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Research article

The impact of land use on eco-environment in the Dianchi Basin

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A R T I C L E I N F O

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Change of land use type
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A B S T R A C T

(1) Studying the dynamic correlation between land use and the eco-environment in the Dianchi Basin is important for improving the basin's spatial layout and enhancing ecological development and conservation; (2) Through dynamic analysis and comprehensive evaluation of land use, the introduction of ecological and environmental quality index, and the use of FLUS models, the impacts on eco-environments in the Dianchi Basin for the recent 20 years were analyzed; (3) The past two decades witnessed a constant increase in the construction land in the Dianchi Basin and a decline in the farmland at an average annual rate of 0.93 %; The utilization level of land in the Dianchi Basin presented a negative correlation with the quality of the area's eco-environment, which reduces first and then increases; When natural production becomes a priority, both the construction land and farmland have witnessed growth. However, when ecological protection becomes a priority, it is projected that by 2035, the Dianchi Basin will achieve its highest eco-environmental quality index; (4) Studying how the change of land use types affects eco-environment is crucial for optimizing the current allocation of land resources and promoting sustainable development in the basin.

1. Introduction

With industrialization and urbanization, China has made remarkable progress in social and economic development, triggering profound changes in the land and spatial restructuring of the land use type and jeopardizing the ecological stability of the area [1,2]. Land use transition refers to the sequential change of land use type [3], a new integrated approach to measure the change of land use and land coverage (LUCC) [4]. The change of land use type plays a significant role in the change of ecological surroundings [5], and has an influence on regional eco-environment elements, ecosystem structure and function [6–10]. Understanding the ecological change of regional land use is a significant method in addressing environmental issues.

At present, many domestic and foreign scholars have conducted extensive studies on LUCC and its eco-environmental effects from global, intercontinental and regional perspectives. However, most of them focus on single factors such as climate, hydrology and biodiversity [11–13]. Domestic researches mainly revolve around ecologically fragile areas, large urban agglomeration and

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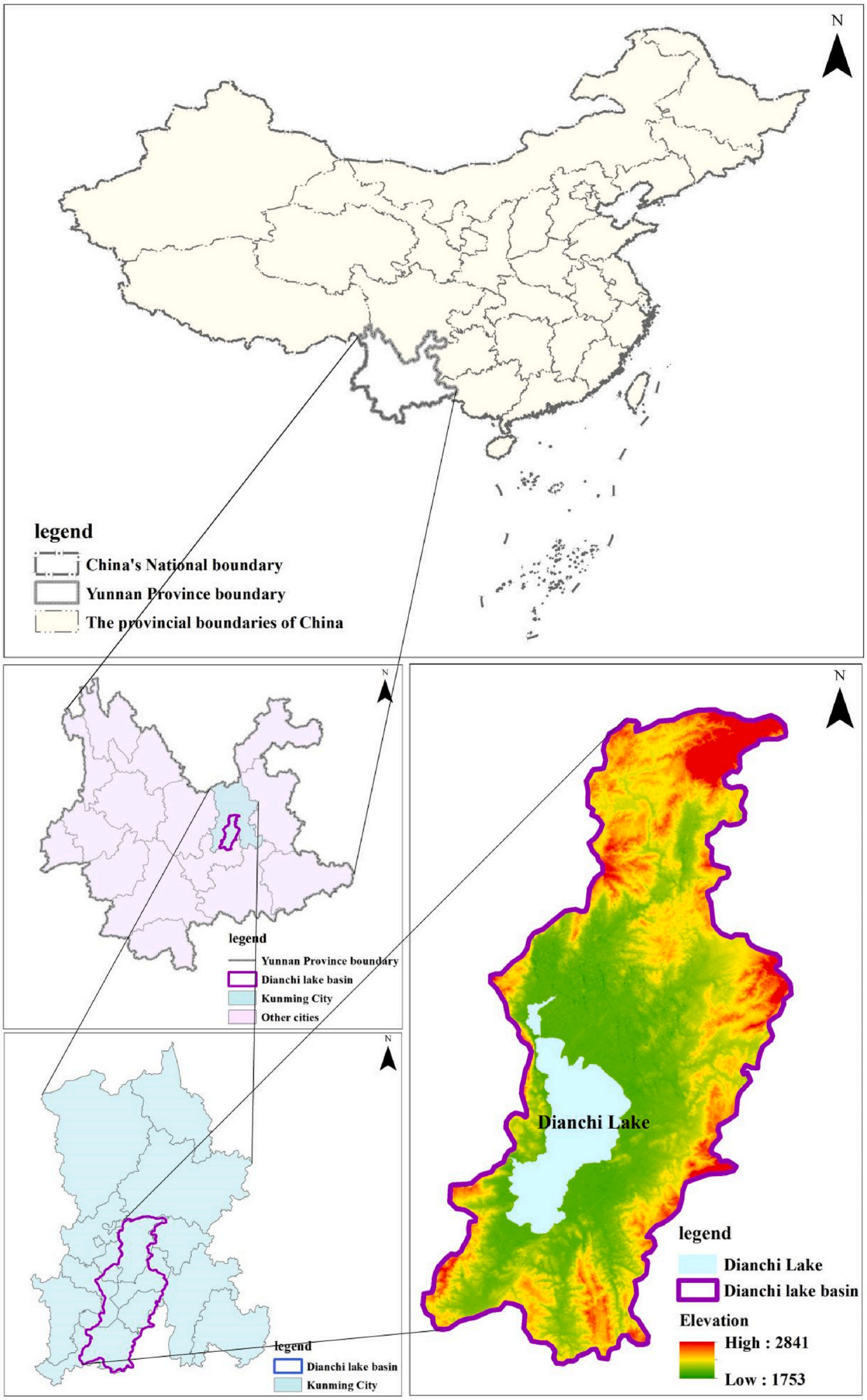

Fig. 1. General infographic of the study area.

economically developed areas, using transfer matrix and expansion intensity index, ecosystem service value assessment, grey correlation evaluation model, landscape ecological pattern factors and other methods to explore the spatio-temporal evolution law, interaction mechanism and regional differences of environmental effects caused by land use function type conversion [14–17]. In general, such studies mostly focused on macro-scale such as provinces and cities, and regional eco-environmental effects are mainly studied from single aspect such as eco-environmental quality and eco-services. On the contrary, there are not sufficient comprehensive quantitative studies on LUCC changes and eco-environmental effects in relation to typical river basins in southwest China. To assess the environmental impact of land use, the first is to measure the biomass and describe the eco-environment's quality level within the region, such as Net Primary Productivity of Vegetation (NPP) [18], Normalized Difference Vegetation Index (NDVI) [19], Enhanced Vegetation Index (EVI) [20] among other indexes, or Ecological Index (EI) [21], Remote Sensing Based Ecological Index(RSEI) [22], Remote Sensing Ecological Distance Index (RSEDI) [23] and other comprehensive index measurement; The second is to measure the change of land use and coverage based on comprehensive quantitative measurement methods, such as Landscape Ecological Risk Index (LERI) [24], Ecosystem Services Value (ESV) [25–27] and Ecoenvironmental Quality Index (EQI) (Gao et al., 2019; [16,28]) and so on. Among them, the eco-environmental quality index is centered on the ecological difference of various land use types. By probing into the correlation between the change of land use and coverage and the eco-environmental quality, we can quantitatively describe the spatio-temporal evolution of eco-environmental quality.

Domestic and foreign scholars usually study the change of land use through simulation factors, including LUCC driving factors [29], LUCC temporal and spatial change [30] and LUCC simulation and prediction [31,32]. Commonly used models are Markov model, CA model, system dynamics model, FLUS model, CLUE-S model, Logistic regression model, etc. [33–36]. As a key model of land use simulation, FLUS considers the distribution opportunity of non-dominant land use types [37], which can partly reflect that the land use would change without any uncertainty. This model provides a reliable basis for regional sustainable development and ecological civilization construction [38].

The Dianchi Basin is the most economically and socially active area in Kunming, even the whole Yunnan Province, and it is the focus of urban and rural development. However, due to climate change, human activities, large-scale and rapid economic development, the ecological adjustment and self-recovery capacity of the basin is gradually weakened, biodiversity is reduced, water quality deteriorates, and lake pollution is getting more serious, all of which are causing stringent problems in eco-environment in the basin region. There are many reasons leading to the intensification of lake pollution and difficult restoration of ecosystem functions in the basin, among which unreasonable land use is one of the most serious.

In order to reveal the changing process of land use and the temporal and spatial characteristics of eco-environment quality in the Dianchi Basin under the influence of human interference and other multiple scenarios, this paper uses FLUS model to predict land use type in the Dianchi Basin in 2035, combining eco-environment quality analysis. The land use data for the Dianchi Basin in 2000, 2005, 2010, 2015 and 2020 are used as the baseline to study the current type of the basin and its effect on the eco-environment for nearly 20 years. According to the "14th Five-Year Plan" and the 2035 Vision Goals, with 2035 as the target year, the layout of the land and the eco-environment condition of Dianchi Basin under multiple scenarios of ecological protection, production priority and natural development are simulated respectively. It is expected to provide reference for the spatial type optimization and ecological conservation of Dianchi Basin in 2035.

2. Overview of the study area

The Dianchi Basin (102°30′-103°02′E, 24°28′-25°23′N) situates in the heart of the Yunnan-Kweichow Plateau. It is the most expansive body of freshwater in the southwestern region of China as well as a crucial part of the nine tableland lake basins in Yunnan. The entire region is located in central Yunnan, with Liangwang Mountain Range in Songming County to the north, Zhaobi Mountain in Jinning District to the south, ranging from Liangwang Mountain in Chenggong District in the east and Daqingshan and Xishan in the west. The basin covers an area of 3061.2015 km^2, involving 7 administrative units. It has a humid subtropical monsoon climate with pleasant weather and flat terrain. The details for the study area are shown in Fig. 1 below.

As the water quality of the Dianchi Lake has reduced to Class V inferior since 1986, it has been brought under national key basin management. It was not until 2016 that the water quality of Dianchi Lake was improved, the water quality has been upgraded from poor Class V to Class V, the comprehensive nutrient status index of the whole lake has reduced to 61.9 [39]. Although the pollution has alleviated somewhat, the quality of ecological conservation in the Dianchi Basin is still not optimistic, the main reason is that Dianchi Lake is located in the lowest terrain of Kunming city and is the only receiving water body of domestic pollution sources, the pollution is let out into the lake increases year by year, and urban pollution has become the number one polluting factor in the Dianchi Basin [40]. The terrestrial ecosystem in the Dianchi Basin is seriously damaged, the lake ecosystem is degraded, and the region lacks capacity for eco-environment system governance and supervision.

