2002–2022 SPATIAL-TEMPORAL DYNAMICS OF LAND USE CHANGE IN TIANSHUI CITY AND ITS ECOLOGICAL AND ENVIRONMENTAL IMPACTS

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Abstract. Based on land use data of Tianshui City from 2002 to 2022, this study analyzed the spatio-temporal change trajectory of land use transfer and the ecological environment index by applying land use change dynamics, land transfer matrix, kernel density analysis model, and ecological environment quality index. The results showed that the main land use types in Tianshui City were cultivated land and woodland. Over the past 20 years, the area of construction land and woodland increased, while cultivated land, grassland, and unused land decreased, and water areas remained relatively unchanged. Land use types in Tianshui City changed primarily from cultivated land to woodland, construction land, and grassland. These changes occurred mainly in the urban area and its surroundings, with the highest frequency in the main urban area. Additionally, the service value of cultivated land, grassland, and unused land showed a downward trend, while forest ecological service value showed an upward trend. Furthermore, the land use types providing services include cultivated land, grassland, and woodland, with woodland and grassland being the main types providing regulating and supporting services.
Keywords: *dynamic attitude of land use, land use transfer matrix, ecological environment index, ArcGIS, Tianshui City*

Introduction

Land use connects social and economic activities with ecological processes and affects ecosystem services (Liang et al., 2021). Land use change is considered one of the important causes of global environmental change and is an important breakthrough in studying the relationship between human activities and the environment (Huang et al., 2024). Previous studies have shown that the spatial heterogeneity of land use change is obvious over time, and the diverse changes have had different impacts on the supply of ecosystem services and affected human well-being (Fedorov et al., 2021). In areas where cities are expanding, the competition between different of land use types, especially between built-up land and adjacent land (such as farmland, forests, grasslands, and water bodies), is very prominent (Gao et al., 2024), leading to fierce conflicts between ecosystem function supply and demand (Okembo et al., 2024a). Therefore, assessing the status and trends of land use change and its ecological environmental impacts in areas where cities are expanding is of great significance for formulating land use planning strategies and implementing ecological environmental protection measures (Palermo et al., 2021).

Land use change affects the environment in many ways. Changes in land use patterns and land use structure (Cherla et al., 2021), as well as the migration of economic development space, have had profound effects on the environment. Since the middle of the 20th century, scholars have begun to study the theory, methods, and applications of ecological environment assessment. In early research, the impact of land use on the environment was evaluated by calculating the changes in the value of ecosystem services (Zhang et al., 2024). Subsequently, more and more researchers began to pay attention to the quality of ecological environment at different scales and its changes (Nyamari and Cabral, 2021), using multi-temporal remote sensing images and landscape pattern analysis methods to construct diverse ecological environment assessment models (Zhang et al., 2024). In terms of research methods, indicators (systems) and comprehensive evaluation methods are usually selected to analyze the changes and laws of ecological environment quality in different regions, and empirical studies are based on multi-source remote sensing data and GIS spatial analysis technology (Gao et al., 2024). Remote sensing technology and GIS have become key tools in all environmental evaluation fields (Zhang et al., 2020).

With the development of social and economic activities, human beings utilization and transformation of land is increasing (Tang et al., 2024), putting more pressure on the self-renewal of the ecological environment (Wang et al., 2024). In the long run, the potential risks of negative ecological effects resulting from changes in land use structure exist (Liu et al., 2022), hindering the high-quality and sustainable development of society (Xu et al., 2022a). Therefore, studying the land use transition and its ecological environmental effects is of great significance for the long-term development of the region.Land use transition is a direct manifestation of the changes in land use patterns in terms of structure and types (Cao et al., 2022), caused by the joint action of natural factors and human activities (Singh et al., 2024). How to strengthen ecological civilization construction based on land use and build a national ecological security barrier is currently a focus of attention in the social field (Hu et al., 2024).

Land is the cornerstone of ecological and environmental protection (Okembo et al., 2024b). The development and management of land constitute the core part of human activities interacting with the natural environment (Park et al., 2024). Currently, China is in a crucial stage of transitioning to high-quality development (Freire et al., 2024). Optimizing the allocation of land resources and protecting and restoring the ecological environment are the inevitable requirements for ensuring the coordinated and sustainable development of regional economies (Cao and Li, 2023).

The city of Tianshui in China has a diverse land type, mainly including plains, hills, and mountains, which provides a rich variety of natural resources and development potential. With the acceleration of urbanization and the continuous expansion of agricultural production in Tianshui, some unreasonable land use methods have caused problems such as soil erosion, affecting the land productivity and quality, and having a negative impact on the local ecological environment. Therefore, this study aims to study the spatial and temporal trajectory of land use transfer in Tianshui and its ecological environment index based on the land use type data from 2002 to 2022, with the goal of providing theoretical support for Tianshui to build a "three-life space" city that balances production, living, and ecological spaces.

Materials and methods

Study area

Tianshui City is located in southeastern Gansu Province of China, with a geographic range of 104°35′–106°44′ E and 34°05′–35°10′ N. It covers a total area of approximately 14,300 km², including five counties and two districts, namely Tianshui District, Maiji District, Ganzhou County, Qingshui County, Wuwei County, Ganji County, and Zhangjiashan Hui Autonomous County. It is adjacent to Guanzhong in the east, Longzhong in the west, Longdong in the north, and Ba Shu in the south. It spans across the Yellow River and Yangtze River basins, with the Qinling Mountains serving as the dividing line. The northern part of the city is in the Wei River basin, which covers about 82% of Tianshui City's total area, while the southern part is in the Jialing River basin, covering about 18% of the total area. It has rich flora and fauna resources and belongs to a continental warm temperate semi-humid climate, with an average annual temperature of about 11°C and annual precipitation of over 500 millimeters (*Figure 1*).

