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Analysis of Land Use/Cover Characteristics and Dynamic of Changes in Huai River Basin from 2000 to 2020

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ABSTRACT

Globally, land use is considered as one of the most closely related link between human being and nature. But land use/cover change (LULC) is regarded as the main cause for global environmental change with possible serious impact on human livelihoods and many parts of social and physical environmental aspects. Huai River Basin (HRB) is among the global river-land ecosystems that has been intensively altered by land use change. Unfortunately, the increasing land use change in HRB is not well scientifically addressed and still, related existing problems are not solved putting the basin ecological status and its basic grain production agricultural capacity at risks. This study adopted data image processing software and various mathematical statistical models to analyze the current LULC characteristics and dynamics of change in the study basin. From the analysis that adopted combined scientific techniques of CA-Markov, InVEST models with ArcGIS and IDRISI software, the results indicate that in 20 years of study, area of cultivated land in HRB declined by -4.34%, grassland declined by -21.28%, forest land declined by -3.22% and unused land declined by -18.84% while area of construction land increased by 26.38% and water area increased by 11.62%. Cultivated land was the major land use type in the basin while unused land was the minor land use type. Land use projection trend of HRB in 2035 predicts decline of areas coverage on cultivated land by -6.92%, on forestland by -9.20% and on grassland by -12.29%. But the basin is expected to have area increase on construction land by 30.07%, on water area by 15.03% and on unused land by 18.45%. Pictorial summary for the analysis of land use/cover characteristics and dynamic of changes in HRB is shown below.

KEYWORDS

Land Use/Cover Change, Riverine Ecosystem, Huai River Basin, Multi-scenario, Simulation, CA-Markov, InVEST.

1. INTRODUCTION

LULC is a major factor for global environmental change with severe impacts on human livelihoods (Chauhan, Kumar & Paliwal, 2020; Guzha et al., 2018; Ning et al., 2018). It is the key modifier to important physical properties of land surface like roughness, albedo and evapotranspiration crucial for ecological processes (Cui et al., 2021). LULC is also a prime driver responsible directly for shaping landscape patterns which in turn change the structure and composition of ecosystems (Hou et al., 2021; Liu et al., 2020; Qi et al., 2019). HRB is among the global river-land ecosystems that has been severely modified by land use change (Cui et al., 2021). Much of the basin fragile natural ecosystem has been reported to be considerably modified (Zhai et al., 2017). In addition, its natural streamflow trend has declined significantly (Pan et al., 2018). Construction of 36 large dams, 5674 reservoirs and 5427 floodgates along the basin (Chen et al., 2020; Zhang et al., 2010) and ongoing South to North Water Transfer Projects (Liu et al., 2013) are the major land use change that have been reported to modify the basin fragile ecosystem.

HRB is the capital asset among the World's ecosystems (Zhao et al., 2011). The basin is endowed with innumerous ecological potential, and it is an important grain producing agriculture region in China (Chen et al., 2020; Zhang et al., 2020; Sun et al., 2019) supplying 22.29% of the national grain (Qiao et al., 2024). Nevertheless, HRB is the most densely inhabited river basin in China with the highest population density of 662 persons per km^2 in the country (Sun et al., 2019; Zhang et al., 2015). Currently, the basin support 206 million people about 13.1% of China population (Xu, Sun & Ji, 2021). The river-land ecosystem of HRB is fragile due to its position on transition climatic zone (Zhang et al., 2020). Besides, frequent occurrence of serious floods disasters and drought event has exposed the basin ecological environment to be more vulnerable (Chen et al., 2020; Sun et al., 2019). The present increasing land use change in the basin greatly threatens ecosystem potentiality of HRB and its grain production agricultural capacity in China (You et al., 2023; Cui et al., 2021).

Given the present situation of the basin, a comprehensive land use analysis of HRB is inevitable for high-quality ecological and sustainable socio-economic development of the basin. Unfortunately, land use change in HRB has not been well addressed. But still, related existing problems are not solved which jeopardize the basin ecological status and its basic grain supply agricultural capacity. Prior studies undertaken on land use change in HRB did not dwell much on the subject but provided a brief analysis. Mostly focused on impact of land uses on water quality variation (Wang et al., 2023; Jun et al., 2018; Wu, Zhang & She, 2017; Zhai et al., 2014; Zhang et al., 2010), changes in surface water (Xia et al., 2019) and stream flow prediction (Sun et al., 2018; Song et al., 2016). This study intend to provide a detailed analysis and discussion on land use/cover change of the basin by exploring land use characteristics and dynamic of changes using scientific methods of CA-Markov, InVEST models with ArcGIS and IDRISI software. Furthermore, it provides insight of HRB's future LULC trend through multi-scenario simulation projection for 2035. The findings of the study are intended to be a tool that will inform and equip ecological policy makers of the basin on high-quality sustainable ecological development planning of the fragile HRB ecosystem. It could be useful as scientific reference for ecological, socio-economic conservation management and rational use of land resources of the basin. Therefore, the study of land use/cover characteristics and dynamic of changes in Huai River Basin is inevitable and of great significance.