Table 1
Classification of land use degree.

type	Unused land level	Forest, grass, water use prefectural level	Agricultural use of prefectural level	Urban settlements use prefecture level
Land use type	Unused land	Forest land, grassland, water body	Farmland	Construction land
Classification index	1	2	3	4

3. Data sources and research methods

3.1. Data source and processing

All the data for DEM data and the change of land use employed in this study are obtained from the Geospatial Data Cloud (https://www.gscloud.cn/sources), with the spatial resolution measuring 30 m by 30 m. This paper uses ArcGIS10.6 to extract the Dianchi Basin data and transforms them into vector data to obtain the vector boundary. Five periods of Landsat data are selected for November 2, 2000 (TM), February 1, 2005 (TM), January 30, 2010 (TM), January 4, 2015 (OLI) and January 18, 2020 (OLI), and the cloud cover is respectively 0 %, 0 %, 0 %, 0.1 % and 0.03 %. The land use images are processed with ENVI5.3 software according to the industry standard of the Ministry of Natural Resources and Guidelines for Classifying Land and Ocean Utilization for the National Space (Trial) [41], involving atmospheric correction, radiation correction, image stitching and cropping. The study area is reclassified into six different land use categories, including farmland, forest land, construction land, grassland, water body and unused land. The accuracy was verified by field verification and Google Earth high-resolution historical images, the Kappa index of classification results of land use data in 2000, 2005, 2010, 2015 and 2020 was 0.93, 0.95, 0.96, 0.95 and 0.94, respectively.

3.2. Research methods

3.2.1. Single land use dynamic attitude

Through quantitative assessment of single land use dynamics, we are able to analyze the variations in human activities across various land use categories within a specific timeframe in the study area. The formulation is presented below [42]:

$$K = [(U_{it2} - U_{it1}) / U_{it1}] / T \times 100\%$$

Where: The dynamic attitude of land use types of type i from t_1 to t_2 is denoted by K; U_{it1} and U_{it2} refer to the number of type i land use types at t_1 and t_2 respectively [43].

3.2.2. Comprehensive index model of land use degree

The comprehensive index model can effectively describe the land use degree and reflect the depth and breadth of human activities on the land development and use of the lake basin. Referring to previous studies [44], the land use types in this area are divided into 4 levels. The higher the level of land use intensity is, the more the land use type is disturbed by human activities. The calculation methodology employed in this study is outlined as below [42] (Table 1).

$$I = \sum_{i=1}^{n} (A_i \times C_i) \times 100\%$$

Whereas: The study area's land use is represented by index I; Ai denotes the classification index of land use for Class i; Ci denotes the ratio of land use for grade i in relation to the overall area [45]. The formula for calculating changes in both quantity and rate of land use is presented as follows [46]:

$$\Delta L_{t2-t1} = L_{t2} - L_{t1}$$

$$\Delta L_{t2-t1} = 100 \times \left[\sum_{i=1}^{n} (A_i \times C_{it2}) - \sum_{i=1}^{n} (A_i \times C_{it1}) \right]$$

$$R = \frac{\sum_{i=1}^{n} (A_i \times C_{it2}) - \sum_{i=1}^{n} (A_i \times C_{it1})}{\sum_{i=1}^{n} (A_i \times C_{it1})}$$

Where: ΔL_{t2-t1} represents the change degree of land use between the initial time point t_1 and the final time point t_2. L_{t1} represents a comprehensive measure for assessing land use at the early stage, while L_{t2} corresponds to a similar measure for evaluating conditions at the late stage [47]. C_{it1} is the proportional representation for Class i's spatial coverage during early stages, whereas C_{it2} signifies its representation during later stages. Ai serves as an indicator for classifying specific types within Class i's use type. Parameter R quantifies changes occurring within overall degrees of land use. If $R < 0$ or $\Delta L_{t2-t1} < 0$, the negative value indicates declining trends; if $R = 0$ or $\Delta L_{t2-t1} = 0$, it implies stability; if $R > 0$ or $\Delta L_{t2-t1} > 0$, the positive values suggest developmental types.

Table 2
Land use type's EQI value.

Land use type	Farmland	Forest land	Grassland	Water body	Construction land	Unused land
Ecological environment quality impact index	0.250	0.716	0.412	0.622	0.200	0.023

3.2.3. Matrix for transferring land use

The matrix below [48] is adopted to study land use change, which can be expressed as follows [49]:

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

Where: S_{ij} refers to area; n represents different types of land use.

3.2.4. FLUS model

The FLUS developed by a Li Xia-led team in 2017 is an extensive simulation model, which integrates both human-induced and natural effects to analyze different land use scenarios [50]. Far superior to traditional cellular automata methods, FLUS can predict and

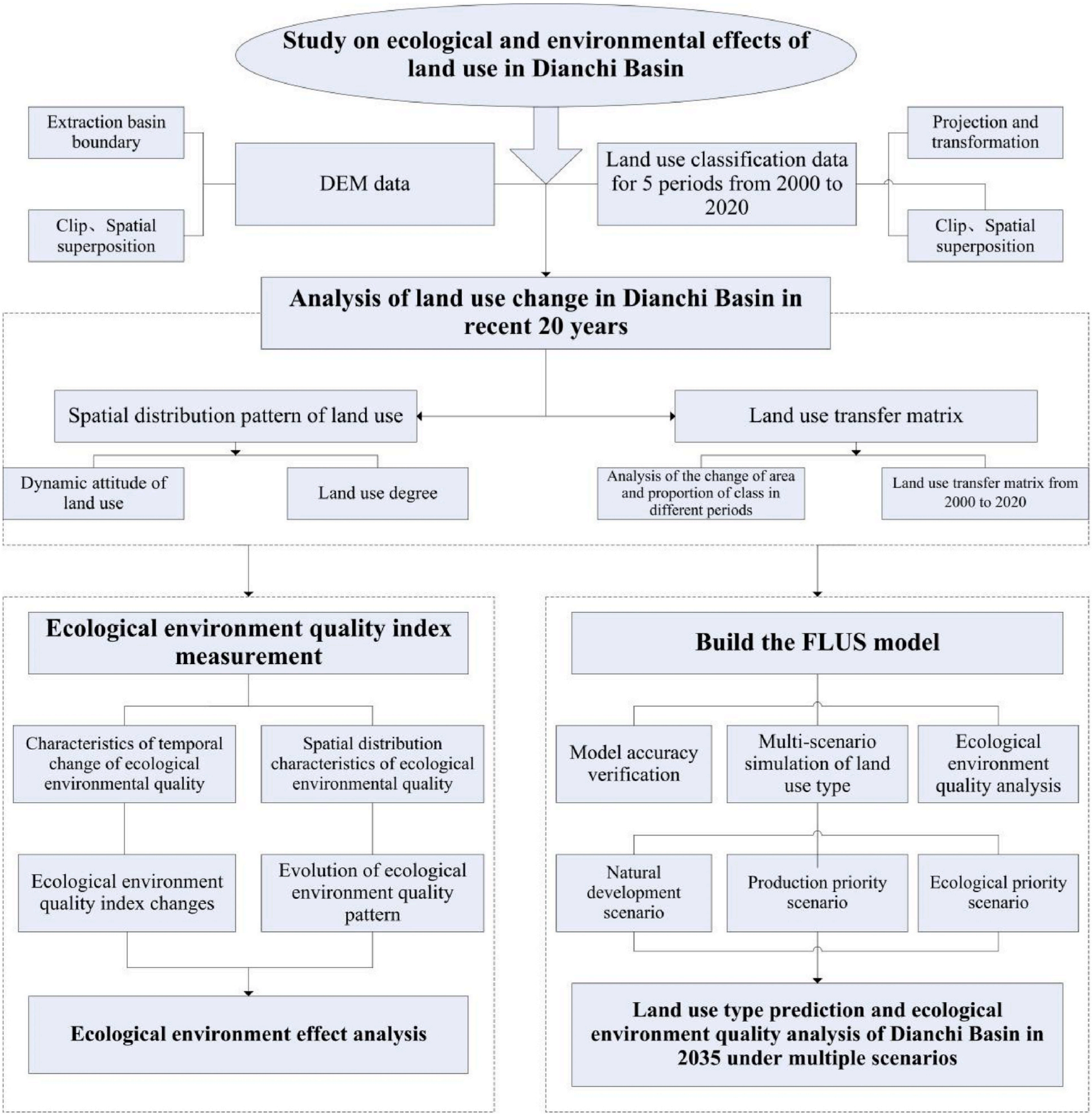

Fig. 2. Technology roadmap.

analyze changes of land utilization in the future [51]. The two primary elements of the model are a neural network-based module for calculating occurrence probabilities, and an adaptive inertia mechanism-based module for cellular automata calculations. In this research, land utilization information from Dianchi Basin in 2015 are selected as the baseline data, and the land use data from 2020 as test data while simulating the future land use patterns in Dianchi Basin by 2035.

(1) Neural network model

Suitability probabilities for various land utilization types within the study area are determined by Artificial Neural Networks (ANN) using initial data on land utilization together with relevant influencing elements such as human activities and natural influences (air temperature, precipitation, soil, terrain, traffic pattern, location, and policy, etc.). The three layers of the ANN model are used to train and assess the likelihood of grid transformations, which is expressed below:

$$sp(p,i,t) = \sum_j w_{j,i} \times 1 \Big/ \left(1 + e^{-net_j(p,t)}\right)$$

$$\sum_i sp(p,i,t) = 1$$

Where: i is the land use category; j is the hidden tier; p signifies the grid; t is time; sp(p, i, t) is the likelihood of suitability; $W_{j,i}$ is the weight; -net_j(p, t) is the received signals. The total suitability probabilities for each type of land utilization conversion computed by the neural network model should be equal to 1 [50].