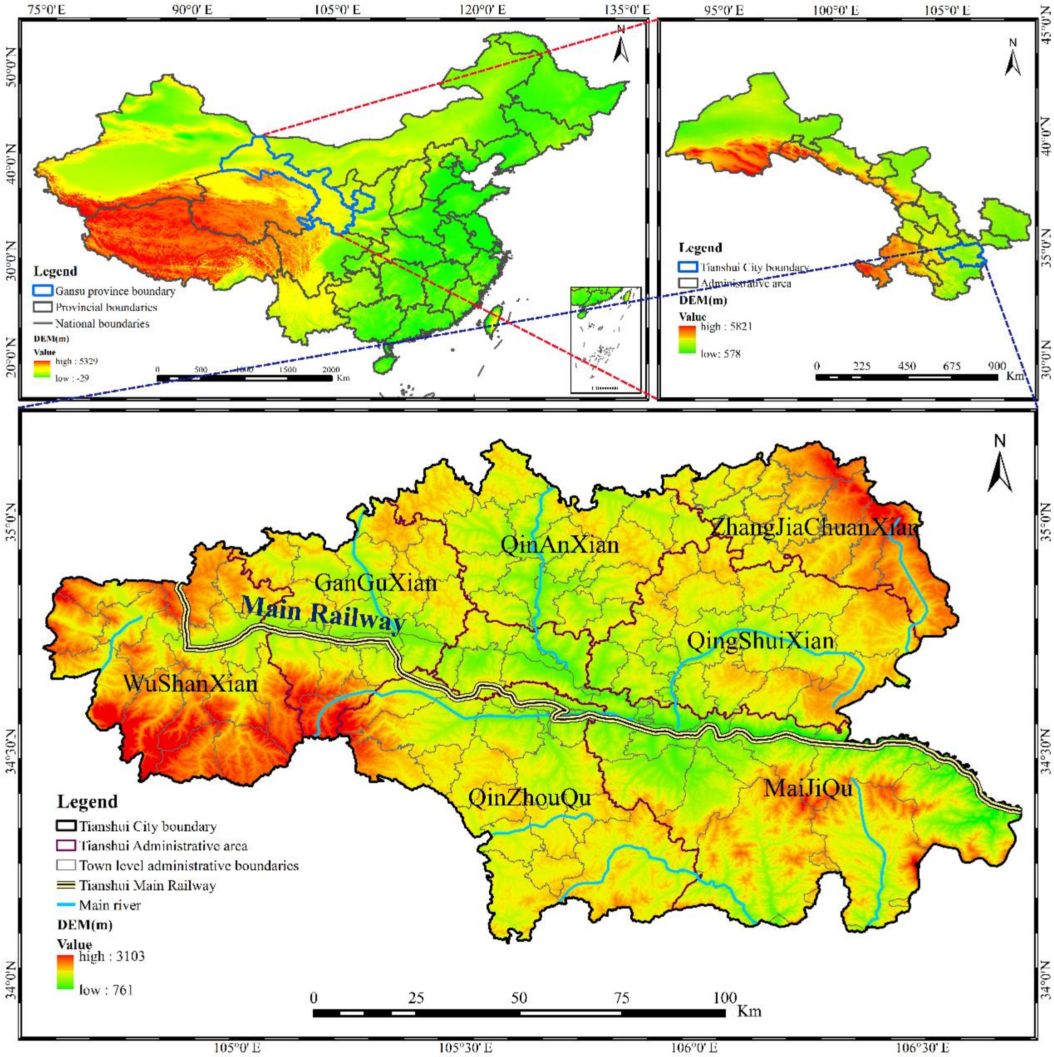

Figure 1. *Maps displaying the location of the Tianshui City in China. Panels B and C represent the enlarged areas outlined in red in panels A and B, respectively. DEM, digital elevation model*

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Data sources

The study involves data, including elevation data, land use data, natural and social factor data. The DEM data is sourced from the China Geographic Spatial Data Cloud Platform (https://www.gscloud.cn/). The land use was reclassified from 21 secondary types into 6 primary types using the ArcGIS reclassification tool, including grassland, cultivated land, forestland, water bodies, built-up land, and unused land. Natural factor data mainly includes climatic and topographic information. Climatic data (temperature, precipitation, etc.) were obtained from the local meteorological bureau from 2003 to 2023 to identify potential impacts of climate variability on land use changes. Additionally, DEM data was used to assess altitude, slope, and other topographical features that may affect land use distributions. Social factor data primarily comes from the Tianshui City Statistical Yearbooks (2003–2023), covering population size, industrial output value, GDP, and urbanization rates. Over the past two decades, the population has shown a steady increase from 2.5048 million to 3.7026 million people, while the industrial output value and GDP have experienced rapid growth, particularly after 2010. This indicates that economic development and industrialization have played a significant role in driving changes in land use.

Research methods

Land use transfer matrix

The land use transfer matrix is a two-dimensional matrix that studies the mutual conversion of different land use types in the study area at different times. The matrix analysis results can reveal the area changes and spatial evolution of land use types and show the dynamic transfer process between land use types (Huang et al., 2023). The following is the calculation formula:

$$P = \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & A_{ij} & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{pmatrix} \quad \text{(Eq.1)}$$

In this formula, *P* represents the land use area; *i* and *j* represent the initial and final land use types, respectively, with n representing the number of land use types.

A kernel density model

A non-parametric visualization method used to detect data distribution and reflect spatial agglomeration effects by analyzing the spatial diffusion patterns of point or line elements in a specific area to reflect the distance decay law of geographical phenomena (Yu et al., 2023). The following is the calculation formula:

$$F(x) = \frac{1}{nh}\sum_{i=1}^{n} K(\frac{x - x_i}{h}) \quad \text{(Eq.2)}$$

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$$K(x) = \frac{1}{\sqrt{2\pi}}(-\frac{x^2}{2} \quad \text{(Eq.3)}$$

In this formula, *K(x)* is the weight function; n is the number of data points; *h* is the threshold; and $(x - x_i)$ is the distance between sample points.

