RESEARCH ARTICLE

# Spatial-temporal changes and driving factors analysis of ecosystem service value in Changsha, Hunan province, China

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**Received:** October 20, 2022; **accepted:** November 28, 2022.

**Research on ecosystem services has a significant positive impact on ecosystem management, conservation, and the creation of ecological compensating systems. For the purpose to explore the characteristics of the geographical and temporal evolution and the driving forces behind the value of ecosystem services in Changsha, Hunan province, China, the four phases of land use data for the city from 2005 to 2020 were employed and analyzed by using geographic information systems and spatial statistics. The findings revealed that: (1) Forest land was the primary type of land used in Changsha. The area of construction land, wetland, and unused land increased, while the area of forest land, paddy field, dry land, and grassland decreased, and the area of water area was stable. (2) From 2005 to 2020, the value of ecosystem services showed a decreasing trend year by year. The forest land had the greatest impact on ecosystem service value (ESV) of all the land use types and the functions of hydrological regulation accounted for the largest share of the various ecosystem service functions. In terms of space, the high-value areas were mainly distributed in the east and west parts and rivers, while the low-value areas were mainly distributed in the middle which had the characteristics of positive agglomeration. (3) The results of the Geodetector revealed that spatial and temporal differences in ecosystem service values in Changsha were influenced by a combination of regional natural factors and socio-economic factors with a greater contribution from factors of Human Impact Index (HAI), Digital Elevation Model (DEM), and mean annual temperature. The interaction types were bivariate enhancement and nonlinear enhancement. The results of this study may serve as a scientific reference for the rational utilization of land resources and ecological environment protection in Changsha, Hunan, China.**

**Keywords:** land use; ecosystem service value; spatial and temporal evolution; Geodetector; driving factors.

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## Introduction

Ecosystem services are life support products and services obtained directly or indirectly through the structure, processes, and functions of ecosystems, and their value assessment is an important basis and foundation for ecological environmental protection, ecological function zoning, environmental economic accounting, and ecological compensation decisions [1]. To categorize and evaluate the global ecosystem service functions, Costanza proposed the global ecosystem service value (ESV) scale in 1997 [2]. Based on this, numerous academics have assessed and forecasted the value of ecosystem services at various spatial scales, including global [3], climatic zone [4], continent [5-6], country [7], and city [8]. In 2003, Chinese scholars Gaodi Xie, *et al*. developed the Chinese ecosystem unit area value equivalence table based on Costanza's table through a questionnaire survey of relevant experts [9], and later corrected it [10], which has been widely used. Chinese scholars have investigated the spatiotemporal changes and driving factors of ecosystem service value at the scales of an ecosystem [11-12], watershed [13-14], provincial, urban agglomeration [15-17], and county [18-20] based on Xie’s table and in conjunction with land use change, which has become a research hotspot in ecology, environmental science, and geography. Geodetector uses spatial heterogeneity to detect the independent variable's level of explanatory power for the dependent variable as well as the strength, direction, linearity or nonlinearity of any interactions between the two independent variables [21], avoiding the coupling effect that can occur when using linear regression. Currently, the research on spatial differentiation drive of ESV in Changsha, Hunan province, China based on spatial factor application of Geodetector has not been involved yet.

Changsha, the capital city of Hunan province, China, serves as a key node city and comprehensive transportation hub in Yangtze River urban agglomeration and the Yangtze River Economic Belt. Additionally, it serves as a key hub for China's grain production and a national pilot region for the "two-oriented society" comprehensive reform. Changsha has recently faced some environmental issues that have made the development of an ecological civilization more difficult, including widespread flooding in the city, deteriorating air quality, a slowing of the Xiangjiang River's flow, a reduction in the water environment's capacity, pollution from rural livestock and poultry, and other environmental issues. Based on 2005, 2010, 2015, and 2020 land use data, with the aid of ArcGIS, Geoda, and Geodetectors, the spatial and temporal evolution of ecosystem service values and driving factors in Changsha were analyzed in this study to provide a reference basis for land use planning, ecological environmental protection, and sustainable development in Changsha.