(2) Adaptive inertial competition model (CA)

CA employs a roulette mechanism with random characteristics, which utilizes the initial input of land use grid and sets the change quantity for each land use type through applying Markov model [52]. Previously, a conversion matrix is usually established for smooth transitions between various land use types. Here, factors of suitability probability, domain weight of types and various parameters are considered to get the land data for the preset year. The expression can be referred to as follows:

$$TP_{p,t}^{t} = sp(p,i,t) \times Inertia_i^t (1 - sc_{c \to i}) \times \frac{\sum_{N \times N} con\left(c_p^{t-1} = i\right)}{N \times (N-1)} \times w_i$$

Table 3
Changes in land use type in Dianchi Basin from 2000 to 2020.

year	item	Farmland	forest land	grassland	water body	construction land	unused land
2000	area/km^2	1189.01	1022.10	473.09	319.03	53.67	4.31
	proportion/%	0.39	0.33	0.15	0.10	0.02	0.00
2005	area/km^2	1119.29	1055.03	493.49	316.47	74.21	2.72
	proportion/%	0.37	0.34	0.16	0.10	0.02	0.00
2010	area/km^2	968.88	1131.43	531.54	311.53	115.38	2.44
	proportion/%	0.32	0.37	0.17	0.10	0.04	0.00
2015	area/km^2	910.17	1180.40	512.94	311.97	141.42	4.30
	proportion/%	0.30	0.39	0.17	0.10	0.05	0.00
2020	area/km^2	944.62	1190.78	427.06	312.02	179.17	7.55
	proportion/%	0.31	0.39	0.14	0.10	0.06	0.00
2000–2005	range of area change/km^2	−69.72	32.93	20.40	−2.56	20.55	−1.59
	Annual range of change	−13.94	6.59	4.08	−0.51	4.11	−0.32
	Single dynamic attitude/%	−1.17	0.64	0.86	−0.16	7.66	−7.38
2005–2010	range of area change/km^2	−150.41	76.40	38.05	−4.94	41.17	−0.27
	Annual range of change	−30.08	15.28	7.61	−0.99	8.23	−0.05
	Single dynamic attitude/%	−2.69	1.45	1.54	−0.31	11.09	−2.01
2010–2015	range of area change/km^2	−58.71	48.98	−18.61	0.44	26.04	1.86
	Annual range of change	−11.74	9.80	−3.72	0.09	5.21	0.37
	Single dynamic attitude/%	−1.21	0.87	−0.70	0.03	4.51	15.20
2015–2020	range of area change/km^2	34.44	10.38	−85.88	0.06	37.75	3.25
	Annual range of change	6.89	2.08	−17.18	0.01	7.55	0.65
	Single dynamic attitude/%	0.76	0.18	−3.35	0.00	5.34	15.11
2000–2010	range of area change/km^2	−220.13	109.32	58.46	−7.50	61.72	−1.86
	Annual range of change	−22.01	10.93	5.85	−0.75	6.17	−0.19
	Single dynamic attitude/%	−1.85	1.07	1.24	−0.24	11.50	−4.33
2010–2020	range of area change/km^2	−24.27	59.35	−104.48	0.50	63.79	5.11
	Annual range of change	−2.43	5.94	−10.45	0.05	6.38	0.51
	Single dynamic attitude/%	−0.21	0.44	−1.64	0.01	4.61	17.42
2000–2020	range of area change/km^2	−244.39	168.68	−46.03	−7.01	125.51	3.25
	Annual range of change	−12.22	8.43	−2.30	−0.35	6.28	0.16
	Single dynamic attitude/%	−0.93	0.75	−0.44	−0.10	10.63	3.42

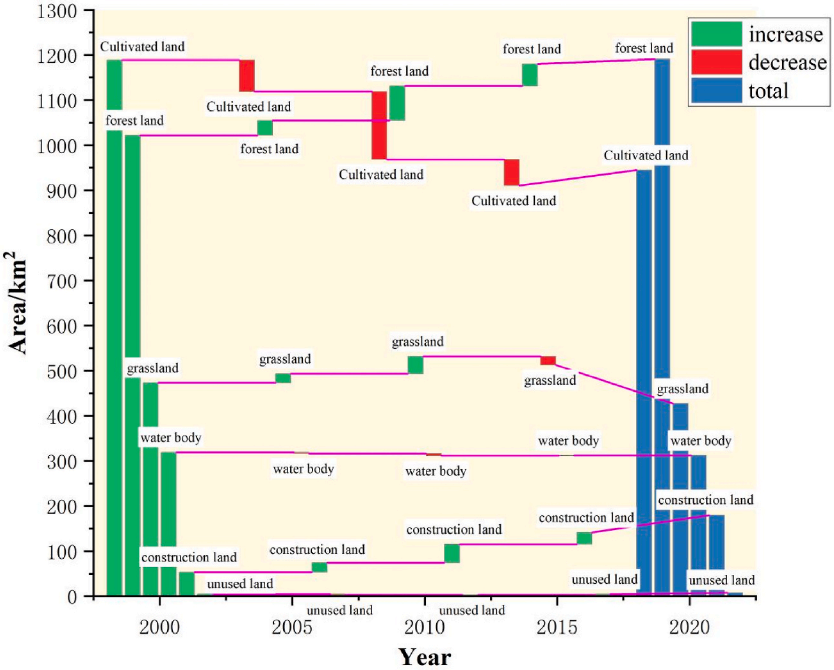

Fig. 3. A map depicting the changes in land use type in the Dianchi Basin from 2000 to 2020.

Where: $TP_{p,t}^{t}$ represents the complete likelihood of change to type p at the t cycle; sp(p, I, t) represents the likelihood of appropriateness; Inertia represents self-adapting inertia coefficient; $sc_{c\rightarrow i}$ represents the cost of space type conversion; $\sum_{N\times N} con\left(c_p^{t-1}=i\right)$ represents the grid number generated by type i at the conclusion of the iteration; w is the neighborhood weight of each land type.

3.2.5. Ecoenvironmental Quality Index (EQI)

The ecological environment quality greatly diverges considering different land use types. In this study corresponding quality values of different land types formulated by Cui et al. [53] and Li et al. (2003) are selected. Together, to avoid the subjectivity of expert score assignment, research results of EQI measurement by Yang et al. [54], Yang et al. [16] and Gao et al. [55] are taken into consideration. Therefore, the method of expert consultation combined with hierarchical analysis is finally adopted, so as to assign the eco-environmental quality of each land use type (Table 2), establish the correlation between land use/land cover and regional eco-environmental quality, and quantitatively analyze the spatial-temporal characteristics of regional LUCC and its ecological environment quality [56,57].

When conducting expert scores and hierarchical analysis, the following influencing factors were considered for the characteristics of each land use type. In cultivated land, fertilizer and pesticide use, soil erosion, surface water change and biodiversity are mainly considered; In woodland, soil and water conservation, biodiversity, carbon sink function and ecological services are mainly considered; In grassland, soil conservation, water conservation, biodiversity, carbon cycle and climate regulation are mainly considered; The construction land mainly considers surface hardening, pollution discharge, heat island effect, biological habitat loss, etc. The water body mainly considers water purification, flood regulation and storage, biodiversity, ecological vulnerability, etc. The unused land mainly considers nature conservation and potential risks, etc. At the same time, the uniqueness of Dianchi Basin in terms of ecological environment is also considered, such as geographical location and topographic characteristics, biodiversity, natural and cultural integration, water resources and hydrological system, eutrophication and ecological challenges, ecological restoration and protection. The expression is as per the following:

$$EV_t = \sum_{i=1}^{n} LU_i \times C_i / T_A$$

Where: EV_t is the EQI of the research area during the t time frame; LU_i is the area of the i type of land use in period t; C_i is the EQI of the i type. The total size of research area is denoted as T_A; n stands for the quantity of corresponding land use category.

The technical flowchart of this study is shown as below (Fig. 2).

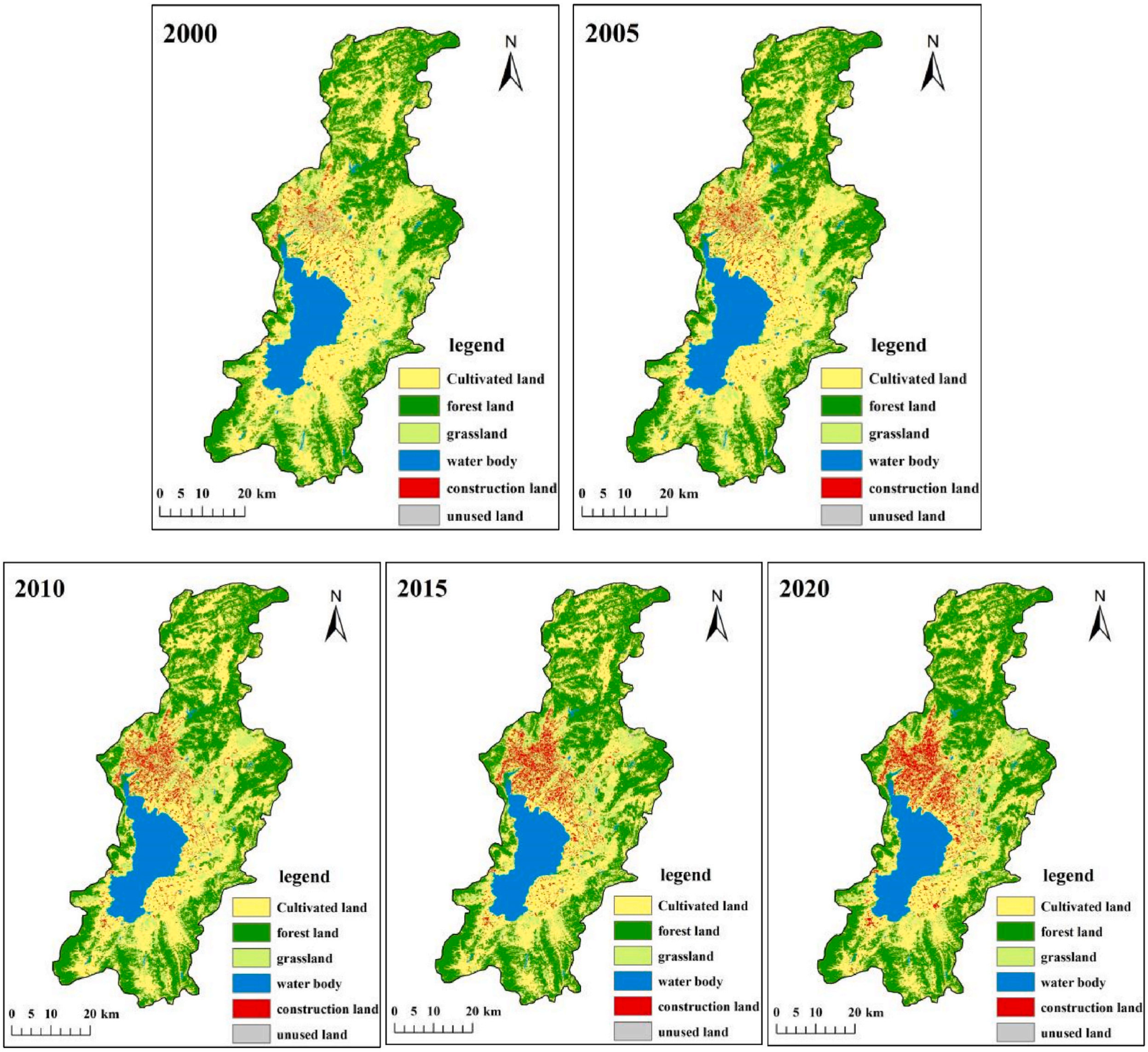

Fig. 4. Spatial-temporal pattern evolution of land use types in Dianchi Basin from 2000 to 2020.