Ecological Service Value

According to a standard ecosystem service economic value equivalent coefficient, the economic value of food production provided by unit area of farmland is 1/7. Combining the lowest purchase price of grain in Tianshui City, Gansu Province, China in 2023, which is 2.29 yuan/kg, and using the formula to correct the coefficient for NPP, precipitation, social and economic factors, and resource scarcity, where NPP is corrected for food production, raw material production, gas regulation, climate regulation, environmental purification, nutrient cycle maintenance, biodiversity, and aesthetic landscape, and then corrected for water resources supply and hydrological regulation based on precipitation data, the ESV of Tianshui City is obtained. To quantitatively analyze the spatial characteristics of the ESV in Tianshui City, the study area is divided into 5 km×5 km grid units, and the ESV of each grid is calculated separately to form a spatial distribution map of ESV.

$$ESV = \sum_{i=1}^{n} VC_i \cdot A_i \quad \text{(Eq.4)}$$

In this formula, *ESV* stands for the ecosystem service value of the regional area; A_i represents the area of the i-th land use type; VC_i represents the unit area ecosystem service value of the i-th land use type; and n represents the number of land use types.

The value of ecosystem services is primarily comprised of the following components:

Supply Services: This refers to resources or products directly provided to humans, such as food and raw materials. The economic value of food production serves as the basis for measurement in this research, using a minimum purchase price for grain (2.29 CNY/kg) as a benchmark. Additionally, adjustments are made to the unit area value based on Net Primary Productivity (NPP), socio-economic factors, and resource scarcity.

Regulation Services: These include climate regulation, gas regulation, hydrological regulation, and environmental purification. The valuation of various regulatory functions is mainly quantified based on adjusted NPP data, precipitation levels, and socio-economic parameters. Furthermore, coefficients are revised in calculations to account for differences in service functions across different regions.

Support Services: Functions such as nutrient cycling, soil formation, biodiversity maintenance, and landscape aesthetics fall under this category. Additional valuations are applied to ecosystem support functions based on the foundational values derived from food production.

Cultural services: Cultural services are assessed by considering the recreational potential of natural landscapes, historical and cultural sites, and the overall aesthetic quality of the environment. The valuation incorporates local preferences and the economic significance of these services to the community.

Through these methodologies, we can derive the unit area Ecosystem Service Value (ESV) for various land use types—such as forests, arable land, grasslands, water bodies,

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unused lands—and constructed areas. By combining these values with their respective land areas within a given region's scope allows us to calculate their total ESV effectively.

Environmental Quality Index

For the Ecological Environment Quality Index (EEQI), we used a set of indicators including the relative ecological service value (LEi and LEj), ecological contribution rate (CR), and proportional land use changes (Ai). These indicators were calculated using the following equations: [*Equations 5, 6, 7* from the manuscript]. The relative ecosystem service values were assigned based on previous studies (e.g., woodlands = 1, grasslands = 0.125), with corrections applied for climate and socioeconomic factors.

The specific expression is as follows:

$$R_{i\to j} = (LE_j - LE_i) \times A_{i\to j} \quad \text{(Eq.5)}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{n} |(LE_j - LE_i) \times A_{i\to j}| \quad \text{(Eq.6)}$$

$$E_n = \sum_{i=1}^{n}(LE_i \times A_i) \quad \text{(Eq.7)}$$

In this formula, $R_{i\to j}$ represents the ecological contribution rate of land use type i changing to type j; E_n is the index of ecological environment quality; LE_i and LE_j are the relative ecological service values of land use type *i* and *j*, respectively; $A_{i\to j}$ is the ratio of the area of type *j* changing to type *i* to the total study area; and A_i is the ratio of the area of land use type i to the total study area; N represents the number of land use types (Fedorov et al., 2021).

To determine land use density, we employed a kernel density model, which utilized a non-parametric estimation technique to analyze the spatial aggregation of land use patterns. The model applied a Gaussian weight function, a threshold (h) of 5 km, and a dataset consisting of point and line elements for land use types during the study period the ecological service value of wood land was the highest, assigned a value of 1, while the ecological service value of built-up land was the lowest, assigned a value of 0 (Palermo et al., 2021). The ecological service value of other land use types was determined relative to that of wood land, with grassland assigned a value of 0.125, arable land assigned a value of 0.327, water bodies assigned a value of 0.246, and unused land assigned a value of 0.004.

Results and analysis

Spatial and temporal analysis of land use type change

The distribution and area migration changes of land use types in Tianshui City from 2002 to 2022 are shown in *Figure 2*. The main land use types in Tianshui City are arable land and wood land. Arable land is mainly distributed along the riversides and in low-lying areas, while wood land is mainly concentrated in the south and east of Tianshui

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City. Built-up land is mainly distributed in the central and northern parts of Tianshui City and is dispersed along the rivers in a ribbon-like pattern.

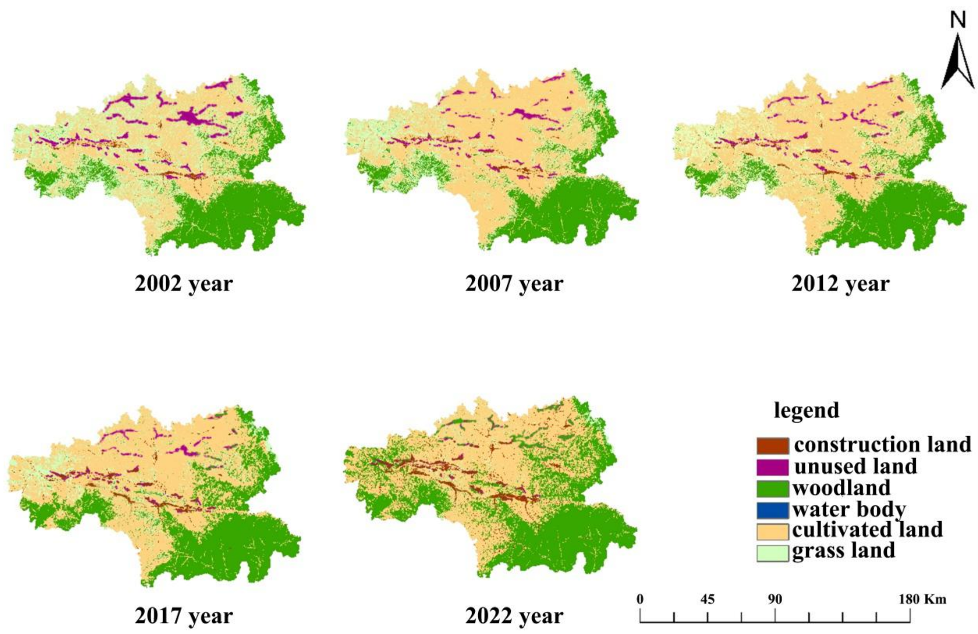

Figure 2. *Distribution of land-use types in the Tianshui city from 2002 to 2022*