## Materials and methods

### The study area

The city of Changsha is in the area from 111°53'E to 114°15'E and 27°51'N to 28°41'N. The climate in Changsha is subtropical monsoonal. Due to its location in the interior of the basin, its distance from the sea, the conversion of the winter and summer winds, the terrain's tilt toward the north, and other factors, the climate is mild with well-defined seasons. East to west, Changsha is roughly 230 kilometers long, and north to south, it is 88 kilometers wide. Changsha has jurisdiction over 6 districts (Furong, Tianxin, Yuelu, Kaifu, Yuhua, Wangcheng), 1 county (Changsha), and 2 county-level cities (Liuyang and Ningxiang) (Figure 1).

### Data sources

The land data of 2005, 2010, 2015, and 2020 were obtained from the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (https://www.resdc.cn/) with the spatial discrimination rate of 30 m. According to the classification system of the product, the land use types of Changsha were divided into paddy field, dry land, woodland, grassland, water area, wetland, construction land, and unused land. The Digital elevation model (DEM) data were derived from the geospatial data cloud (https://www.gscloud.cn/). The precipitation and temperature data were obtained from the National Geographic System Science Data Center (http://www.geodata.cn/). The Normalized Difference Vegetation Index (NDVI) data were also obtained from the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. The Human Active Index (HAI) data were referred from the "Geostatistical analysis of Anthropogenic Impact Index of land use/Cover and its Change in Fujian" [22]. The social and economic data such as mean land gross domestic product (GDP), population density, per capita income of urban and rural residents, total retail sales of social consumer goods in districts and counties, the proportion of the primary industry, grain output, and grain prices were obtained from Hunan Statistical Yearbook and Changsha Statistical Yearbook.

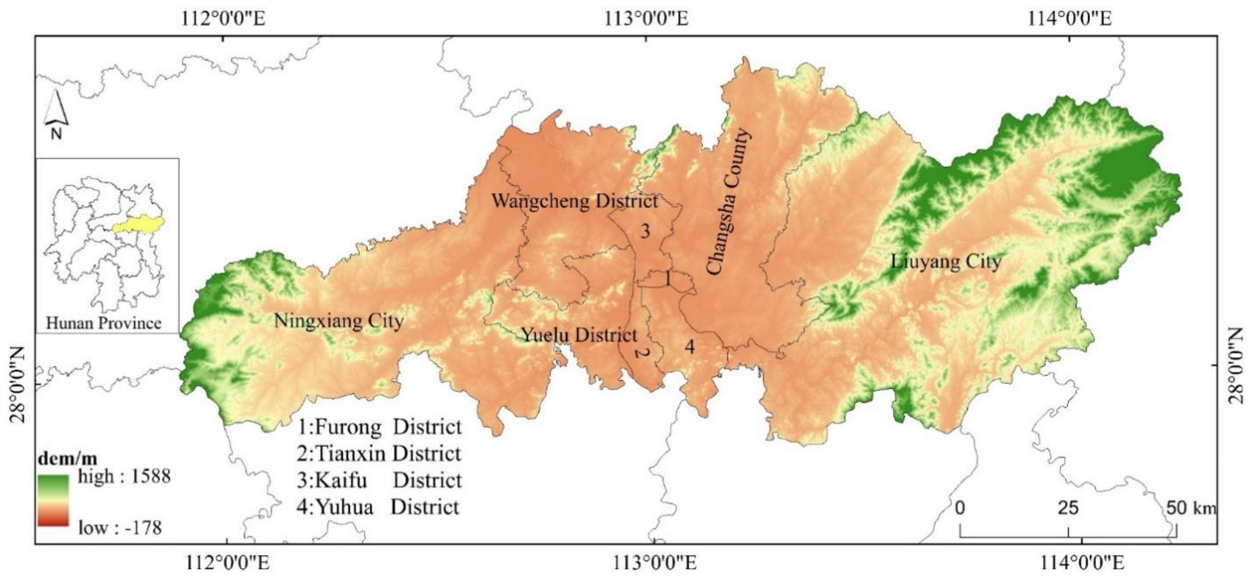

**Figure 1.** The location of Changsha, Hunan province, China.

## Change of land use

The Changsha land use types were examined by using ArcGIS (https://www.esri.com) to produce the land transfer matrix which accurately illustrated the magnitude and direction of change in land use type from 2005 to 2020. The land transfer matrix is shown in the Table1. $A_1A_2……A_n$ denoted $n$ land use types, $T_1T_2$ stood for the period, and $P_{mn}$ stood for moved to $m$ area of land types during the $T_1$-$T_2$ [23].