2. METHODS

2.1. Study Area

HRB is located between Yangtze River and Yellow River (Xu et al., 2019) along Latitude 30°55′ to 36°36′N and Longitude 111°55′ to 121°25′E (Mou et al., 2020). It is the sixth largest river basin in China (Zhao et al., 2011) composing five provinces (Figure 1) including Hubei, Henan, Anhui, Jiangsu and Shandong with total area of 274,657km^2 (Xia et al., 2019; Pan et al., 2018).

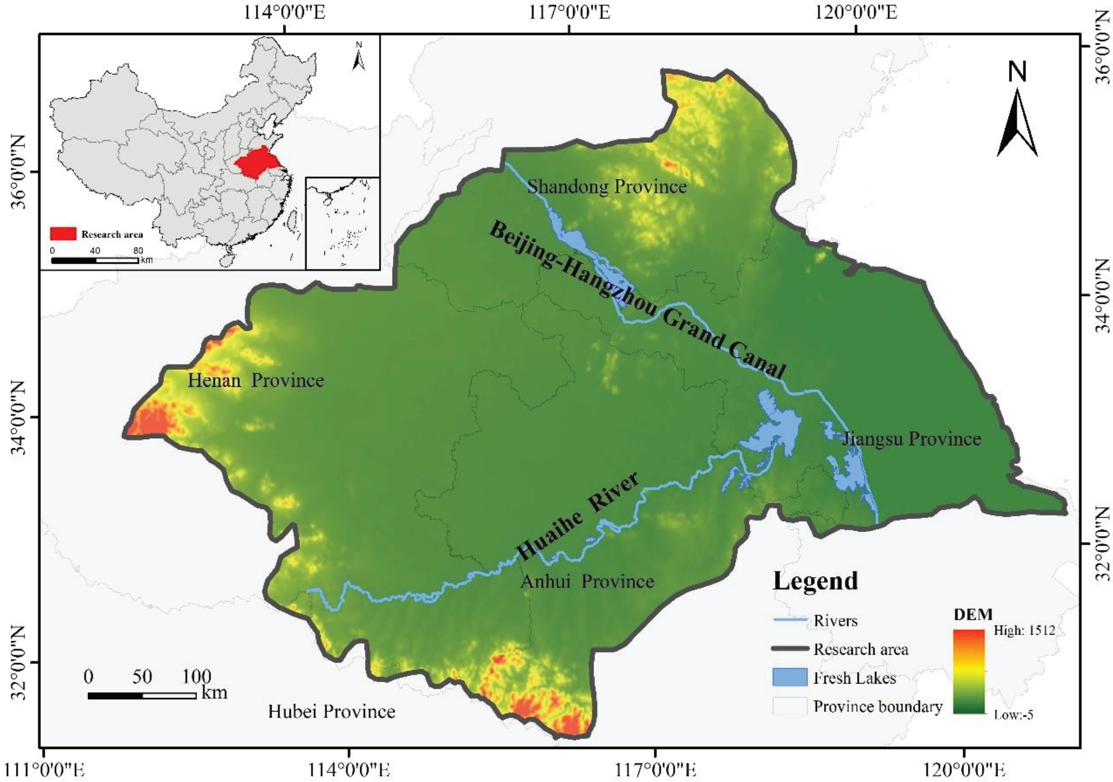

Figure 1. Geographical Position of Huai River Basin

HRB is drained by Huai River flowing from Tongbai mountains in Henan province (Li et al., 2021; Xu, Sun & Ji, 2021). It flows from the West to the East of the basin with 1,200km long through five provinces into the Yellow Sea (Xia et al., 2019; Xu et al., 2019). The general basin topography is substantial plain with mountains and hills in the North, West, South and Southwest of the basin (Song et al., 2023; Li et al., 2022). HRB is situated along North-South climate transition zone (Mou et al., 2020; Zhai, Xia & Zhang, 2017) thus, lies along humid and semi-humid monsoon climate (Sun et al., 2019). Annual precipitation ranges from 637mm to 1287.5mm per year (Jun et al., 2018) with annual average of 970mm (Li et al., 2021; Xia et al., 2019) which is unevenly spatial temporal distributed in the basin (Kai, Deyi & Zhaohui, 2016; Xia et al., 2014). Annual mean temperature range between 11^{o}C to 16^{o}C (Xia et al., 2019; Pan et al., 2018; Jun et al., 2018) increases from North to South of the basin and from coastal areas to inland areas (Li et al., 2021; Song et al., 2016). The conducive climatic condition of the basin is suitable for crop cultivation making the basin to be the best grain producing region in China (Zhang et al., 2015).

2.2. Data Source and Data Analysis

This paper adopted combination of different scientific techniques including CA-Markov, statistical and mathematical models with ArcGIS and IDRISI software in acquiring of data, data analysis and presentation of the findings. Land use/cover characteristics and dynamic changes was examined through adopted models and software using gathered data sets from different data sources (Table 1). Acquired land use data were initially reclassified into six categories according to the land use classification system using ArcGIS software. From six land use types obtained, corresponding land use maps were made. The output semantic maps were then adopted in the analysis of quantitative structure of land use but also in multi-scenario simulation of LULC of HRB in 2035. Table 1 shows the gathered data from different data sources which were used by this study.