There have been different degrees of increases and decreases in the main land use types in Tianshui City from 2002 to 2022 (*Table 1*). The area of built-up land and wood land has increased, with the built-up land area increasing by 93.44 km^2 and the area proportion rising by 0.65%. The wood land area has increased by 296.36 km^2, and the area proportion has risen by 2.07%. The area of cultivated land, grassland, and unused land has decreased, with the cultivated land area decreasing by 358.85 km^2 and the area proportion falling by 2.52%. The grassland area has decreased by 10.72 km^2, and the area proportion has fallen by 0.07%. The area of water bodies has not shown significant changes over the 20 years.

Table 1. *Land use change amount in Tianshui City from 2002 to 2022*

Land type	Cultivated land		Wood land		Grass land		Water body		Construction land		Unused land	
	Area/ km^2	Ratio /%	Area /km^2	Ratio /%	Area /km^2	Ratio /%	Area /km^2	Ratio /%	Area /km^2	Ratio /%	Area /km^2	Ratio %
2002	7998.74	56.03%	4492.62	31.47%	1504.96	10.54%	26.53	0.19%	165.47	1.16%	88.43	0.62%
2007	7901.83	55.35%	4683.55	32.81%	1405.50	9.84%	26.39	0.18%	176.82	1.24%	82.66	0.58%
2012	7801.24	54.64%	4729.57	33.13%	1408.47	9.87%	26.32	0.18%	232.31	1.63%	78.84	0.55%
2017	7724.43	54.10%	4757.81	33.33%	1451.19	10.16%	26.61	0.19%	243.31	1.70%	73.40	0.51%
2022	7639.89	53.51%	4788.98	33.54%	1494.24	10.47%	26.62	0.19%	258.91	1.81%	68.10	0.48%

Land use density analysis

The land use changes in Tianshui City from 2002 to 2022 mainly occurred in the downtown area and its surrounding areas. The highest frequency of change occurred in the downtown area, which is a high-density area, and has always shown the same trend

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of change. The trend of land use nucleus density change has shifted from the downtown area to the surrounding areas. The areas where the administrative agencies of each district and county are located are medium-high density areas and medium-density areas, and have always shown the same trend of change. The trend of land use nucleus density change has shifted from the downtown area to the surrounding areas. The remaining areas of Tianshui City are medium-low density areas and low-density areas, and are distributed in patches and clusters (*Fig. 3*).

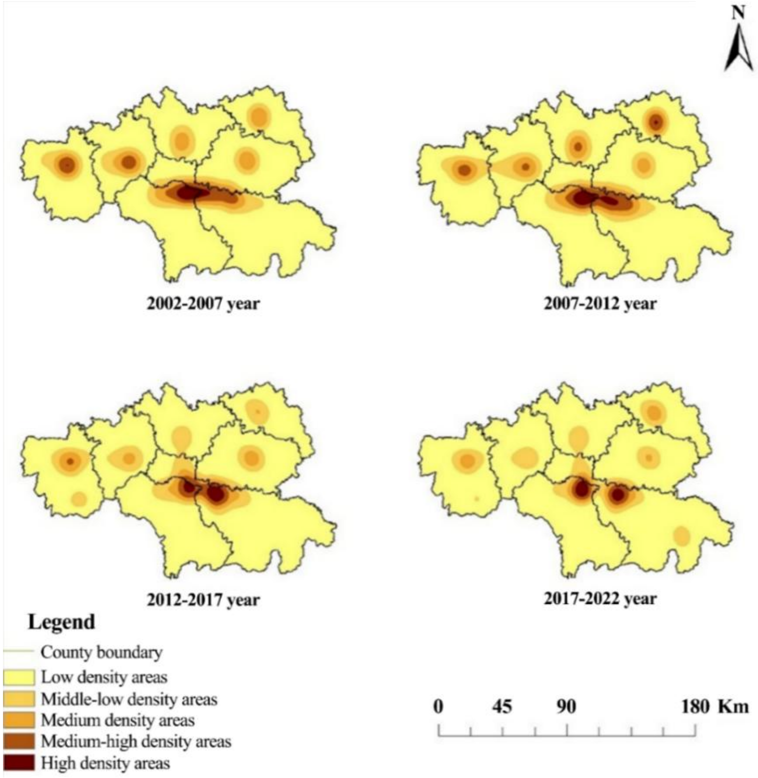

Figure 3. *Kernel density analysis of land use change in Tianshui City*

Ecosystem service value

In 2002-2022, the ESV ranking of different land uses was wood land > cultivated land > grass land > water body > unused land > construction land. Among them, the service value of cultivated land, grassland, and unused land showed a downward trend, while the rest showed an upward trend, with forest land increasing the most (*Table 2*).

By assigning different land use types values, the ecological service value map of land use types in Tianshui City from 2002 to 2022 was obtained (*Figure 4*). Overall, the ecological service value in Tianshui City has changed little. The land use types that mainly provide supply services are cultivated land, grass land, and wood land. Among them, the supply service value of forestland is decreasing, while the reduction of cultivated land has caused the supply capacity of ecological service value in Tianshui City to weaken gradually. The land use types that mainly provide regulation and support services are wood land and grass land. Among them, the regulation and support service capacity of wood land is increasing due to the increase in its area, while the cultural service mainly provided by wood land and water body.