**Table 1.** Land use transfer matrix.

| | | T1 | | | |
|---|---|---|---|---|---|
| | | A1 | A2 | … | An |
| T2 | A1 | P11 | P12 | … | P1n |
| | A2 | P21 | P22 | … | P2n |
| | … | … | … | … | … |
| | An | Pn1 | P2n | … | Pmn |

## Ecosystem service value (ESV)

Ecosystem service value is divided into four categories: supply, regulation, support, and culture. The value equivalent was updated by the actual situation in Changsha based on the "Scale of Ecosystem Services per Unit Area of Chinese Ecosystem" developed by Xie and other academics [1]. The equivalent value of construction land service was according to the research findings of Hu [24]. According to the data of the Changsha Statistical Yearbook, the average grain output in Changsha from 2005 to 2020 was 6,695.9 kg/hm, and the average value of grain from 2005 to 2020 was ¥2.41/kg (Chinese Yuan ¥) after adjusting for currency inflation. According to Xie, *et al*., the equivalent factor of ecosystem service value was the relative contribution rate of ecosystem potential service value, which was equal to 1/7 of the annual output value of grain per hectare [1]. Therefore, the equivalent factor of ecosystem service value in Changsha was ¥2,305.3/hm. Table 2 displayed the ecosystem service value coefficients per unit area for Changsha. The formula for calculating the ecosystem service value in Changsha was as follows:

$$ESV = \sum_{k=1}^{n} \left( A_k \times VC_k \right) \quad (1)$$

$$ESV_f = \sum \left( A_k \times VC_{fk} \right) \quad (2)$$

where $ESV$ was the ecosystem services value. $A_k$ was class $k$ land, and $VC_k$ was the coefficient of ecosystem services value of class $k$ land. The $ESV_f$

**Table 2.** ESV coefficients per unit area in Changsha (¥/hm).

| | | paddy field | dry land | forest land | grassland | water | wetland | construction land | unused land |
|---|---|---|---|---|---|---|---|---|---|
| supply | food production | 3135.21 | 1959.51 | 582.09 | 537.90 | 1844.24 | 1175.70 | 23.05 | 0.00 |
| | raw material production | 207.48 | 922.12 | 1337.07 | 791.49 | 530.22 | 1152.65 | 0.00 | 0.00 |
| | water supply | 6062.94 | 46.11 | 691.59 | 438.01 | 19110.94 | 5970.73 | 17312.80 | 0.00 |
| regulation | gas regulation | 2558.88 | 1544.55 | 4397.36 | 2781.73 | 1775.08 | 4380.07 | -5578.83 | 46.11 |
| | climate regulation | 1314.02 | 829.91 | 13157.50 | 7353.91 | 5279.14 | 8299.08 | 0.00 | 0.00 |
| | hydrological regulation | 6270.42 | 622.43 | 8610.30 | 5386.72 | 235693.87 | 55857.42 | 0.00 | 69.16 |
| | purification of the environment | 391.90 | 230.53 | 3855.61 | 2428.25 | 12794.42 | 8299.08 | -5671.04 | 230.53 |
| support | soil conservation | 23.05 | 2374.46 | 5354.06 | 3388.79 | 2143.93 | 5325.24 | 46.11 | 46.11 |
| | maintenance of nutrient circulation | 438.01 | 276.64 | 409.19 | 261.27 | 161.37 | 414.95 | 0.00 | 0.00 |
| | Biodiversity | 484.11 | 299.69 | 4875.71 | 3081.42 | 5878.52 | 18142.71 | 783.80 | 46.11 |
| culture | aesthetic viewing | 207.48 | 138.32 | 2138.17 | 1360.13 | 4357.02 | 10904.07 | 23.05 | 23.05 |

and $VC_f$ were the ecosystem service value *f* and the coefficient of ecosystem service value *f* of class *k* land, respectively.