Table 4
Comprehensive index and change table of land use in Dianchi Basin from 2000 to 2020.

year	Comprehensive index of land use degree	Land use degree change		Change rate of land use degree
2000	242.21	–	–	–
2005	241.32	−0.88	−3.38 (2000–2015 is negative value)	−0.01
2010	239.11	−2.21		
2015	238.83	−0.28		
2020	242.32	3.49	3.49 (2015–2020 is positive value)	0.01

4. Analysis and results

4.1. Land use change process

4.1.1. Spatial distribution pattern of land use

Based on software-processed(ENVI5.3) and precision verified land use remote sensing data, the ArcGIS10.6 was employed to perform classified statistics on the land use status collected during five separate years (2000, 2005, 2010, 2015, and 2020) in the

Table 5
Land use type transfer matrix of Diachi Basin from 2000 to 2005 km^2.

year	year	2005							
	land type	Farmland	forest land	grassland	water body	construction land	unused land	reduce total	net reduction
2000	Farmland	1047.89	34.77	94.89	1.45	9.97	0.04	1189.01	141.12
	forest land	33.48	986.78	1.76	0.02	0.07		1022.10	35.33
	grassland	34.91	33.17	393.77	0.11	10.30	0.84	473.09	79.32
	water body	3.01	0.31	0.78	314.88	0.04		319.03	4.15
	construction land				0.01	53.66		53.67	0.01
	unused land	0.00		2.28		0.18	1.85	4.31	2.46
	add up	1119.29	1055.03	493.49	316.47	74.21	2.72	3061.20	–
	net increase	71.39	68.25	99.72	1.58	20.56	0.87	–	–

Table 6
Land use type transfer matrix in Dianchi Basin from 2005 to 2010 km^2.

year	year	2010							
	land type	Farmland	forest land	grassland	water body	construction land	unused land	reduce total	net reduction
2005	Farmland	916.96	45.65	133.73	0.67	22.16	0.12	1119.29	202.33
	forest land	16.50	1037.21	0.90		0.43		1055.03	17.82
	grassland	31.61	47.68	394.76	0.19	18.25	1.00	493.49	98.73
	water body	3.78	0.90	1.07	310.65	0.06	0.01	316.47	5.81
	construction land				0.01	74.20		74.21	0.01
	unused land	0.04		1.08		0.28	1.32	2.72	1.40
	add up	968.88	1131.43	531.54	311.53	115.38	2.44	3061.20	–
	net increase	51.92	94.22	136.78	0.87	41.18	1.12	–	–

Table 7
Land use type transfer matrix of Dianchi basin from 2010 to 2015 km^2.

year	year	2015							
	land type	Farmland	forest land	grassland	water body	construction land	unused land	reduce total	net reduction
2010	Farmland	807.47	43.73	105.22	2.69	9.65	0.12	968.88	161.41
	forest land	31.23	1098.47	1.60	0.03	0.10		1131.43	32.96
	grassland	69.25	37.86	405.03	0.62	16.05	2.73	531.54	126.51
	water body	2.19	0.34	0.37	308.55	0.05	0.02	311.53	2.97
	construction land				0.07	115.31		115.38	0.07
	unused land	0.03		0.72		0.25	1.44	2.44	1.00
	add up	910.17	1180.40	512.94	311.97	141.42	4.30	3061.20	–
	net increase	102.70	81.94	107.91	3.41	26.11	2.86	–	–

Table 8
Land use type transfer matrix of Dianchi Basin from 2015 to 2020 km^2.

year	year	2020							
	land type	Farmland	forest land	grassland	water body	construction land	unused land	reduce total	net reduction
2015	Farmland	818.54	30.09	51.54	1.42	8.47	0.11	910.17	91.63
	forest land	38.90	1140.90	0.42	0.01	0.17		1180.40	39.50
	grassland	85.84	19.60	374.00	0.27	28.90	4.31	512.94	138.93
	water body	1.29	0.19	0.16	310.30	0.03		311.97	1.66
	construction land				0.01	141.40		141.42	0.01
	unused land	0.04		0.93		0.20	3.13	4.30	1.17
	add up	944.62	1190.78	427.06	312.02	179.17	7.55	3061.20	–
	net increase	126.07	49.88	53.05	1.72	37.77	4.42	–	–

research region. This analysis provides valuable insights into both different quantities and spatial arrangements of diverse land utilization categories within the basin across four specific periods (Table 3, Figs. 3–4). According to spatial arrangement analysis, farmland, forest land, and grassland are the primary categories in Dianchi Basin, which together covers more than 80 % of the whole basin. However, the size of water body, construction land, and unused land is less than 20 % and scattered except for the Dianchi Lake. According to the overall distribution pattern, the farmland is mainly located in the areas surrounding the relatively flat terrain of Dianchi Lake. More, the basin's northern region and the surrounding mountainous areas with higher elevation are mainly forest land and grassland. And the central Kunming in the northern part of Dianchi Lake, along with certain areas in the eastern and southern sides

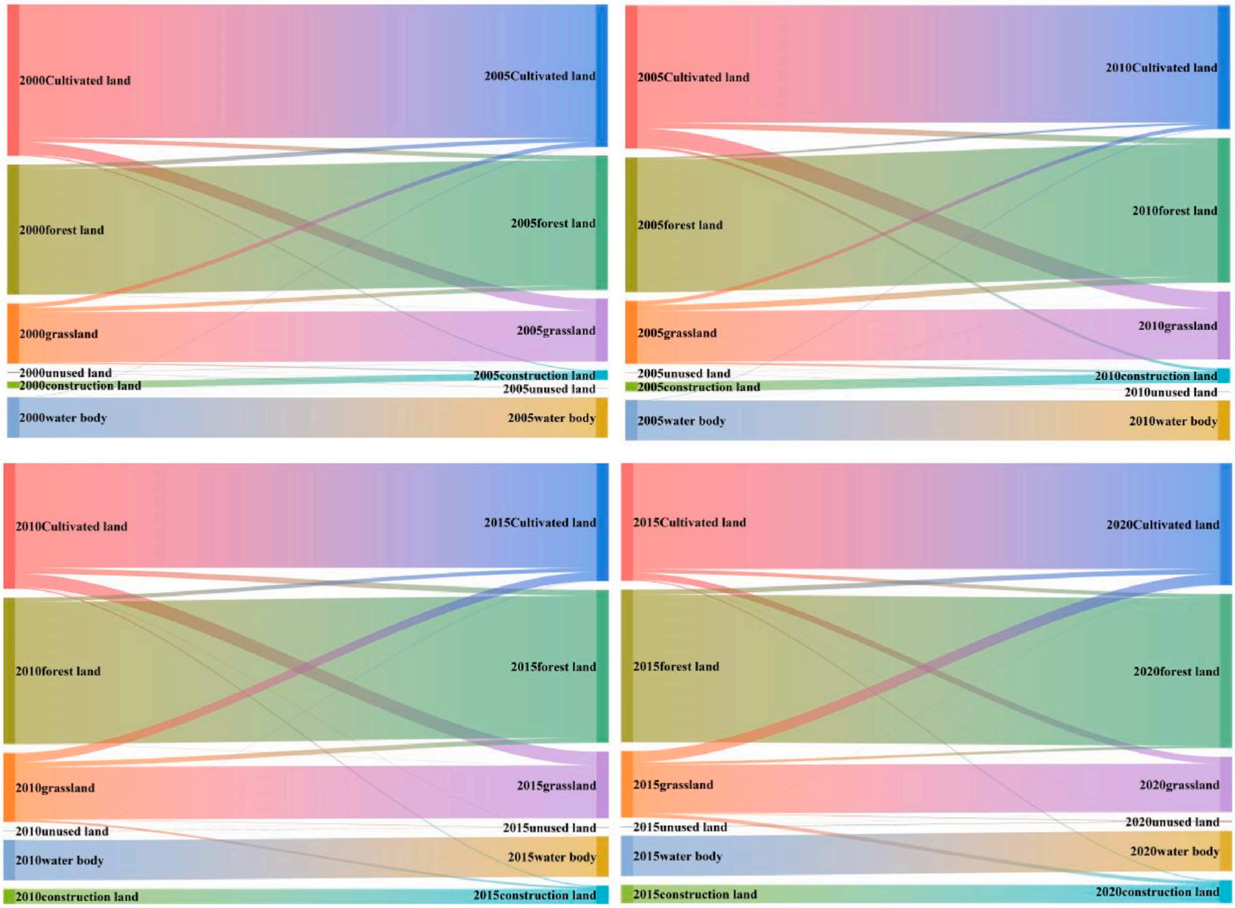

Fig. 5. Schematic diagram of land use type transfer in Dianchi Basin from 2000 to 2020.

are predominantly construction land.

4.1.2. The degree of dynamism in land utilization

Considering differences in land use types, the area of farmland, grassland and water body all showed a decreasing trend in recent 20 years. Among them, the farmland ranked top of 244.39 km^2, the grassland came second of 46.03 km^2, and next was the water body's surface area with a decrease of 7.01 km^2. Moreover, the forest land, construction land, and unused land all experienced a significant increase, with the most notable growth of the forest area (168.68 km^2), followed by construction land (125.51 km^2) and unused land (3.25 km^2). In each study period, the amount of farmland exhibited a pattern of initial decline then increase afterwards, with an average decrease of 12.22 km^2 per year. Conversely, there was a consistent annual growth in the extent of construction land, with an average annual increase of 6.28 km^2 over the entire study period.

In terms of the dynamic attitudes of single land use, the last two decades witnessed the most rapid decline of the farmland, with an average annual decline rate of 0.93 %. However, this rate was initially high and then gradually slowed down over time. More specifically, the average annual decrease was 1.85 % in the first decade, then down to 0.21 % per year coming into the next decade. In the second place was the grassland area, with an average decrease of 0.44 % in quantity despite initial rise. Featured by a gradual upturn in the first ten years, the average yearly growth was 1.24 %, and then came a yearly average rapid decrease of 1.64 % in the last ten years. In terms of land increase, the construction land grew most sharply, with a mean yearly expansion rate of 10.63 %, exhibiting a pattern of initial rapid growth followed by deceleration. In the first ten years, the increase rate was relatively fast with an average yearly growth rate of 11.5 %. But in the last ten years, the increase rate slowed down to an average yearly value of 4.61 %. In addition, the forest area came second featured by an initial fast growth followed by gradual deceleration, having a mean yearly increase of 1.07 % in the first ten years and 0.44 % in the past decade. To be noted, the overall changes of unused land and water body area are small and relatively stable.