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Table 2. *Ecological service value of land in Tianshui City from 2002 to 2022*

	Year	Cultivated land	Wood land	Grass land	Water body	Cultivated land	Unused land	Total
Ecological Service Value	2002	38.21	109.29	14.79	2.81	0.00	0.07	165.17
	2007	37.75	113.93	13.81	2.79	0.00	0.06	168.35
	2012	37.27	115.05	13.84	2.79	0.00	0.06	169.01
	2017	36.90	115.74	14.26	2.82	0.00	0.06	169.78
	2022	36.50	116.50	14.69	2.82	0.00	0.05	170.55
5 Years of Ecological Service Value	2002-2007	-0.46	4.64	-0.98	-0.01	0.00	0.00	3.18
	2007-2012	-0.48	1.12	0.03	-0.01	0.00	0.00	0.66
	2012-2017	-0.37	0.69	0.42	0.03	0.00	0.00	0.77
	2017-2022	-0.40	0.76	0.42	0.00	0.00	0.00	0.77
10 Years of Ecological Service Value	2002-2012	-0.94	5.76	-0.95	-0.02	0.00	-0.01	3.84
	2012-2022	-0.77	1.45	0.84	0.03	0.00	-0.01	1.54
20Years of Ecological Service Value	2002-2022	-1.71	7.21	-0.11	0.01	0.00	-0.02	5.38

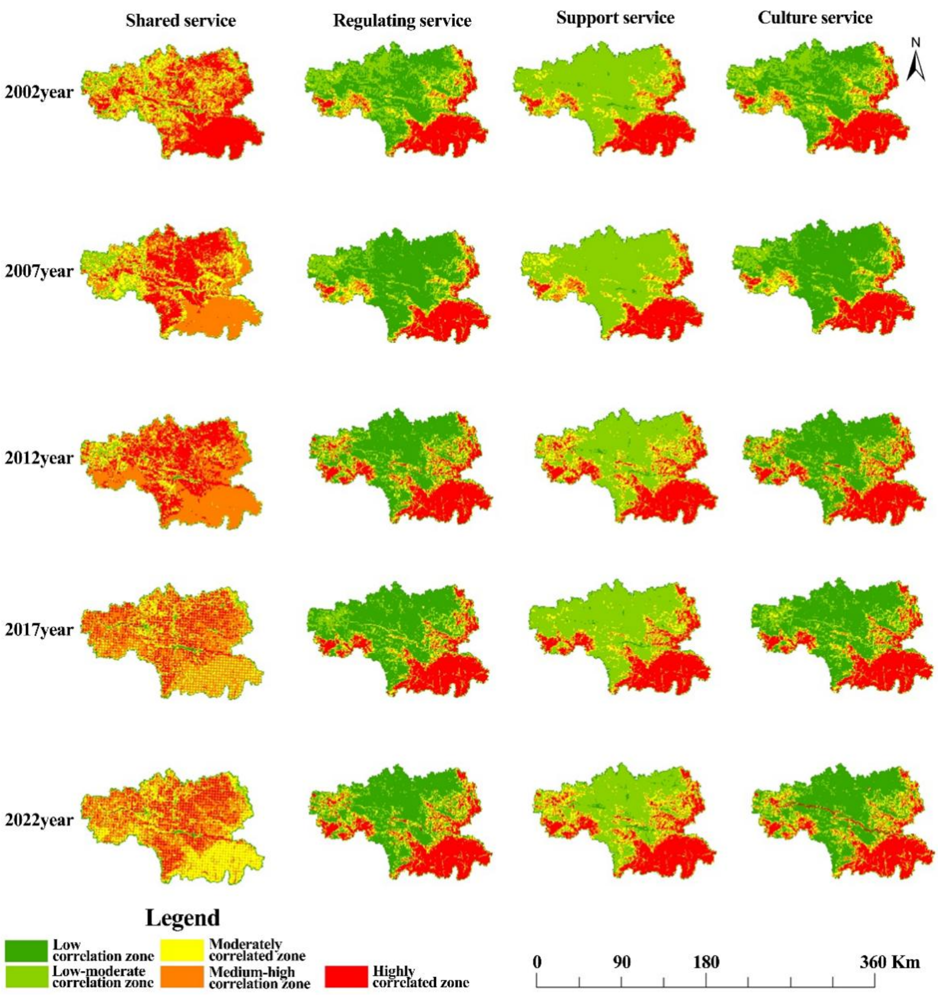

Figure 4. *Ecological service value of land types in Tianshui City from 2002 to 2022*

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Analysis of ecological environment quality index

The ecological environment index of Tianshui City at different time nodes was calculated, and the ecological environment quality in Tianshui City has shown a steady growth trend over the past 20 years, ranging from 0.5123 to 0.5348 (*Table 3*). Among them, the ecological service value of Cultivated land showed a decreasing and then increasing trend, decreasing from 0.1837 in 2002 to 0.173 in 2022, while the ecological service value of Wood land has always shown an increasing trend, increasing from 0.3147 in 2002 to 0.3367 in 2022. The ecological service value of Grassland showed a decreasing and then increasing trend, increasing from 0.0132 in 2002 to 0.0231 in 2022. Other land use types showed little change in ecological index (*Table 4*).

Table 3. *Environmental quality index for Tianshui City from 2002 to 2022*

Land type	Ecosystem service value	Ecological Environment Index				
		2002	**2007**	**2012**	**2017**	**2022**
Cultivated land	0.3274	0.1837	0.1817	0.1789	0.1713	0.1743
Wood land	1.0000	0.3147	0.3281	0.3313	0.3333	0.3367
Grassland	0.1252	0.0132	0.0123	0.0124	0.0236	0.0231
Water body	0.2459	0.0005	0.0005	0.0005	0.0005	0.0005
Construction land	0	0	0	0	0	0
Unused land	0.0004	0.0003	0.0002	0.0002	0.0002	0.0002
Total		0.5123	0.5227	0.5232	0.5289	0.5348

The ecological environment quality in Tianshui City is closely related to the distribution of land use types. The high-quality and medium-high-quality areas are mainly concentrated in the southeastern Wood land and Grassland areas of Tianshui City, while the medium-quality areas are mainly distributed in the central Grassland and Cultivated land areas of Tianshui City. The medium-low quality and low-quality areas are mainly distributed in the Construction land areas of each county (*Fig. 5*).