Table 1. Type of Data and Data Sources

Data Type	Form/ Resolution	Sources
Land-use data	Grid, 30 m	https://zenodo.org/record/5816591#.YwSEFXZByF6, http://www.resdc.cn/
DEM and population density data	Grid, 1 km	http://www.resdc.cn/Default.aspx
Basic geographic information data	Vector shapefile, 1 km	http://www.resdc.cn/Default.aspx
Administrative boundaries data		http://ngcc.sbsm.gov.cn/
Socio-economic data	Dbf	Derived from respective provincial statistical yearbooks: http://www.statshb.gov.cn/, http://www.ahtjj.gov.cn/, http://www.ha.stats.gov.cn/, http://www.jssb.gov.cn/ http://www.stats-sd.gov.cn/

Quantitative structure of land use in HRB was examined in terms of statistics of land use change and land use transfer matrix. Land use classification data of 2000, 2005, 2010, 2015 and 2020 were initially converted into vector data format using spatial analysis function of ArcGIS. Then, acquired results were loaded into analysis tools overlay intersect of ArcGIS whereby, statistics of land use change of the study basin from 2000 to 2020 in different land use types were established. Furthermore, area transfer matrix between different land use types were analyzed as well. The study established quantitative transformation relationship of land use types using land use transfer matrix from 2000 to 2020. According to Ma, Han & Wang (2020), established transformation relationship reflect direction of area reduction, or source of area increase of the studied land use type in HRB, mathematically expressed by Formula 1.

$$C = \begin{bmatrix} C_{11} & C_{12} & \cdots & C_{1j} \\ C_{21} & C_{22} & \cdots & C_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ C_{i1} & C_{i2} & \cdots & C_{ij} \end{bmatrix} \quad (1)$$

Where:

C_{ij} is the number of conversions between the i and the j land use types.

Multi-scenario simulation projection of LULC in 2035 of the basin was examined using CA-Markov model and IDRISI software. Initially, land transformation suitability atlas was established. Employing IDRISI RGF grid layer, suitability images of all land use types of the basin were integrated. Thereafter, the Land Transformation Suitability Atlas was generated through Collection Editor. But then, simulation accuracy and reliability of transition rule in CA-Markov prediction was run before projection of LULC trend of the basin. Accuracy analysis was performed by simulating land use type of HRB in 2020 using IDRISI software. The difference between land use type in 2020 and actual land use type in 2020 was calculated using CA-Markov module. Land use type in 2015 was set as the base period image and Markov transfer area file as transfer area file was obtained by Markov module.

Transformation rules was set to land suitability atlas 2015 together with land use data in 2015 to 2020, cycle number was set to 5.

3. RESULTS

3.1. Quantitative Structure of Land Use in HRB

Six identified proportion land use types in the basin namely cultivated land, forest land (woodland), grassland, water area, construction land (building) and unused land were established from land use classification system. Analysis and discussion of quantitative structure of land use in HRB was conducted in terms of Statistics of Land Use Change and Land Use Transfer Matrix using established classified land use types together with corresponding output of land use semantic maps.

3.1.1. Statistics of Land Use Change in HRB

The findings (Table 2.) indicate all land use types under study in HRB had changes during the 20 years of study. The study show that cultivated land was the dominant land use type in the basin. It accounted for 71.87% of the basin area coverage in 2000, 71.45% in 2005, 71% in 2010, 70.44% in 2015 and 68.8% in 2020. Unused land was the minor land use type with area coverage of 0.08%, 0.08%, 0.08%, 0.09% and 0.06% respectively, of the basin. Construction land had 12.92%, 13.26%, 13.68%, 14.24% and 16.36% respectively, area coverage. Forest land had 6.33%, 6.32%, 6.33%, 6.31% and 6.14% respectively, area coverage. Water area had 4.88%, 5.02%, 5.05%, 5.08% and 5.46% respectively, area coverage and grassland had 3.92%, 3.87%, 3.86%, 3.83% and 3.09% respectively, of the basin area coverage (Table 2.).

Table 2. Area of Land Use types in HRB from 2000 to 2020 (in km2)

	2000	2005	2010	2015	2020
Cultivated Land	188337	187254	186078	184597	180161
Woodland	16586	16550	16593	16539	16052
Grassland	10268	10149	10117	10049	8083
Water Area	12795	13159	13224	13326	14282
Building	33868	34739	35841	37326	42801
Unused Land	207	213	212	231	168

From 2000 to 2020, the basin recorded great changes on land use types as shown by Figure 2. and Figure 3. The study exposed that the basin recorded area increase on construction land by 26.38% (8,933km^2) from 33,868km^2 in 2000 to 42,801km^2 in 2020 and water area by 11.62% (1,487km^2) from 12,795km^2 in 2000 to 14,282km^2 in 2020. But then, basin recorded area coverage decline on cultivated land by -4.34% (8,176km^2) from 188,337km^2 in 2000 to 180,161km^2 in 2020. On grassland by -21.28% (2,185km^2) declined from 10,268km^2 in 2000 to 8,083km^2 in 2020. From forest land by -3.22% (534km^2) declined from 16,586km^2 in 2000 to 16,052km^2 in 2020. Furthermore, unused land declined by -18.84% (39km^2) from 207km^2 in 2000 to 168km^2 in 2020. Land use changes in the basin are illustrated by Figure 2. and Figure 3 are Semantic Maps depicting land use in the study basin during the study time.

