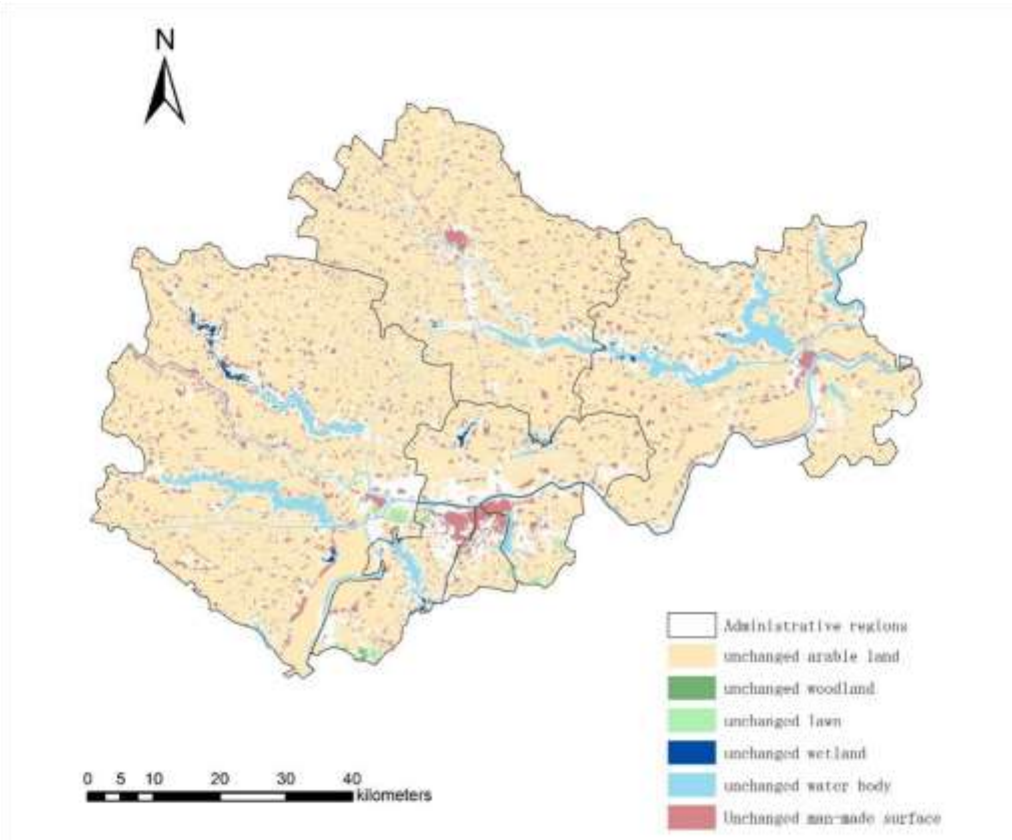

Figure 2-3 Distribution of unchanged land in Bengaluru in 2020

It is more obvious from Figure 2-3 2000-2020 Bengbu city no-change land distribution map that even though there is a certain magnitude of land use conversion area (blank area in Figure 2-3), no-change arable land (yellow area in Figure 2-3) still occupies the majority of the area in the figure, indicating that the basic characteristics of land use in Bengbu city, which is mainly arable land, have not changed. At the same time, a large area of land change in the figure is concentrated around the man-made surface, which also reflects the urban expansion of Bengbu City in the past two decades, resulting in the transformation of land use types around the city.

land category	inward shift /hm²	transfer out /hm²	Total change/hm²	Exchange variation /hm²	Net-increase /hm²	Dynamics	Magnitude of change
arable land	28562.40	49444.7	78007.1	98889.4	-20882.3	-0.223%	-3.510
woodland	964.80	307.1	1271.9	1929.6	657.6	3.922%	0.111
lawn	4817.25	5015.4	9832.6	10030.8	-198.1	-0.140%	-0.033
wetland	12199.41	2116.5	14315.9	24398.8	10082.8	11.719%	1.695
water body	4070.70	18002.0	22072.7	36004.1	-13931.3	-1.412%	-2.342
Man-made surface	42309.00	18037.6	60346.6	84618.0	24271.3	1.851%	4.080