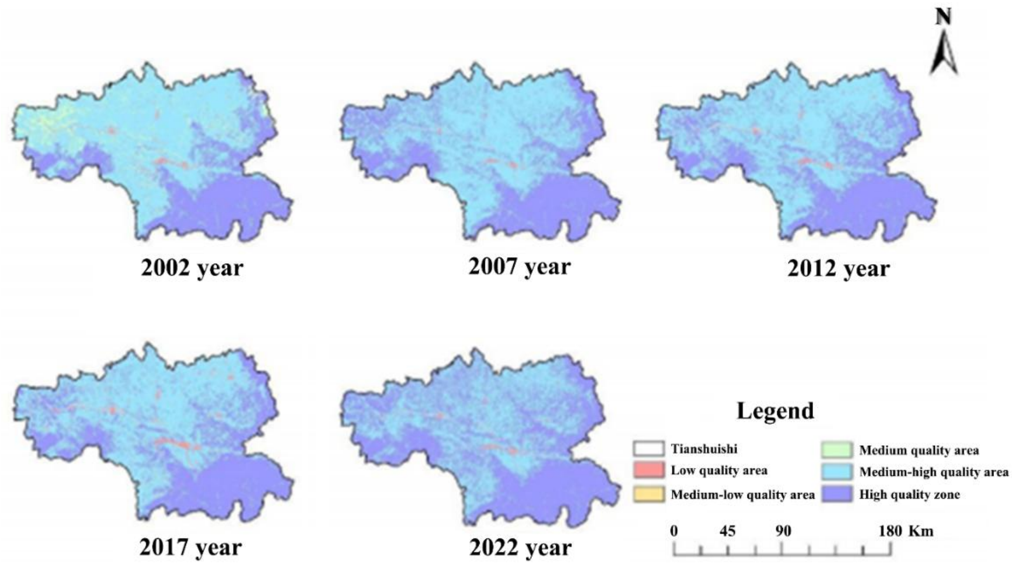

Figure 5. *Environmental quality map of Tianshui City*

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Table 4. *Changes in ecological environment index caused by land use changes in Tianshui City from 2002 to 2022*

	Types of land use conversion	**Area/km^2**	**Environmental Index Contribution Rate**	**Proportion**
Improvement of ecological environment	Cultivated land-Wood land	352.94	0.016628	24.679%
	Grass land-Cultivated land	247.39	0.003504	5.200%
	Grass land-Wood land	761.18	0.046641	69.225%
	Grass land-Water body	2.64	0.000022	0.033%
	Unused land-Cultivated land	0.07	0.000002	0.002%
	Unused land-Wood land	0.00	0.000000	0.000%
	Water body-Cultivated land	7.30	0.000042	0.062%
	Water body-Wood land	1.19	0.000063	0.093%
	Construction land-Cultivated land	15.97	0.000366	0.544%
	Construction land-Wood land	1.40	0.000098	0.146%
	Construction land-Grass land	0.61	0.000005	0.008%
	Construction land-Unused land	0.06	0.000004	0.006%
	Construction land-Water	0.06	0.000001	0.002%
	Total	1390.81	0.067376	100.000%
Deterioration of the ecological environment	Cultivated land-Grass land	86.2371	-0.001221	8.475%
	Cultivated land-Unused land	0.3708	-0.000009	0.059%
	Cultivated land-Water body	3.4803	-0.000020	0.138%
	Cultivated land-Construction land	263.5668	-0.006044	41.938%
	Wood land-Cultivated land	103.7862	-0.004890	33.926%
	Wood land-Grass land	28.1718	-0.001726	11.977%
	Wood land-Water body	0.4239	-0.000022	0.155%
	Wood land-Construction land	4.8375	-0.000339	2.351%
	Grassland-Unused land	1.9008	-0.000017	0.115%
	Grassland-Construction land	10.5273	-0.000092	0.639%
	Water body-Grassland	0.7407	-0.000006	0.043%
	Water body-Unused	0.5886	-0.000010	0.070%
	Water body-Construction land	0.9405	-0.000016	0.112%
	Total	505.5723	-0.014412	100.000%

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The land use conversion order of ecological environment degradation in Tianshui City is: Cultivated land converted to Construction land > Wood land converted to Cultivated land > Wood land converted to Grassland > Cultivated land converted to Grassland, accounting for 96.317% of the total contribution rate of ecological environment degradation and 17.62% of the total contribution rate of ecological environment. Over the past 20 years, with the acceleration of urbanization in Tianshui City, a large amount of Cultivated land around urban areas has been converted to Construction land, resulting in a decline in the ecological environment quality of the city and its surrounding areas. The land use conversion order of ecological environment improvement is: Grassland converted to Wood land > Cultivated land converted to Wood land > Grassland converted to Cultivated land, accounting for 99.104% of the total contribution rate of ecological environment improvement and 82.38% of the total contribution rate of ecological environment. This reflects that the ecological environment quality in Tianshui City has shown an upward trend over the past 20 years, and to build a "three-life space" city that coordinates production, life, and ecology, it is necessary to continue to strengthen urban land use management, protect Cultivated land, promote the coordinated development of production and ecological protection, and continue to implement the policy of reforestation and afforestation.

Discussion

Tianshui City is located in the Guanzhong Plain Urban Agglomeration in China, not only serving as a key pillar for regional integration and development, but also as a core node of the Yellow River Economic Belt. Research on Tianshui City helps to gain a deeper understanding of the relationship between urbanization, land use change, and ecological environment in western China, providing important theoretical support and decision-making basis for sustainable development in the region.