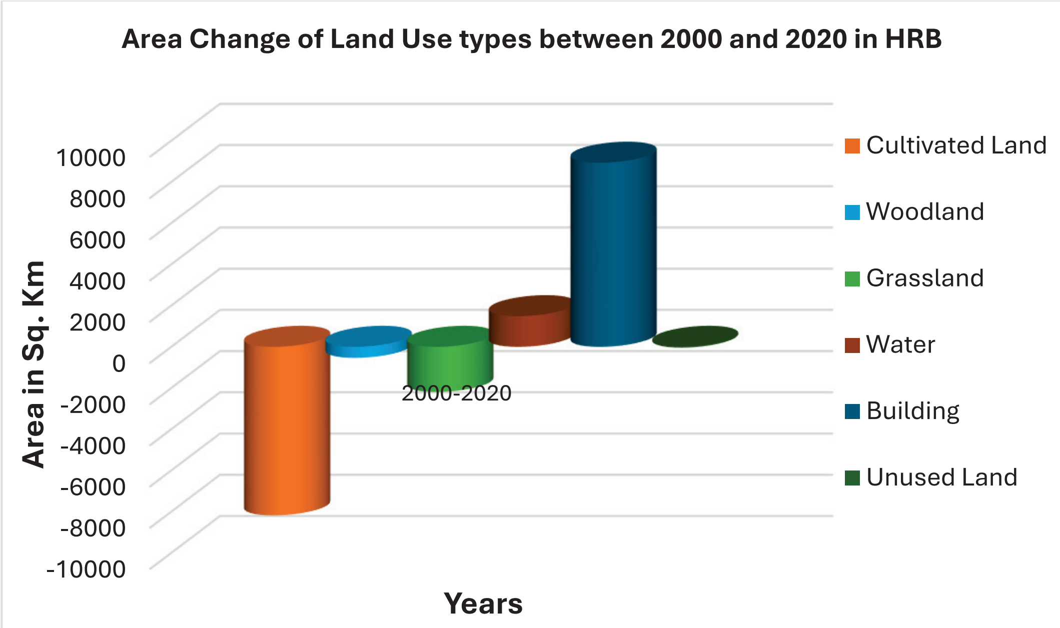

Figure 2. Changes of Land Use in Huai River Basin from 2000 to 2020

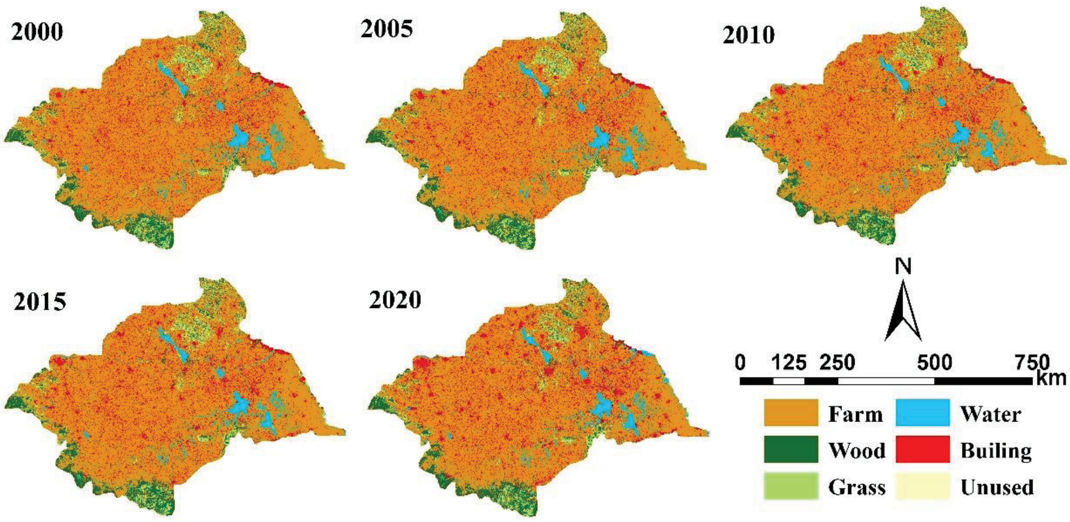

Figure 3. Semantic Maps showing Land Use in HRB from 2000 to 2020

3.1.2. Land Use Transfer Matrix in HRB

From 2000 to 2020, the study exposed significant land use conversion of different land use types under study in the basin. The findings (Table 3), show that major land use transformation occurred in basin were from grassland, about 3,441km^2 were converted into cultivated land, 1,583km^2 into woodland, 543km^2 into construction land and 457km^2 into water area. But then, 29,555km^2 of cultivated land were transformed into construction land, 4,335km^2 into water area, 3,329km^2 into woodland and 1,945km^2 into grassland. A total of 3,436km^2 of woodland were also changed into cultivated land, 1,616km^2 into grassland, 510km^2 into construction land and 294km^2 into water area. Moreover, 20,901km^2 of construction land were transformed into cultivated land, 1,160km^2 into water area, 199km^2 into grassland, 177km^2 into woodland and 16km^2 into unused land. From water area, 3,519km^2 were transformed into cultivated land, 805km^2 into construction land, 256km^2 into woodland and 140km^2 into grassland. 17km^2 into unused land. Semantic Map (Figure 4) also depict transformation of land use types that occurred in the basin.