4.1.3. Land use degree

After we calculated the land use degree using related equations, we obtained the comprehensive index of land use degree in the study area (Table 4). Over the past two decades, the index showed a U-turn shape with a declining trend before 2015 and an increasing trend after 2015. The index of land use degree first declined from 242.21 in 2000 to 238.83 in 2015, with a variation quantity of −3.38 and a change rate of −0.01. It suggests that land use during this period was reducing. After 2015, the study area witnessed a growth in the land use degree. The index of land use degree increased from 238.83 in 2015 to 242.32 by the end of 2020, with the variation quantity of 3.49 and the rate of change of 0.01. This indicates that, during this period, more land was used for various purposes, with a higher speed. this is due to a growing population and accelerating urbanization in the Dianchi Basin, which greatly increases the land use degree.

4.1.4. Land use transfer matrix

Tables 5–8, Fig. 5 show the conversion of land use types. Over the past two decades, the land use types in the study area has changed and the patterns are as follows:

(1) From 2000 to 2005, a total of 141.12 km^2 of farmland was transformed into other land types, of which 91.88 % was converted to grassland and forest land, 7.06 % into construction land, 1.06 % into water body and unused land. In contrast, 46.89 % of forest land, 48.9 % of grassland and 4.21 % of water body were changed to farmland. All in all, the farmland decreased by 69.72 km^2. A total of 35.33 km^2 of forest land were transformed into other types of land, of which 94.77 % was transformed to farmland, 4.98 % into grassland, 0.19 % into construction land, and only 0.06 % was converted to water. In contrast, 50.95 % of farmland, 48.59 % of grassland and 0.46 % of water body were transformed into forest land. This escalated the forest land by 32.93 km^2. A total of 79.32 km^2 of grassland was transformed into other types of land. To be specific, 44.01 % of the grassland was converted into farmland, 41.81 % into forest land, 12.99 % into construction land, and 1.19 % into water body and unused land. In contrast, 95.16 % of farmland, 1.77 % of forest land, 0.79 % of water body and 2.29 % of the unused land were transformed into grassland, which increased the grassland by 20.40 km^2. A total of 0.01 km^2 of construction land was converted into other types of land, of which were transformed into water body. On the other side, 48.48 % of farmland, 50.11 % of grassland, 0.32 % of forest land, 0.21 % of water body and 0.87 % of unused land were transformed into construction land, resulting in a 20.55 km^2 expansion of the construction area. Not much unused lands or the water body had been transformed to the construction land.

(2) From 2005 to 2010, a total of 203.33 km^2 of farmland was converted to other types of land, of which 88.66 % was transformed into grassland and forest land, 10.95 % into construction land, and 0.39 % into the water body and unused land. Moreover, 31.77 % of forest land, 60.89 % of grassland, 7.28 % of the water body and 0.07 % of unused land were transformed to farmland. As a result, the farmland decreased by 150.41 km^2. A total of 17.82 km^2 of forest land was converted into farmland, grassland, and construction land. This was much smaller than its expansion – 76.4 km^2. Most of the new forest lands were once a farmland, a grassland, or a piece of water body. An area of 98.73 km^2 of grassland was transformed into other types of land, among which 32.02 % was converted into farmland, 48.29 % into forest land, 18.48 % into construction land, 1.21 % into unused land and water body, while 97.77 % of farmland, 0.78 % of water body, 0.66 % of forest land and 0.79 % of unused land were converted into grassland. The increase of grassland reached 38.05 km^2. In addition, the area of construction land also rose significantly. A total of 53.8 % of farmland, 44.31 % of grassland, 1.04 % of forest land, 0.15 % of water body, and 0.68 % of unused land were converted into construction land. All in all, the area of construction land increased by 41.17 km^2. The conversion of water body and unused land was not as high as other types of land.

(3) From 2010 to 2015, a total of 161.41 km^2 of farmland was converted to other types of land. Among them, 92.28 % of farmland was transformed into grassland or forests; 5.98 % was converted into construction land; 1.74 % was converted into water body or unused land. On the other side, 30.41 % of forests, 67.43 % of grassland and 2.13 % of water body were transformed into farmland. As a result, the farmland decreased by 58.71 km^2. A total of 32.96 km^2 of forest land was converted into other types of land. Among them, 94.75 % was transformed into farmland, 4.86 % to grassland, 0.30 % to construction land, 0.09 % to water body. In contrast, 53.37 % of farmland, 46.21 % of grassland and 0.42 % of water body had been transformed into forest land. Thanks to the reforestation, the forest area expanded notably, with an increase of 48.98 km^2. A total of 126.51 km^2 of grassland was converted into other types of land. Among them, 54.74 % was transformed into farmland; 29.93 % was transformed into forest land; 12.69 % was transformed into construction land; and 2.64 % was converted into water body and unused land. In contrast, 97.5 % of farmland, 1.48 % of forest land, 0.35 % of water body and 0.66 % of unused land had been converted to grassland. As a result, the grassland was reduced by 18.61 km^2. An area of 0.07 km^2 construction land was converted to water body, with no other types involved. In contrast, 36.98 % of farmland, 0.38 % of forest land, 61.48 % of grassland, 0.19 % of water body and 0.96 % of unused land were transformed into construction land. After the conversion, the construction land increased by 26.04 km^2. The conversion degree of the water body and the unused land is relatively low.

(4) From 2015 to 2020, a total of 91.63 km^2 farmland was converted to other types, among which 89.09 % was transformed into grassland and forest land; 9.25 % was converted to the construction land, and 1.66 % was transformed into unused land and water body. A total of 30.86 % of forest land, 68.09 % of grassland, 1.02 % of water body and 0.03 % of unused land were transformed to farmland. This increased area of farmland by 34.44 km^2. 39.5 km^2 of forest land was transformed into other

Table 9
Changes of EQI in Dianchi basin from 2000 to 2020.

year	2000	2005	2010	2015	2020
ecological environment quality index	0.4683	0.4738	0.4862	0.4921	0.4883

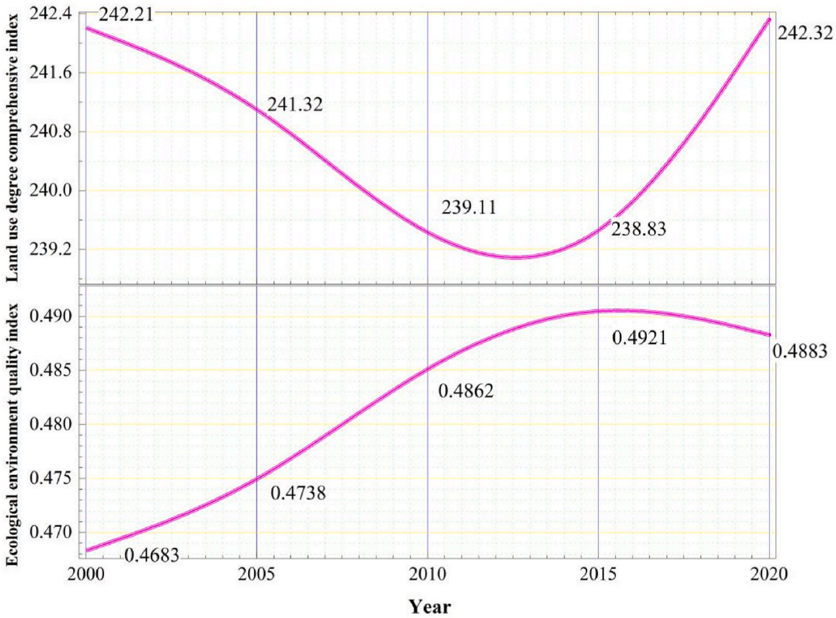

Fig. 6. Relationship between land use degree comprehensive index and ecological environmental quality in Dianchi Basin.

types of land. Among them, 98.49 % was converted to farmland; 1.06 % was changed into grassland; 0.42 % to construction land and 0.04 % to water body. In contrast, 60.32 % of farmland, 39.3 % of grassland and 0.37 % of water body were converted to forest land. As a result, the forest land increased by 10.38 km^2. A total of 138.93 km^2 grassland was converted into other types of land. This was much larger than the area the other land types converted to it, which was 53.05 km^2. As a result, the area of grassland reduced by 85.88 km^2. In contrast, 22.43 % of farmland, 0.44 % of forest land, 76.52 % of grassland, 0.08 % of water body, and 0.53 % of unused land was converted into construction land. Thus, the construction area grew by 37.76 km^2 in total. The conversion degree of water body and unused land was relatively low.

In summary, when we analyze the area transferred out from its land use types, we find that farmland has the most areas converted out, accounting for 82.17 % of the total converted area. Most of the land was transferred into forest land, accounting for 56.71 % of the total, followed by the construction land, accounting for 42.2 % of the total. A large area of farmland had been transferred into construction land and forest land. A higher conversion into the construction land is due to the urbanization of Dianchi Basin during the past 20 years. According to Kunming city's development plan, many construction projects were carried out surrounding the Dianchi Lake urban. The fast expansion of urban areas increased the area of construction land. The area of forest land increased in recent years due to the implementation of the "returning farmland to forest" policy, the promotion of ecological civilization, and the implementation of ecological protection policies in Dianchi Basin.

4.2. Analysis of ecological and environmental effects

4.2.1. Temporal variations in the quality of the ecological environment

In recent years, the environment quality index of Dianchi Basin (Table 9) is improving in general. It increased from 0.4683 in 2000 to 0.4921 in 2015. Then, the index declined slightly from 2015 to 2020, falling to 0.4883 in 2020. The overall trend was still increasing, from 0.4683 in 2000 to 0.4883 in 2020. Based on the relationship depicted in Fig. 6, an inverse correlation can be identified between the overall environment quality and the land use index of Dianchi Basin. In other words, when land use increases, the ecological environment will deteriorate. Conversely, as the land use becomes less, the ecological environment will be better.

4.2.2. Characteristics of the spatial distribution of ecological environmental quality

The natural breaks in the ArcGIS software were adopted to classify the EQI data into five levels: the low-quality area ($EV \leq 0.15$), the relatively low-quality area ($0.15 < EV \leq 0.3$), the medium quality area ($0.3 < EV \leq 0.45$), the relatively high-quality area ($0.45 < EV \leq 0.6$) and high quality area ($0.6 < EV \leq 0.75$). Based on the classification, we made 5 EQI spatial distribution maps for the Dianchi Basin during the 5 different periods (Fig. 7). The results show that there was a notable variation in the eco-environmental quality across the Dianchi Basin. The overall distribution pattern exhibits a gradual transition from poor to good as we move from the periphery of Dianchi Lake to the outside areas. The low-quality area and the relatively low-quality area are primarily distributed in the central urban area or at the periphery of the Dianchi Lake. The relatively high-quality area and high quality area are situated in the Dianchi Lake water area or on the outskirts of the central urban area.