This study found that land use change in Tianshui City from 1990 to 2020 mainly involved a reduction in farmland and grassland areas and an increase in built-up land areas. Population growth and economic development were the main driving factors. As the population of Tianshui City continued to grow and the economy developed, the demand for construction land increased, leading to the large-scale encroachment of farmland to meet the needs for industrial, transportation, and construction land. In addition, the adjustment of agricultural structure was also an important reason for the reduction in farmland area. With the transformation of agricultural production methods, some farmland was converted into wood land or other uses to meet market needs and the needs for environmental protection. The policy of reforestation and abandonment of farmland in Tianshui encouraged the conversion of some farmland with steep slopes and serious soil erosion into wood land to improve the ecological environment (Zhang et al., 2020). At the same time, the adjustment of the agricultural industrial structure also led to the conversion of some farmland into wood land and grassland to meet the market demand for specialty agricultural products and ecological products. The acceleration of urbanization was also an important reason for the increase in built-up land area, with the continuous expansion of the urban population and the continuous improvement of urban infrastructure leading to an increasing demand for construction land. Meanwhile, the expansion of cities has led to the large-scale encroachment of farmland and wood land in the surrounding areas to meet the demand for urban land. Although the increase in construction land area has had a negative impact on the ecological environment, the

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overall quality of Tianshui's ecological environment has continued to improve, consistent with the research results of other parts of the country. This is mainly due to the ecological protection policies implemented by the Chinese government, such as reforestation and rewetting of farmland, which have effectively improved the ecological environment. Therefore, when formulating land use planning, it is necessary to fully consider the impact of different land use types on the ecological environment. Land use change is mainly influenced by socioeconomic factors, and the interaction between socioeconomic factors has the most significant impact on land use change, which is consistent with the research results of other regions in China. In order to achieve the coordinated development of economic development and ecological protection, it is necessary to fully consider the impact of the ecological environment. At the same time, the research results can be used as a reference to formulate a more scientific and reasonable urbanization development strategy to achieve coordinated development of economic development and ecological protection (Li et al., 2022).

The ecological and environmental effects of regional land use transformation are an important part of global change research (Rodrigues et al., 2016). Scientifically and rationally measuring the ecological and environmental effects of land use transformation is of great significance for improving regional ecological and environmental quality (Zhang et al., 2020). This study combines regional land use change with ecological and environmental quality evaluation results to provide a more comprehensive reflection of the changing trends in regional ecological and environmental quality (Ma et al., 2023). It provides a new perspective for revealing the ecological and environmental effects of land use transformation. The changes in environmental quality, to a certain extent, can provide scientific references and policy suggestions for the sustainable utilization of land resources (Gao et al., 2023). However, it is still limited by data acquisition and quantitative evaluation methods, and there is further room for exploration in some aspects: (1) The limitation of data sources: This study mainly used remote sensing data, which may not fully reflect the actual land use changes. For example, some regions may have data gaps or insufficient accuracy. (2) The limitation of research methods: This study mainly used ecological and environmental evaluation models to evaluate ecological and environmental quality. Although this model can comprehensively reflect the multiple aspects of ecological and environmental quality, its index system and methods may have certain limitations, such as not reflecting the changes in all ecosystem service functions. Future studies can try to use more diverse data sources, such as field survey data and social and economic statistical data, to improve the completeness and reliability of the data. And try to use other ecological and environmental evaluation methods, such as ecosystem service value assessment and landscape ecology methods, to more comprehensively evaluate the impact of land use changes on ecological and environmental quality.

In Tianshui, population growth and economic development were identified as key drivers of land use change, consistent with findings in other regions. However, the influence of agricultural restructuring—resulting in the conversion of farmland to woodland and grassland—emerges as a unique characteristic of this region, driven by market demands for specialty agricultural products and ecological conservation initiatives. For instance, the implementation of reforestation policies in Tianshui has led to a greater proportion of land being converted to ecological uses compared to other regions in western China.

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Moreover, while urbanization and industrial expansion have led to the encroachment of farmland and woodlands, the ecological protection policies implemented in Tianshui have mitigated the negative environmental impacts. These findings align with broader national trends in ecological improvement attributed to China’s "Grain for Green" program, but the localized impacts of such policies in Tianshui reveal a more pronounced ecological benefit due to the region’s focus on soil erosion control and biodiversity enhancement.

Conclusion

(1) Cultivated land and Wood land are the main land use types in Tianshui City, and the areas of Construction land and Wood land have increased, while the areas of Cultivated land, Grassland, and Unused land have decreased. The area of water bodies has not shown significant changes over the past 20 years. The land use type change and transfer in Tianshui City mainly involves the conversion of Cultivated land to Wood land, Construction land, and Grassland.

(2) Land use change mainly occurs in the main urban area and its surrounding areas in Tianshui City, with the highest frequency of change in the central urban area, which is a high-density area. The areas around the administrative offices of each district and county are medium-high density and medium-density areas, while the rest of Tianshui City is a medium-low density and low-density area.

(3) The service value of Cultivated land, Grassland, and Unused land in Tianshui City has decreased, while the ecological service value of Wood land has increased.

(4) The land use types in Tianshui City that provide supply services are Cultivated land, Grassland, and Wood land, while those that provide regulation and support services are Wood land and Grassland. The ecological environment quality in Tianshui City has shown an upward trend over the past 20 years, but to build a "three-life space" city that coordinates production, living, and ecological spaces, it is necessary to continue to strengthen urban land use management, protect Cultivated land, and formulate land use policies that promote the coordination of production, construction land use, and ecological environmental protection.2024 Projects for Philosophical and Social Sciences Research in Gansu Province.

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REFERENCES

[1] Cao, X., Liu, Z., Li, S., Gao, Z. (2022): Integrating the Ecological Security Pattern and the PLUS Model to Assess the Effects of Regional Ecological Restoration: A Case Study of Hefei City, Anhui Province. – International Journal of Environmental Research and Public Health 19.