Table 2-3 Characteristic quantities of land use transformation in Bengbu City, 2000-2020

In terms of land use dynamics, wetland > woodlands > man-made surfaces > grasslands > water bodies > croplands, where the annual rate of change of wetlands reached 11.719%. In terms of the magnitude of change, man-made surface > wetland > woodland > grassland > water bodies > cropland, where the magnitude of change of cropland, grassland and water bodies are less than zero, indicating that their total area is in a state of decrease, while the area of woodland, wetland, and the man-made surface is in a state of increase, where the magnitude of change of cropland and the man-made surface is greater, and the magnitude of change as a clear reflection of the various land types Compared to the degree of change in the total land area of the study area, this result indicates that the drastic changes in cultivated land and man-made surface during the study period have had an important impact on the overall spatial changes in land use in Bengbu City.

3.3 Projections of the evolution of the land-use structure

3.3.1 Determination of initial state matrix and state transfer matrix

Using the satellite image data, the initial probability matrix used the percentage of each land use type to the total area in 2010; since a step of 10 years was chosen, the same steps as those used to calculate the land use state transfer matrix from 2000 to 2020 were used to obtain the land use state transfer matrix between 2010 and 2020. The results are shown in Tables 2-4 and 2-5, respectively.

land type	arable land	woodland	lawn	wetland	**water body**	artificial surface
initial probability	0.7659	0.003	0.0117	0.0178	0.0913	0.1104

Table 2-4 Initial probability matrix

Land category 2010	Land category 2020						
	arable land	woodland	lawn	wetland	**water body**	**Man-made surface**	2010
arable land	419080.05	63.63	2438.01	183.24	546.21	33281.37	455592.51
woodland	224.10	1024.47	374.13	18.45	54.00	77.76	1772.91
lawn	949.50	316.44	3447.45	778.95	1118.61	356.94	6967.89

wetland	1587.15	12.24	37.89	7712.82	1035.27	190.26	10575.63
water body	15355.35	39.24	265.41	5673.51	32612.94	360.36	54306.81
Man-made surface	9687.24	40.05	303.39	17.82	16.83	55581.30	65646.63
2020	446883.39	1496.07	6866.28	14384.79	35383.86	89847.99	

Note: Where all land use change areas are in hm^2.

Table 2-5 State Transfer Matrix by Land Use Type, Bengbu City, 2010-2020

3.3.2 Calculation of the transfer probability matrix

Based on the land use state transfer matrix calculated in Table 2-5, a state transfer probability matrix was created as a proportion of the area of different land types after conversion to the area of that land use type before conversion, as shown in Table 2-6.

	2000 land	Land class 2020				
category	arable land	woodland	lawn	wetland	**water body**	**Man-made surface**
arable land	0.9199	0.0001	0.0054	0.0004	0.0012	0.0731
woodland	0.1264	0.5778	0.2110	0.0104	0.0305	0.0439
lawn	0.1363	0.0454	0.4948	0.1118	0.1605	0.0512
wetland	0.1501	0.0012	0.0036	0.7293	0.0979	0.0180
water body	0.2828	0.0007	0.0049	0.1045	0.6005	0.0066
Man-made surface	0.1476	0.0006	0.0046	0.0003	0.0003	0.8467

Table 2-6 Probability matrix of state shift by land use type in Bengbu City, 2010-2020

3.3.3 Dynamic simulation of land use change types in Bengbu City

With the help of the MATLAB programming platform, based on the land use structure of Bengbu City in 2010, in 10-year steps, based on the data and formulas in
Table 2-4 and Table 2-5.