## Spatial autocorrelation

The degree of connection on a certain attribute between the study area and the surrounding areas is referred to as spatial autocorrelation. The study area was divided into a grid matrix by using a 1 × 1 $km^2$ grid. The ESV of each rectangle was calculated for the years of 2005, 2010, 2015, and 2020. The EVS was then classified into five levels by using the natural breaks with the first level being the lowest. With the use of univariate Moran's I in Geoda (https://geodacenter.github.io/), the spatial characteristics of ecosystem service values in the study region were examined, and the local indicators of spatial association (LISA) agglomeration maps were created. If 0 < Moran's I < 1, it indicated that the spatial distribution showed positive correlation and spatial aggregation; if -1 < Moran's I < 0, it indicated that the spatial distribution showed negative correlation and spatial dispersion; if Moran's I = 0, it indicated that the spatial distribution does not correlation.

$$Moran'sI_i = \frac{x_i - \bar{x}}{S_i^2} \sum_{j=1, j\neq i}^{n} w_{i,j}\left(x_i - \bar{X}\right) \qquad (3)$$

where $x_i$ was the attribute of element *I*. $\overline{X}$ *was* the mean of the corresponding attribute. $w_{i,j}$ was the spatial weight between elements *i* and *j*. *n* was the total number of elements. $S^2 = \frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2$ was the variance [27].

## Geodetector

Geodetector is a set of statistical methods proposed by Wang, *et al*. to detect spatial differentiation and reveal the driving force behind it [22]. It consists of four modules: risk detection, factor detection, ecological detection, and interactive detection. The primary idea of Geodetector is based on the following assumptions: an independent variable has a significant impact on the dependent variable if its influence weight is high. Thus, there will be a statistical correlation and the spatial distributions of the two variables should be substantially comparable. Through regional spatial analytical detection, Geodetector can reflect the similarities of geographical phenomena in the same region and the differences in various regions, and then, examine the factors that contribute to the spatial differentiation of geographical phenomena. Geodetector's factor detector and interaction detector were utilized to investigate the driving factors of ESV spatial and temporal evolution in Changsha city from 2005 to 2020. The

**Table 3.** Interaction types of the detection factors.

| Type of interaction | Judgment criteria |
|---|---|
| Nonlinear weaken | $q(X_1 \cap X_2) < \mathrm{Min}[q(X_1), q(X_2)]$ |
| Univariate nonlinear weaken | $\mathrm{Min}[q(X_1), q(X_2)] < q(X_1 \cap X_2) < \mathrm{Max}[q(X_1), q(X_2)]$ |
| Bivariate enhance | $q(X_1 \cap X_2) > \mathrm{Max}[q(X_1), q(X_2)]$ |
| Non-linear enhance | $q(X_1 \cap X_2) > q(X_1) + q(X_2)$ |
| Independent | $q(X_1 \cap X_2) = q(X_1) + q(X_2)$ |