Table 3. Land Use Transfer Matrix in HRB from 2000 to 2020 (in km2)

Time	2020							
	Type	Grassland	Cultivated Land	Building	Woodland	Water Area	Unused Land	Total
2000	Grassland	4162	3441	543	1583	457	37	10223
	Cultivated land	1945	148747	29555	3329	4335	48	187959
	Building	199	20901	11349	177	1160	16	33802
	Woodland	1616	3436	510	10676	294	17	16549
	Water Area	140	3519	805	256	8002	17	12739
	Unused Land	19	88	32	27	8	33	207
	Total	8081	180132	42794	16048	14256	168	261479

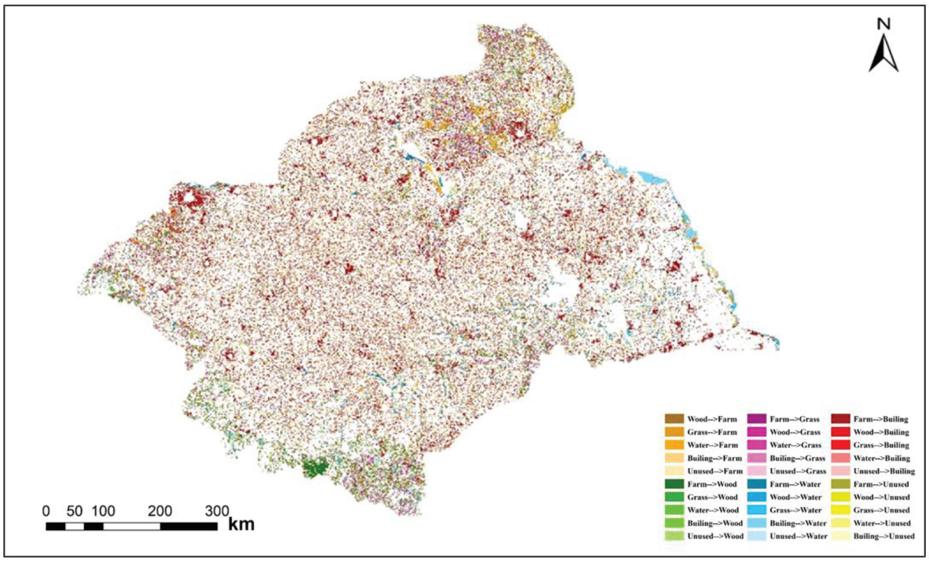

Figure 4. Semantic Map showing Land Use Changes in HRB from 2000 to 2020

3.2. Multi-scenario Simulation of LULC in HRB in 2035

Different scientific techniques were adopted for multi-scenario simulation projection. The study established land transformation suitability atlas and conducted simulation accuracy verification for 2035 land use projection in the basin.

3.2.1. Establishment of Land Transformation Suitability Atlas

Weighted Linear Combination (WLC) method was employed by the study among the Multiple Criteria Evaluation (MCE) methods to generate around suitability images. MCE is characterized by three multiple standards including Boolean Intersection, WLC and OWA methods. The study used WLC method in generating different types of land use suitability images because it ensure scientific nature and rationality of the results. Limiting and impact factors in the basin were set for analysis of each land use change of the land use types under study. For instance, rivers, elevation and slope were set as limiting factors for cultivated land because there was no cultivated land distributed in rivers and lakes. Thus, Land Transformation Suitability Atlas of the basin (Figure 5) was generated according to the sequence of land type coding through collection editor module. It was then used as CA transformation rule for prediction of land use type in 2035. Figure 5 depicts images of class suitability of different regions in HRB.