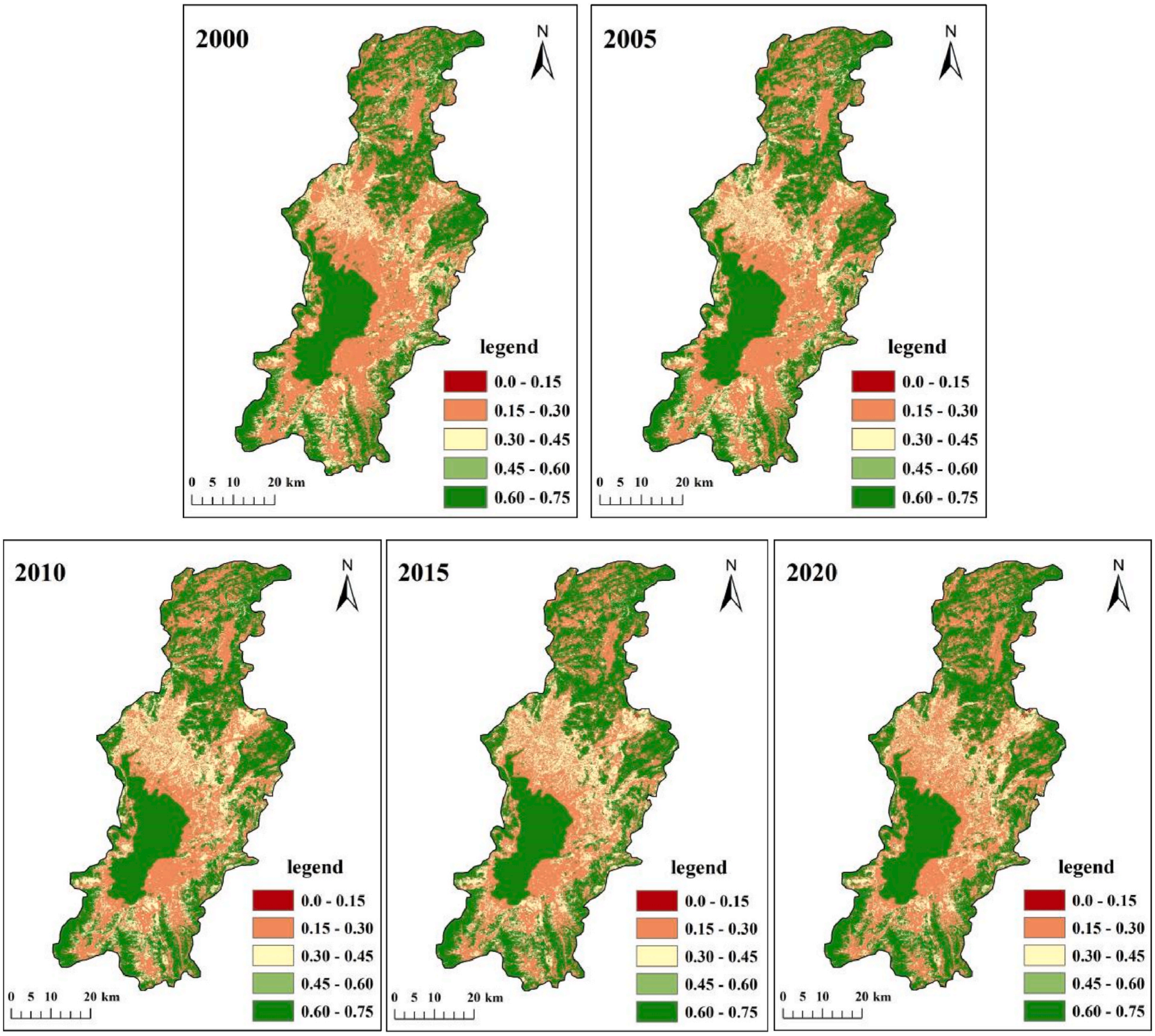

Fig. 7. Spatial distribution of EQI in Dianchi Basin from 2000 to 2020.

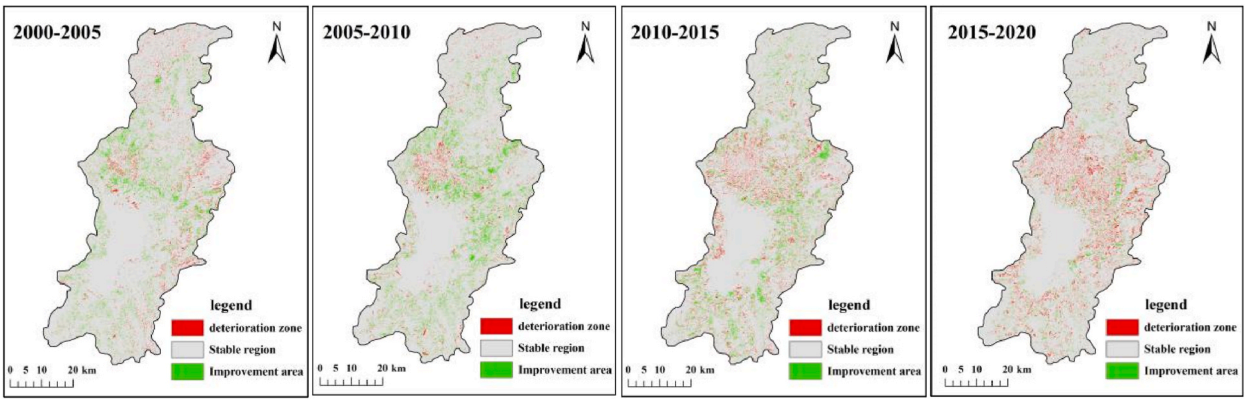

Fig. 8. Evolution of eco-environmental quality pattern in Dianchi Basin from 2000 to 2020.

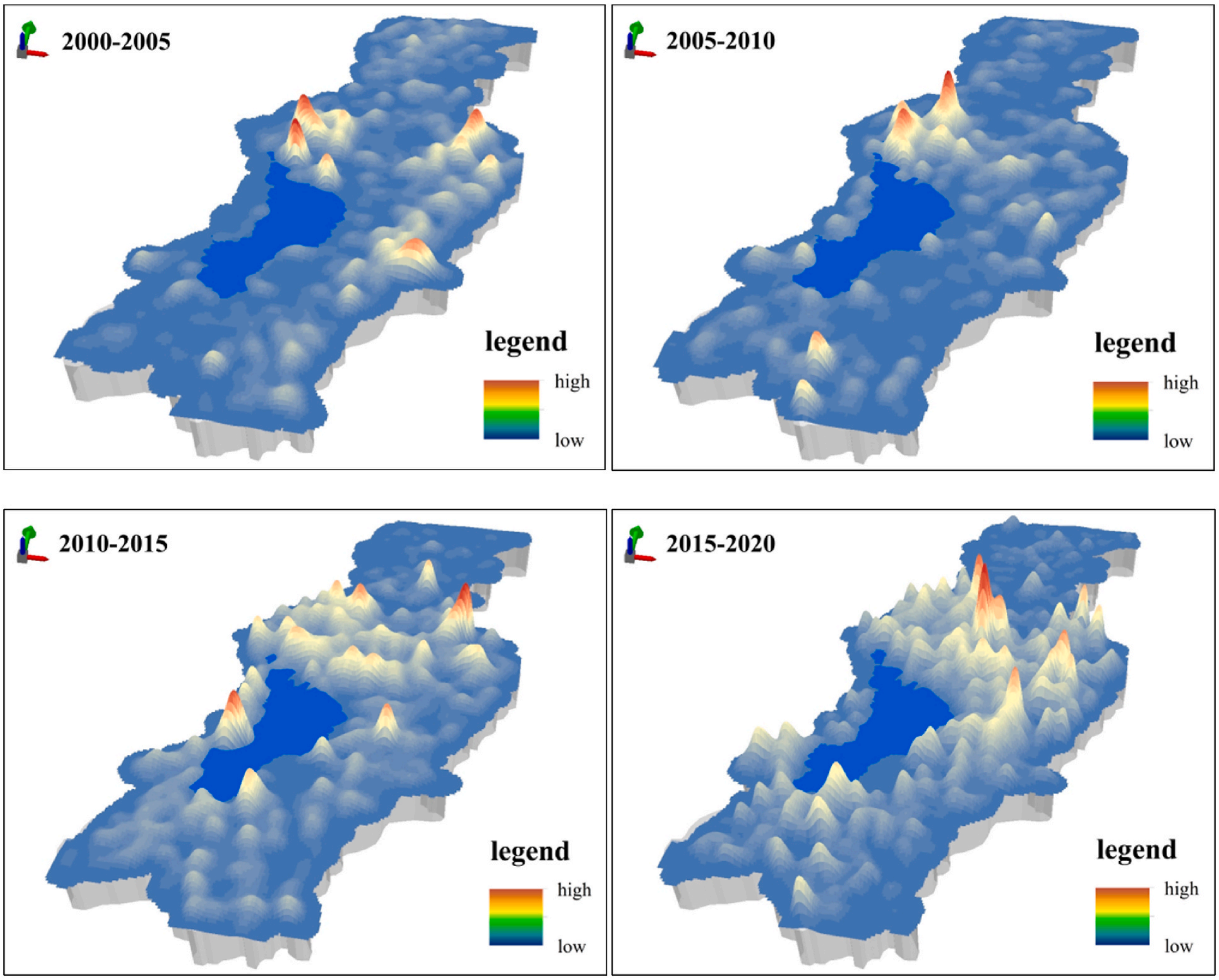

Fig. 9. Evolution of ecological environment deterioration in Dianchi Basin from 2000 to 2020.

Based on the EQI, the eco-environment of the Dianchi Basin can be classified into three areas: the deteriorating area, the stable area, and the improving area (Fig. 8). Then we simulated a diagram of the deterioration area of the Dianchi Basin (Fig. 9) [58]. When we look at the changes of the three areas, we can discover that the deteriorating area in the Dianchi Basin has become larger over the past two decades. This indicates that the eco-environment quality of the Dianchi Basin has been deteriorating. The deteriorating area started from the central area of Kunming, which was located in the north of Dianchi Lake, during the period of 2000–2010, and then gradually spread out to the lake's surrounding area from 2010 to 2020. The area of the improving area decreases annually. It is primarily distributed on the outskirts of the central urban area. This is because of urbanization in the central area steps up during these years and more and more land has been transformed into the construction land, greatly reducing the natural space. As a result, the quality of eco-environment goes down. Overall, the changes of eco-environment quality shows obvious spatial agglomeration pattern. A deterioration area that surrounds central urban area and Dianchi Lake has been formed.