**Note:** $X_1$, $X_2$: driving factors.

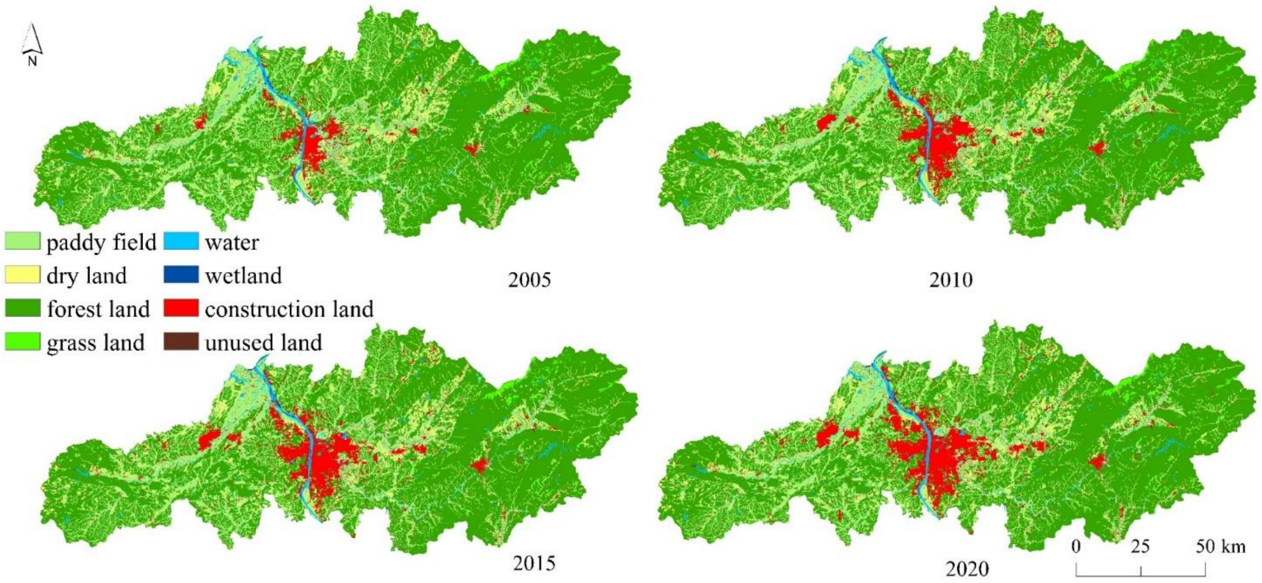

**Figure 2.** Land use in Changsha from 2005 to 2020.

fundamental idea behind factor detection was that the geographic distributions of independent and dependent variables should converge if independent variable *X* influenced dependent variable *Y*. Its calculation formula was as follows:

$$q = 1 - \frac{1}{n\sigma^2}\sum_{h=1}^{L} n_h \sigma_h^2 \tag{4}$$

where *q* was the level of explanatory power between the independent and dependent variables, $q \in [0, 1]$. The bigger the value of *q*, the stronger the explanatory power of independent variable *X* to dependent variable *Y*. Otherwise, it would be weaker. *n* and $\sigma^2$ denoted the total sample size and variance of the study area. L denoted the number of probe partitions. $n_h$ and $\sigma_i^2$ indicated the sample size and variance of different partitions. Interactive detection primarily involves calculating the *q* values of independent variables $X_1$ and $X_2$ for dependent variables *Y* and the *q* values of $X_1$ and $X_2$ for *Y* after the interaction, and then, comparing the *q* values of the single factor and the *q* values of the double factor interaction to determine the type and direction of the interaction. Interaction relations were categorized into five different groups (Table 3).

## Results and discussion

### Analysis of land use change

Forest land, which accounted for more than 60% of the research area's land between 2005 and

**Table 4.** Land use and ESV transfer matrix of Changsha from 2005 to 2020.

| | | 2005 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **land use type** | **paddy field** | **dry land** | **forest land** | **grassland** | **water** | **wetland** | **construction land** | **unused land** |
| **2020** | **paddy field** | 2713.06 | 21.02 | 144.25 | 1.43 | 15.16 | 2.01 | 16.34 | 0.00 |
| | **dry land** | 20.58 | 411.79 | 25.97 | 0.19 | 1.18 | 0.02 | 4.93 | 0.00 |
| | **forest land** | 145.15 | 36.38 | 6899.68 | 10.32 | 8.89 | 0.21 | 16.23 | 0.00 |
| | **grassland** | 1.40 | 1.15 | 6.25 | 129.07 | 0.19 | 0.03 | 0.16 | 0.00 |
| | **water** | 23.42 | 1.88 | 10.24 | 0.24 | 193.46 | 4.87 | 3.23 | 0.00 |
| | **wetland** | 3.74 | 0.36 | 1.90 | 0.00 | 4.21 | 9.24 | 0.81 | 0.00 |
| | **construction land** | 254.44 | 53.19 | 238.24 | 1.66 | 14.40 | 1.33 | 361.94 | 0.00 |
| | **unused land** | 0.09 | 0.29 | 3.00 | 0.00 | 0.00 | 0.04 | 0.15 | 0.00 |