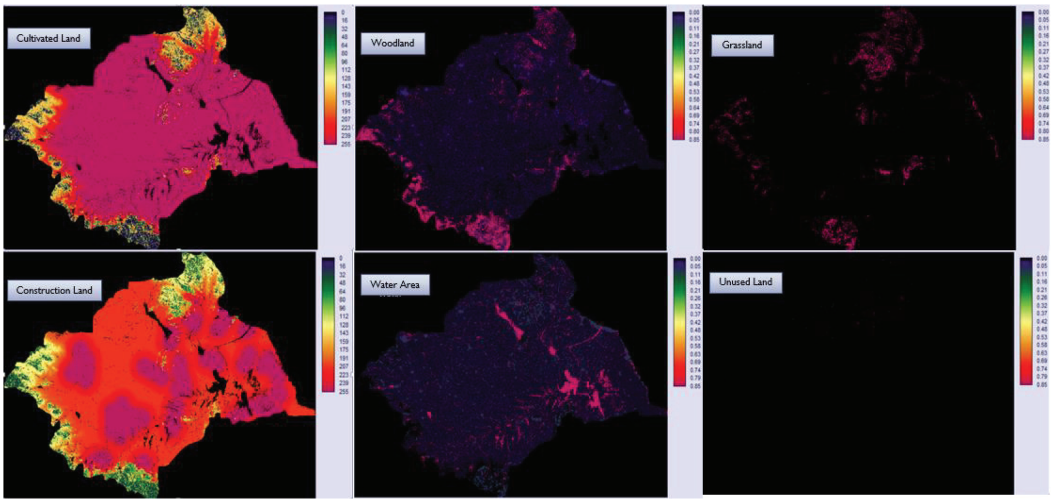

Figure 5. Image of Local Suitability in HRB in 2020

3.2.2. Simulation and Prediction of Land Use in HRB in 2035

CA-Markov model was adopted to run accuracy and reliability verification. The study verified simulation accuracy in quantity and space. The output (Figure 6) predicted simulation map of land use types of 2020 was compared with actual land use types in 2020.

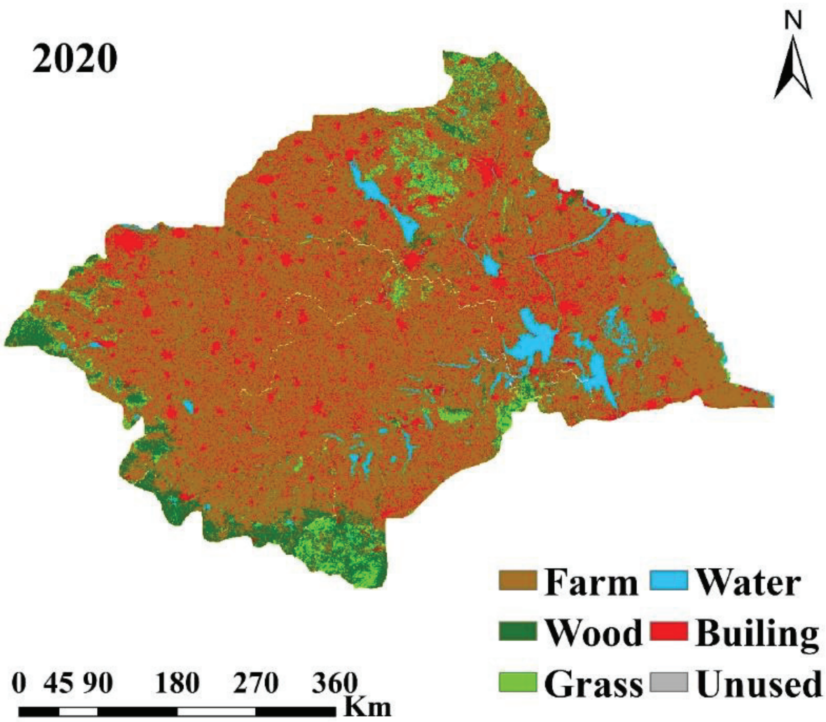

Figure 6. Land use type simulation Map for 2020

3.2.2.1 Quantitative Simulation Accuracy

The absolute error value of actual area and simulated area of each land use type in 2020 was calculated to verify its quantitative simulation accuracy as shown by formula 2. and the result are presented by Table 4.

$$E = \left(\frac{X_{ip} - X_{it}}{X_{it}} \right) \times 100\% \tag{2}$$

Where:

E represents the quantitative accuracy of the land use type in I

X_{ip} is the predicted area of land use type in study area I

X_{it} is the actual area of the land use type in study area I

Formula 2. indicate that the smaller the absolute value of E, the higher the accuracy of simulation results. When E > 0, it means that the predicted area of the land use type is larger than the actual area. When E < 0, it means that the predicted area of the land use type is smaller than the actual area.

Table 4. Accuracy Analysis of Land Use Forecasts in HRB in 2020 (in Km^2)

Type	True	Predict	Error Precision
Cultivated land	180161	156002	-13.41
Woodland	16052	16426	2.33
Grassland	8083	6798	-15.89
Water Area	14282	15059	5.44
Building	42801	46469	8.57
Unused Land	168	154	-8.33

Table 4 shows comparison of quantitative accuracy of land use prediction map of 2020 and actual land use map of 2020 of HRB. The error values of all other regions are small except for construction land. This is due to small distribution area of construction land in the base period image in 2015. Development of social economy and influence of government planning in recent years affected urban construction land by artificial uncertainty. Generally, CA-Markov prediction is good as it can reasonably predict the variation trend of each category in the study basin.