4.3. Land use type forecast and eco-environment quality analysis in 2035

4.3.1. Verification of the model's accuracy

The FLUS model was used to verify the model's accuracy. The land use data of Dianchi Basin in 2015 served as the baseline data. The land use data of Dianchi Basin in 2020 was taken as the verification data. We adopted the uniform sampling method, and set the value of the hidden layer to be 12. The six selected driving factors included: elevation, slope, aspect of slope, distance from highway, distance to the water channel, and distance from the district or county areas (Fig. 10). The neural network model was used to convert data and obtain the probability of suitability. The quantity change predicted by Markov model was also used to support the process [59]. Meanwhile, the neighborhood parameters are set to be within the range of 0–1. The closer the parameter value is from 1, the better this type of land is at expanding [60]. Based on our experience and previous studies [61], we set the parameter of the construction land to be 1, after multiple tests. The parameter of the farmland was set to be 0.7, 0.5 for grassland and unused land, 0.3 for

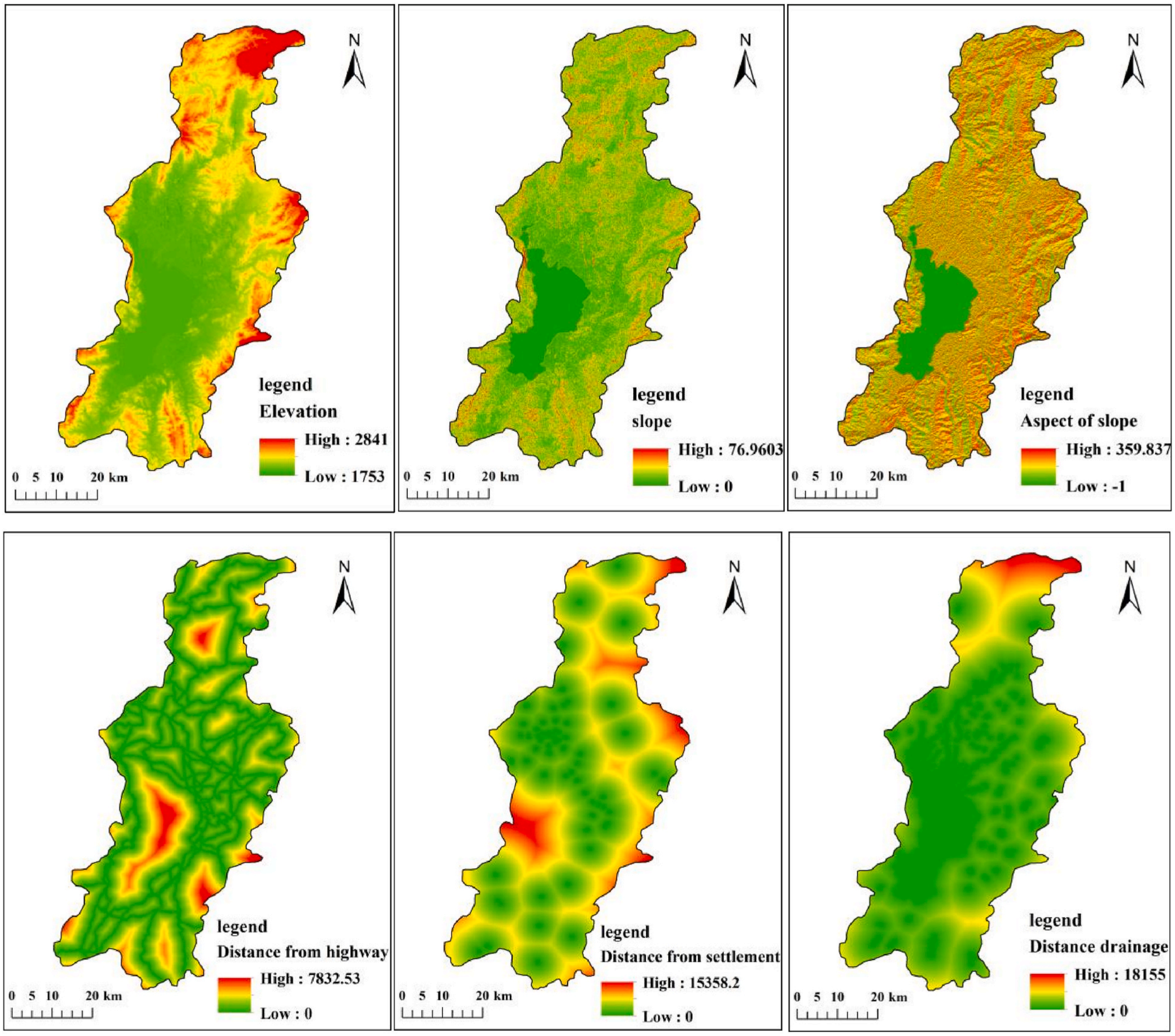

Fig. 10. Diagram of various driving factors.

Table 10
Setting neighborhood parameters.

Land use type	Farmland	forest land	grassland	water body	construction land	unused land
Neighborhood parameter	0.7	0.3	0.5	0.1	1	0.5

forest land, and 0.1 for water body (Table 10). After comparing with the practical data in 2020, we found that the simulation precision would be best when the Kappa parameter value and the overall precision approached 1 [62]. According to the test results, the overall precision was 0.86 and the Kappa parameter was 0.8. The simulation accuracy of the experiment was very high. Thus, the FLUS model shows a great practicality, which can be used to simulate the land use types of Dianchi Basin in 2035.

4.3.2. Simulation result analysis

The FLUS model was adopted (Fig. 11) to simulate land use changes in Dianchi Basin by 2035. According to simulations, corresponding results in different scenarios vary significantly.

Considering natural development and contrasted with 2020, the farmland of Dianchi Basin expanded from 944.62 km^2 to 963.47 km^2, with a rise of 2 %; the construction land from 179.17 km^2 to 248.72 km^2, with an increase of 38.82 % together with an obvious expansion trend; the forest land from 1190.78 km^2 to 1202.34 km^2, increasing by 0.97 %. However, the grassland was down from 427.06 km^2 to 324.9 km^2, with a decrease of 23.92 %. The unused land and water body changed little.

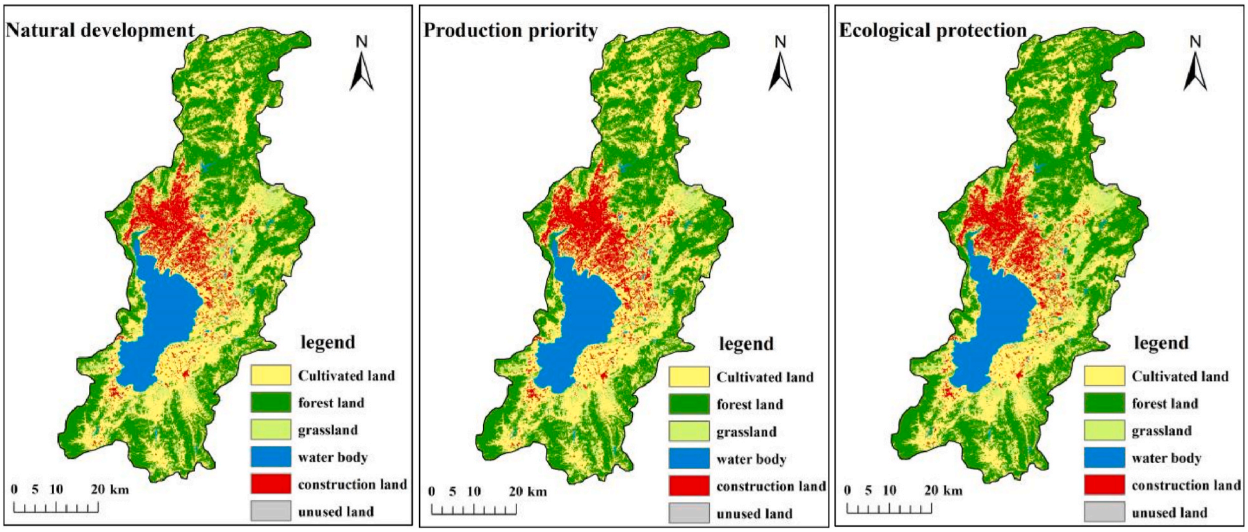

Fig. 11. Multi-scenario simulation of land use types in Dianchi Basin in 2035.

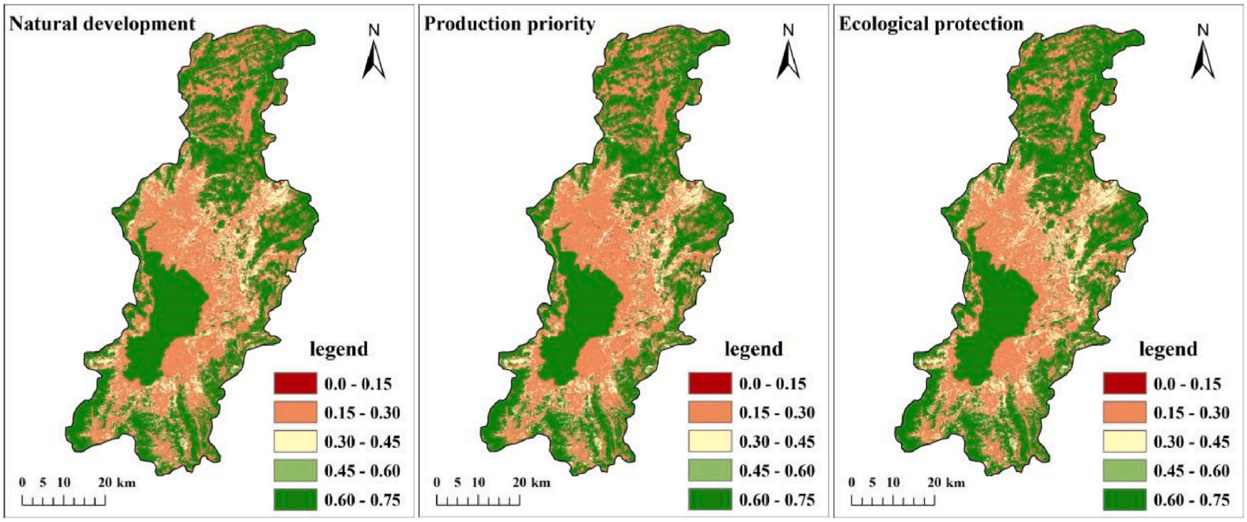

Fig. 12. Spatial distribution of eco-environmental quality in Dianchi Basin under multiple scenarios in 2035.