$$A^{(n)} = \left[A_1^{(n)} \quad A_2^{(n)} \quad A_3^{(n)} \quad \cdots \quad A_n^{(n)}\right] = A^{(0)} \cdot P^{(n)}$$

The simulation predicts the proportion of the area of each land use type to the total area of Bengbu City in 2030 and 2040, and the results are shown in Table 2-7.

year	arable land	woodland	lawn	wetland	**water body**	**Man-made surface**
2020	75.12	0.25	1.15	2.42	5.95	15.10
2030	73.57	0.22	1.13	2.55	4.10	18.43
2040	72.11	0.21	1.12	2.45	2.99	21.12

Table 2-7 Projected Area Distribution of Future Land Use Types in Bengbu City in 2030 and 2040/%

From the table, it can be found that the trend of future land use change in Bengbu City still shows a decrease in arable land, which is predicted to decrease to 73.57% of the total area by 2030 and 72.11% of the total area by 2040; while the area of the manmade surface shows a trend of the increasing year by year, which is predicted to increase to 18.43% and 21.12% of the total area by 2030 and 2040 respectively. Although the projected changes in the area of woodland and grassland sub-dimensions are not significant, the change of 0.04% from 2020 to 2040 is still not negligible due to the large total area base; the area of wetlands and water bodies is expected to increase to 2.55% and 4.10% of the total area in 2030, respectively, while the proportion of wetlands area decreases to 2.42% in 2040 compared to 2030, while the proportion of water body area will continue to decrease to 2.99% of the total area.

4. CONCLUSION

4.1 Trends and Drivers of Land Use Change in Bengbu City

Based on the land use classification data of multispectral image classification, using ArcGIS software, we analyze the spatial evolution trend of various types of land in Bengbu city during the 20 years from 2000 to 2020 using land use dynamic attitude and land use change magnitude, we can see that the city's land use type is mainly cultivated land, and the land use change during the study period shows a continuous decrease of cultivated land and a continuous increase of man-made land surface The reasons for this trend are as follows.

With the accelerated urbanization and industrialization, Bengbu City was in a state of comprehensive development during the study period, with high input costs, extensive construction, and large-scale industries, while for the improvement of public facilities and the promotion of rural revitalization, a large amount of land was needed for support. Therefore, the demand for all kinds of land in Bengbu City during the study period shows an increase, especially for urban construction land, which also leads to an increasingly sharp contradiction between land supply and demand in Bengbu City. While Bengbu City, is an industrial city, today's industrialization level is in urgent need of improvement, the vitality of market players is not enough, and the overall industrial quality also needs to be improved, so Bengbu City is vigorously promoting the construction of the central city, infrastructure construction, and service facilities during the 13th Five-Year Plan period, while the influx of rural population into the city, to meet the requirements of the urbanization process, leading to the growing trend of the manmade land surface and the arable land area in Bengbu City decrease.

4.2 Future Land Use Structure and Planning Recommendations for Bengbu City

By constructing a Markov model to predict the trend of land use structure change in Bengbu City during the new planning period, Bengbu City will still continue with the current change pattern in the next 20 years, but the decrease of arable land area is small and will not lead to a significant decrease of arable land area in the next 20 years, but during the new planning period, Bengbu City will continue to enhance the level of urban capacity and public services and accelerate the development of a city with important influence in the Huaihe River Basin and the central city in northern Anhui Province, the arable land area may not decrease at the expected rate, and in order to prevent the acceleration of the reduction of the arable land area, this foretells people to strengthen the protection of arable land in the next decade or so, and at the same time should coordinate the layout of urban and rural industries, infrastructure, resources and energy, ecological environment, etc., improve the degree of economical and intensive use of urban construction land itself, and form A spatial pattern of urban and rural areas with a reasonable layout, clear hierarchy, clear functions and distinctive features.

ACKNOWLEDGMENT

This work was supported in part by the Natural Science Foundation of the Higher Education Institutions of 2021 National Project of Student Innovation and Entrepreneurship Training Program under Grant No. 202110378095.

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