3.2.2.2 Spatial Simulation Accuracy

The study used Crosstab Module of IDRISI software to calculate Kappa coefficient of land use type simulation of HRB in 2020 to realize spatial accuracy analysis as shown by formula 3.

$$\text{Kappa} = (P_o - P_a)/(P_p - P_a) \tag{3}$$

Where:

P_o is the correct simulated ratio

P_a is the correct proportion of expectation simulation under random

P_p is the ideal ratio to simulate correctly

Through crosstab module of IDRISI software, the study performed spatial superposition analysis of 2020 land use simulation map and actual map. Kappa coefficient of forecast map and actual map was derived as the evaluation index of the spatial accuracy of trend prediction in HRB. Kappa coefficient of 0.8984 was obtained indicating the simulation condition of the study basin was good. It is certainly reliable. When the result of simulation is 0.75 indicates strong reliability. Thereafter, the study conducted land use change projection trend of HRB in 2035 using CA-Markov module of IDRISI software.

Land transition suitability atlas, land use types in 2020 as the base period data, land use transfer matrix from 2000 to 2020 combined with suitability images of each land use type in 2020 were adopted in the projection process. Acquired results were HRB land use change trend in 2035 (Figure 7) and established semantic map of land use projection of HRB in 2035 as depicted by Figure 8.

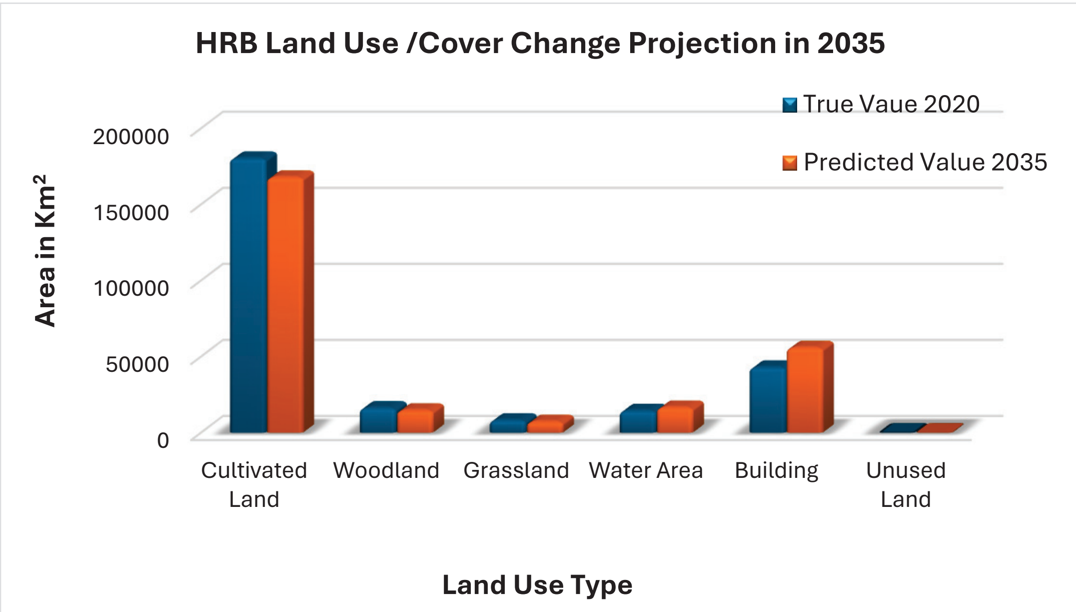

Figure 7. Projection Trends of Land Use Change in HRB in 2035

Results of land use projection trend (Figure 7) predict a substantial change will occur on HRB land use/cover in 2035. One of the main factor is rapid development of human activities and social economy. From Figure 7, the study expect areas coverage of cultivated land to decline by -6.92% (12,474km^2) in 2035 from 180,161km^2 in 2020 to 167,687km^2 in 2035. But also, area coverage of forestland will decline by -9.20% (1476km^2) in 2035 from 16,052km^2 in 2020 to 14,576km^2 in 2035. Similarly, grassland is projected to decline by -12.29% (993 km^2) in 2035 from 8,083km^2 in 2020 to 7,090km^2 in 2035. With the present development of modernization, part of forestland and grassland could be transformed into construction land. But then, the study expect area coverage increase on construction land by 30.07% (12,870km^2) in 2035 from 42,801km^2 in 2020 to 55,671km^2 in 2035. Similarly, water area coverage will increase by 15.03% (2,147km^2) in 2035 from 14,282km^2 in 2020 to 16,429km^2 in 2035. The area coverage increase of water area could be related with the influence of the ongoing water transfer projects in the basin like the middle route of South-to-North Water

Transfer Project. Lastly, the study project area coverage increase on unused land by 18.45% (31km^2) in 2035 from 168km^2 in 2020 to 199km^2 in 2035. Figure 8 is a Semantic Map depicting the land use change trend projection in HRB.