[2] Cao, J., Li, T. (2023): Analysis of spatiotemporal changes in cultural heritage protected cities and their influencing factors: Evidence from China. – Ecological Indicators 151: 110327.
[3] Cherla, A., Howard, N., Mossialos, E. (2021): The 'Netflix plus model': can subscription financing improve access to medicines in low- and middle-income countries? – Health Economics Policy and Law 16: 113-123.
[4] Fedorov, A. V., Dubinin, Y. V., Yeletsky, P. M., Fedorov, I. A., Shelest, S. N., Yakovlev, V. A. (2021): Combustion of sewage sludge in a fluidized bed of catalyst: ASPEN PLUS model. – Journal of Hazardous Materials 405: 124196.
[5] Freire, T., Hu, Z., Wood, K. B., Gjini, E. (2024): Modeling spatial evolution of multi-drug resistance under drug environmental gradients. – PLoS Computational Biology 20: e1012098.
[6] Gao, F., Xin, X., Song, J., Li, X., Zhang, L., Zhang, Y., Liu, J. (2023): Simulation of LUCC Dynamics and Estimation of Carbon Stock under Different SSP-RCP Scenarios in Heilongjiang Province. – Land 12: 1665.
[7] Gao, J., Gong, J., Li, Y., Yang, J., Liang, X. (2024): Ecological network assessment in dynamic landscapes: Multi-scenario simulation and conservation priority analysis. – Land Use Policy 139: 107059.
[8] Hu, Z., Song, G., Hu, Z., Fang, J. (2024): An improved dynamic game analysis of farmers, enterprises and rural collective economic organizations based on idle land reuse policy. – Land Use Policy 140: 107098.
[9] Huang, T., Wang, Z., Wu, Z., Xiao, P., Liu, Y. (2023): Attribution analysis of runoff evolution in Kuye River Basin based on the time-varying budyko framework. – Frontiers in Earth Science 10.
[10] Huang, C., Zhou, Y., Wu, T., Zhang, M., Qiu, Y. (2024): A cellular automata model coupled with partitioning CNN-LSTM and PLUS models for urban land change simulation. – Journal of Environmental Management 351: 119828.
[11] Li, Y., Li, J., Chu, J. (2022): Research on land-use evolution and ecosystem services value response in mountainous counties based on the SD-PLUS model. – Ecology and Evolution 12: e9431.
[12] Liang, X., Guan, Q., Clarke, K. C., Liu, S., Wang, B., Yao, Y. (2021): Understanding the drivers of sustainable land expansion using a patch-generating land use simulation (PLUS) model: A case study in Wuhan, China. – Computers, Environment and Urban Systems 85: 101569.
[13] Liu, Q., Yu, F., Mu, X. (2022): Evaluation of the Ecological Environment Quality of the Kuye River Source Basin Using the Remote Sensing Ecological Index. – International Journal of Environmental Research and Public Health 19: 12500.
[14] Ma, G., Li, Q., Zhang, J., Zhang, L., Cheng, H., Ju, Z., Sun, G. (2023): Simulation and Analysis of Land-Use Change Based on the PLUS Model in the Fuxian Lake Basin (Yunnan–Guizhou Plateau, China). – Land 12: 120.
[15] Nyamari, N., Cabral, P. (2021): Impact of land cover changes on carbon stock trends in Kenya for spatial implementation of REDD+ policy. – Applied geography (Sevenoaks) 133: 102479.
[16] Okembo, C., Morales, J., Lemmen, C., Zevenbergen, J., Kuria, D. (2024a): A Land Administration Data Exchange and Interoperability Framework for Kenya and Its Significance to the Sustainable Development Goals. – Land 13: 435.
[17] Palermo, T., Prencipe, L., Kajula, L. (2021): Effects of Government-Implemented Cash Plus Model on Violence Experiences and Perpetration Among Adolescents in Tanzania, 2018–2019. – American Journal of Public Health 111: 2227-2238.
[18] Park, S. S., Lee, Y. K., Choi, Y. W., Lim, S. B., Park, S. H., Kim, H. K., Shin, J. S., Kim, Y. H., Lee, D. H., Kim, J. H., Park, T. J. (2024): Cellular senescence is associated with the spatial evolution toward a higher metastatic phenotype in colorectal cancer. – Cell Reports 43: 113912.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_35733588

[19] Rodrigues, N. C., Lino, V. T., Daumas, R. P., Andrade, M. K., O'Dwyer, G., Monteiro, D. L., Gerardi, A., Fernandes, G. H., Ramos, J. A., Ferreira, C. E., Leite, I. D. (2016): Temporal and Spatial Evolution of Dengue Incidence in Brazil, 2001-2012. – PLoS One 11: e165945.

[20] Singh, P., Fu, N., Dale, S., Orzol, S., Laird, J., Markovitz, A., Shin, E., O'Malley, A. S., McCall, N., Day, T. J. (2024): The Comprehensive Primary Care Plus Model and Health Care Spending, Service Use, and Quality. – JAMA-Journal of the American Medical Association 331: 132-146.

[21] Tang, H., Halike, A., Yao, K., Wei, Q., Yao, L., Tuheti, B., Luo, J., Duan, Y. (2024): Ecosystem service valuation and multi-scenario simulation in the Ebinur Lake Basin using a coupled GMOP-PLUS model. – Scientific Reports 14: 5071.

[22] Wang, S., Zhai, C., Zhang, Y. (2024): Evaluating the Impact of Urban Digital Infrastructure on Land Use Efficiency Based on 279 Cities in China. – Land 13: 404.

[23] Xu, L., Liu, X., Tong, D., Liu, Z., Yin, L., Zheng, W. (2022a): Forecasting Urban Land Use Change Based on Cellular Automata and the PLUS Model. – Land 11: 652.

[24] Yu, Z., Zhao, M., Gao, Y., Wang, T., Zhao, Z., Wang, S. (2023): Multiscenario Simulation and Prediction of Land Use in Huaibei City Based on CLUE-S and PLUS Models. – Applied Sciences 13: 7142.

[25] Zhang, Y., Song, W., Fu, S., Yang, D. (2020): Decoupling of Land Use Intensity and Ecological Environment in Gansu Province, China. – Sustainability 12: 2779.

[26] Zhang, J., Wang, J., Zhao, N., Shi, J., Wang, Y. (2024): Analysis of Changes in Runoff and Sediment Load and Their Attribution in the Kuye River Basin of the Middle Yellow River Based on the Slope Change Ratio of Cumulative Quantity Method. – Water 16: 944.

[27] Zhang, Z., Li, X., Liu, X., Zhao, K. (2024): Dynamic simulation and projection of land use change using system dynamics model in the Chinese Tianshan mountainous region, central Asia. – Ecological Modelling 487: 110564.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2302_35733588