Following production priority, compared with 2020, the construction land of Dianchi Basin increased to 279.59 km^2, with an increase of 56.05 %. Despite little growth, the farmland also increased from 944.62 km^2 to 953.36 km^2, realizing the production priority goal. Likewise, other land types witnessed little expansion, with unused land, forest land and water body growing by 1.17 km^2, 8.67 km^2 and 1.01 km^2, separately. However, the grassland kept on diminishing to 307.05km2, with a 23.92 % decrease.

From the point of ecological protection, if compared with 2020, the forest land in Dianchi Basin increased most by 82.53 km^2, the construction land by 73.86km2, the water body by 3.84km2. However, the farmland area diminished by 96.56 km^2, the grassland by 60.06 km^2, and the unused land by 3.6 km^2.

4.3.3. Analysis of ecological environment quality

According to calculations, the Dianchi Basin's spatial distribution map of EQI in 2035 under various scenarios (Fig. 12) shows that:

In terms of natural development, the EQI of the Dianchi Basin in 2035 is 0.4836. Compared with figures in 2020, the distribution of low quality region and lower quality region of the ecological environment is significantly expanded. Most of them tend to be clustered within the urban core and the surrounding area of Dianchi Lake, while a few are scattered in northern Dianchi Basin. The low quality region increases by 0.9km2–8.4 km^2 in 2035; the lower quality region increased with 88.21km2–1212.19 km^2 in 2035. With more lower quality regions, the medium-quality and high-quality regions decreased year after year, primarily dispersed within the Dianchi Lake and the area far from the urban region.

From the production priority perspective, the EQI of Dianchi Basin in 2035 is 0.4817. Compared with that in 2020, lower quality regions expanded greatly by 108.97 km^2, comparing to less increase by 1.23km2 and 9.62km2 of low-quality and high-quality regions respectively. In addition, the medium-quality region decreased significantly to 119.82 km^2. Typically, if production is prioritized, the high-quality region changes little, while the medium-quality region decreases and the low-quality region increases significantly, which indicates deteriorating ecological environment quality in the Dianchi Basin in this scenario.

Considering ecological preservation, the Dianchi Basin's EQI in 2035 is 0.4972, which is the highest among the three scenarios. Contrasted with 2020, as the high-quality region increased significantly by 86.31 km^2, other regions subsequently decreased year after year. Specifically, the medium-quality region decreased by 59.87 km^2–367km2, the lower quality region by 22.98 km^2, and the low-quality region by 3.46 km^2. Clearly under this scenario, the Dianchi Basin's ecological environment quality level is the highest among the three.

To sum up, through EQI comparison, the eco-environmental quality of Dianchi Basin develops well if prioritizing ecological preservation, while that quality is low under the production priority scenario, which further indicates that vast demands for higher life quality boost residing needs and together with rocketing land demand. In this case, ecological land will be gradually occupied, so ecological protection in the Dianchi Basin should be a key issue in the future. Therefore, actual situations and various influencing factors in the Dianchi Basin should be considered to rationally arrange the spatial layout and ecological civilization development.

5. Discussion and conclusion

5.1. Discussion

According to the results of this study, the ecological environment quality in Dianchi Basin has deteriorated since 2015, which is closely related to the urban planning of Kunming city in this period. Dianchi Lake is a renowned plateau lake in western China. With rapid economic growth, the population saturation in the old metropolitan Kunming along with the development of urbanization, the transportation, housing, entertainment and other environment in the central area already can't satisfy people's needs. Actually, the urban expansion is imminent and the urban concept with Cuihu Lake as the core can no longer keep up with the speed of urbanization development. In 2003, Kunming proposed to replace with Dianchi Lake as its center by the "One Lake, Four Rings" and "One Lake, four districts" project. In 2016, Kunming City issued the "Kunming City Master Plan (2011–2020)", which clarified the development direction of Kunming's central urban area as "Southward extension, northward expansion", featured by replacement with Dianchi Lake as the core. In particular, after 2015, the phenomenon of "development around the lake" and "development on the line" in Dianchi Lake was prominent, and the surrounding areas of Dianchi Lake were encroached by real estate development projects, some of which directly occupied the Dianchi Lake protection area, seriously crowded the environmental space of the Dianchi Basin, and led to large-scale land transfers with high habitat quality, which was the primary cause for the decline of the ecological and environmental condition of the Dianchi Basin during this period.

In recent years, with the advancement of "the Silk Road Economic Belt and the 21st-Century Maritime Silk Road (The Belt and Road)" and gradual implementation of the strategy of "Regulations on the Protection of Dianchi Lake in Yunnan Province (Amendment)", the Dianchi Basin has ushered in a rare development opportunity and favorable policies. Beyond economic growth, more attention is also paid to the preservation and development of the ecological system. *The Guiding Opinions of People's Government of Yunnan Province on the Control of the "Three Zones" of nine Plateau Lakes* has clearly delineated the lakeside ecological red line and the yellow line (the "two lines") along with the ecological protection core zone, the ecological protection buffer zone, and the green development zone (the "three zones"). In addition, the ecological engineering including "returning farmland to forest and grassland", together with the security and rebuilding of key ecological functional regions have been implemented successively, thus the further deteriorating ecological and environmental quality has been mitigated. In this aspect, the ecological civilization concept should further practiced in the Dianchi Basin in the future by better preservation and rehabilitation of the lake basin area's environment, so as to build a spatial pattern of land use that organically integrates "mountains, water, forests, fields, lakes and grasses", In this way, a solid plateau ecological security barrier can be built to realize balanced land resource sustainability and ecological environment protection.

There are several innovation highlights in this paper. Specifically: (1) based on previous work and taking Dianchi Basin as the research object, this study adopts LUCC theory and method, environmental ecology, land resource management, RS, GIS, FLUS and other land system dynamic simulation theories and statistical methods, so as to systematically and comprehensively analyze the process of land use changes in the past 20 years, the characteristics and laws of land use change and ecological environment effect in Dianchi Basin were revealed. (2) In light of the "14th Five-Year Plan" and the 2035 vision goal, taking 2035 as the target year, the land distribution pattern and the ecological environment condition of Dianchi Basin under multiple scenarios of ecological protection, production priority and natural development were simulated respectively. It is of use to explore a balanced new land use model with ecological civilization building, and a new approach for economic development and ecological protection of typical urbanization areas of plateau lakes from the perspective of land use, and relevant references are available for the spatial pattern optimization and ecological civilization development of Dianchi Basin in 2035. (3) In addition, Dianchi Basin is a typical ecological civilization development area of plateau lakes with a fragile ecological environment, taking it as the method application and theoretical basis to enrich the research on land use changes and its ecological environment effect in typical urbanization areas can provide important scientific references and practical significance for the ecological civilization building of Kunming and even China. Moreover, the typical cases of the harmonious relationship between land use and lake protection are enriched.

However, more improvements can be made in this paper. More specifically: (1) the ecological index can only represent the ecological environment of a region in a certain period of time while the mutual transformation of land use types will also affect the ecological environment, this study only analyzes the ecological quality index, spatial distribution and deterioration degree evolution over the past years, without further analysis of the ecological environment changes caused by the conversion of land use types. (2) This study analyzed the effects of ecological environment from the perspective of land use change, and there are many factors that affect ecological change, such as map patch size and landscape ecological index, under the influence of these factors, how the ecological environment will change remains to be studied. (3) when forecasting by the FLUS model, only 6 important driving factors are considered in this paper, but in fact, the driving factors include a wide range, policy, soil and other factors belong to the category of driving factors, which should be added in future research to further improve the simulation accuracy. (4) At present, the ecological environment quality is mostly calculated by assignment method, which lacks consideration of the typicality and spatial heterogeneity of special regions. Therefore, in the future research process, appropriate ecological environment quality assessment model can be selected according to the actual situation of the study area to scientifically evaluate ecological environment quality and provide scientific reference for regional sustainable development.

As an important ecological and economic region in southwest China, the Dianchi Basin has extensive and significant future prospects for land use and ecological environment research. In order to deepen the understanding of this field and provide scientific guidance for environmental protection and sustainable development, it can be conducted from multiple dimensions, such as long-term dynamic monitoring and prediction, urban expansion and land use optimization, socio-economic factors and policy impacts, application of new technologies, cross-border cooperation and regional collaboration, and restoration of ecosystem services and functions.

5.2. Conclusion

(1) The primary categories of land utilization of Dianchi Basin are farmland, grassland, forest land, and construction land. The farmland is diminishing with the introduction of “returning farmland to forest” and the ceaseless extension of construction land. In the past two decades, this type of land use “first declined and then increased”. After 2015, Dianchi Basin was in the stage of development, showing growing degree of development and utilization.

(2) For nearly 20 years, all land use types have shown a multi-direction dynamic transfer. Construction land and forest land have the uppermost transfer quantity; farmland is the primary transfer source; grassland is mainly converted into farmland, construction land and forest land; and the conversion range of water body and unused land is small.

(3) For nearly 20 years, the overall change range of ecological environment quality shows an upward trend, with a small decline from 2015 to 2020, which is negatively correlated with the level of land improvement and usage in the region. Among them, the intensity of land development and utilization was low from 2000 to 2015, and the ecological environment quality was enhanced driven by ecological policies such as “returning farmland to forest and grassland”. After 2015, with more intense land use, the ecological environment quality worsened accordingly. The spatial difference of ecological environment quality was significant, and the overall distribution pattern was gradually changed from poor to good along the Dianchi Lake. Generally speaking, the ecological environment quality worsened, forming a deterioration area centering on the central city and Dianchi Lake.

(4) In the three simulation scenarios, the land use design and distribution of Dianchi Basin in 2035 are basically consistent. If prioritizing natural development and production, the area of construction land and farmland will increase significantly; however, if considering ecological protection, the area of forest land will increment essentially, while the area of farmland will diminish each passing year.

(5) According to the comparison of the three scenarios, the EQI of Dianchi Basin in 2035 is the highest within the context of ecological preservation. In the production priority scenario, the ecological environment quality in the Dianchi Basin is low, which further indicates that ecological protection in the Dianchi Basin will be the top priority in the future. It is important to combine the current circumstances and various influencing elements to rationally plan the spatial layout and guarantee the development of environmental progress.

Consent to publish

The manuscript has been read and approved by all listed authors.

Ethical approval

Written informed consent was obtained from all the participants of this study.

Consent to participate

Written informed consent was obtained from all the participants of this study.

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Wenjuan Pei: Writing – original draft. **Yilong Peng:** Writing – original draft. **Kai Fan:** Data curation, Conceptualization. **Jian-sheng Zhang:** Investigation, Formal analysis. **Yunchun Chen:** Methodology. **Bo Wang:** Resources. **Lihong Chen:** Supervision. **Shixin Liu:** Visualization, Validation. **Jianhua Li:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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