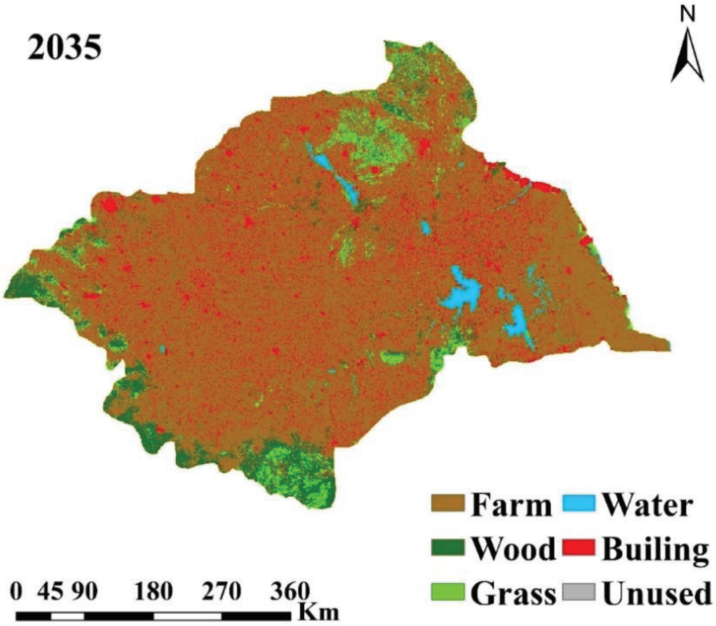

Figure 8. Land Use Projection for HRB in 2035

4. DISCUSSION

This paper presented analysis and discussion on land use/cover characteristics and dynamic of changes in HRB. At present, HRB is facing a new ecological condition and economic development that pose new ecological needs and conservation strengthening requirements. In 20 years of study, the paper has identified grassland, construction land, cultivated land, forest land, water area and unused land as proportion land use types of the basin as it was also identified by Sun et al. (2019). Cultivated land and construction land were the most commonly distributed in the basin as similarly reported by Zhai, Xia & Zhang (2017) and Zhang et al. (2015). Cultivated land was predominantly distributed in plain areas where mostly exploited as farmland. Zhang et al. (2020) and Pan et al. (2018) confirmed about 12.7 million hectares in plain areas of the basin are utilized for cultivation. Construction land in the basin is distributed around counties and cities. But then, water area is distributed in lakes like Luoma and Gaoyou (Huang et al., 2022). Grassland and forest land are found in Funiu, Tongbai, Dabie and Yimeng Mountains. However, the paper revealed that during the entire study time, changes have occurred on land use in HRB. The study observed:

(1) From 2000 to 2020, land use/cover characteristics and dynamic of changes analysis showed cultivated land was a dominant land use type covering 70.7% of the basin area. Wang et al. (2023) reported, cultivated land accounted for 72.3% of the basin total area coverage in 2000 similarly to 71.87% reported by this paper. Area coverage in the basin increased on construction land by 26.38% and water area by 11.62%. But area coverage in the basin declined on cultivated land by -4.34%, grassland by -21.28%, forest land by -3.22% and unused land by -18.84% during the study period.

(2) From land use transfer matrix analysis, the paper revealed HRB experienced land use transformation during the entire study time. The main land use transformation were from grassland to cultivated land and woodland, from cultivated land to construction land, water area, woodland and

grassland, and from woodland to cultivated land. However, substantial land use conversion in the basin were from other land use into water area. Construction of more than 5,700 dams and 5,427 floodgates in the basin (Zhang et al., 2015; Xia et al., 2014; Liu et al., 2013; Zhang et al., 2010) is one scenario. Another scenario is the current water transfer projects like the Middle Route Project of South to North Water Transfer and the East Route Project (Yuan et al., 2015; Hu et al., 2008). Conversion of cultivated land to water area, forest land to water area and grassland to water area were mainly concentrated near water resources. Other land use types, especially those located on places with unsuitable slope were converted into planting trees and grass under influence of returning farmland to forest and grassland policy on the basin (Deng, Shangguan & Li, 2012). Lastly, conversion of cultivated land into construction land were largely found around construction land due to expansion of urbanization.

(3) From multi-scenario simulation projection, the paper predict that in 2035, HRB will have area coverage decline on cultivated land by -6.92%, on forestland by -9.20% and on grassland by -12.29%. The decline of the area coverage of the mentioned land use types could be associated with the current rapid development undertaking in basin that in turn, trigger conversion of forestland and grassland into construction land. But then, it could also be related with 30.07% area coverage projection increase on construction land in 2035. The paper also predict coverage increase on water area by 15.03% and unused land by 18.45% in 2035.

5. CONCLUSION

The ecological potentiality of HRB fragile ecosystem together with its important basic grain production agricultural capacity in China is at risk if the increasing land use change observed by the study continue to accelerate. The projected -6.92% decline of cultivated land as a dominant (70.7%) land use type in the basin pose a threat the future food security of China as well. The present basin ecological situation is also attributed by exposed land use conversion like from grassland to cultivated land and woodland, and from cultivated land to construction land, water area, woodland and grassland by the study. However, the forecasted future land use change of HRB in 2035 reflect the ongoing rapid population increase, rapid growth of human activities and social economy development in the basin. The findings of this paper provide an insight of the impact of land use change in the basin but could also be a scientific reference for the HRB management and policy formulation to the riverine ecosystem. The study proposes that it is so urgent now to establish and improve ecological conservation system of the fragile HRB ecosystem while improving regional coordination and cooperation mechanism in the basin. There is also a vital need to expand the scope of protection while taking protection measures to promote common sustainable development of ecology and the basin economy.

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