**Table 5.** Changes of ecosystem service value in Changsha from 2005 to 2020.

| | **ESV** | | | | |
|---|---|---|---|---|---|
| **land use type** | **2005** | **2010** | **2015** | **2020** | **2005-2020 changes** |
| **paddy field** | 28.36 | 27.31 | 26.75 | 26.13 | -2.23 |
| **dry land** | 4.86 | 4.49 | 4.42 | 4.30 | -0.57 |
| **forest land** | 332.97 | 328.12 | 326.02 | 323.32 | -9.66 |
| **grassland** | 3.98 | 3.89 | 3.85 | 3.85 | -0.13 |
| **water** | 68.82 | 68.40 | 68.83 | 68.76 | -0.05 |
| **wetland** | 2.13 | 2.33 | 2.24 | 2.43 | 0.30 |
| **construction land** | -11.18 | -18.48 | -21.68 | -25.62 | -14.44 |
| **unused land** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **total** | 429.94 | 416.03 | 410.44 | 403.14 | -26.77 |

2020, was mostly dispersed in the study area's eastern and western mountainous regions. Paddy fields and building land, which made up 30%~32% of the total area and were primarily dispersed in the central plains and close to rivers, come in second. There was a minor portion of other sorts of land (Figure 2).

The area of land used for construction land increased by more than 1.3 times between 2005 and 2020 (Table 4). Paddy fields and forest land made up the majority of the transferred area, which made up to 94.5% of the new construction land. Due primarily to forest land and water, the unused land and wetland areas rose by 3.58 km$^2$ and 2.50 km$^2$, respectively. Other terrain types showed varying degrees of loss in the area. Paddy fields lost the most land (448.81 km$^2$) followed by forest land (429.45 km$^2$). 61.4 km$^2$ of dryland was lost and 53.19 km$^2$ was converted to construction land. Water and grassland areas both somewhat decreased in size.

### Analysis of ecosystem service value

The ecosystem services value in Changsha declined by ¥2.677 billion from ¥42.994 billion to ¥40.317 billion from 2005 to 2020 (Table 5). The entire value tended to progressive decline with the period from 2005 to 2010 experiencing the highest decline of ¥1.391 billion. The contribution of different types of land in Changsha to ecosystem service value (ESV) from 2005 to 2020 was ranked as follows: forest land > water > paddy field > dry land > grassland > wetland > unused land > construction land. Between 77% and 80% of ESV came from forested land, and this percentage increased year over year. In terms of ESV changes, all other land categories had varying degrees of decrease in ESV, except wetland and unused land, which had a tiny gain. The expansion of building land caused its ESV to drop by ¥1.444 billion with a change rate of -129%. The loss of water, grassland, and dry land area were minimal, and the change in ESV was insignificant. Paddy fields' ESV fell by ¥966 million and forestland's by ¥223 million

**Table 6.** Ecosystem service value of each kind of service function in Changsha from 2005 to 2020.

| | | ESV | | | | 2005-2020 | |
|---|---|---|---|---|---|---|---|
| **level 1 type** | **level 2 type** | **2005** | **2010** | **2015** | **2020** | **changes** | **rate of change** |
| **supply** | **food production** | 15.76 | 15.25 | 15.02 | 14.75 | -1.01 | -6.42 % |
| | **raw material production** | 11.21 | 10.10 | 10.92 | 10.81 | -0.39 | -3.51% |
| | **water supply** | -16.36 | -20.31 | -21.94 | -24.02 | -7.66 | -46.84 % |
| **regulation** | **gas regulation** | 39.80 | 37.48 | 36.47 | 35.22 | -4.58 | -11.50 % |
| | **climate regulation** | 103.53 | 101.91 | 101.21 | 100.34 | -3.19 | -3.08 % |
| | **hydrological regulation** | 141.07 | 139.13 | 138.64 | 137.71 | -3.36 | -2.38 % |
| | **purification of the environment** | 30.88 | 28.90 | 28.06 | 26.30 | -3.88 | -12.57 % |
| **support** | **soil conservation** | 41.69 | 41.02 | 40.76 | 40.42 | -1.27 | -3.04 % |
| | **maintenance of nutrient circulation** | 4.61 | 4.51 | 4.46 | 4.40 | -0.21 | -4.62 % |
| | **biodiversity** | 39.92 | 39.54 | 39.37 | 39.18 | -0.74 | -1.85 % |
| **culture** | **aesthetic viewing** | 17.84 | 17.59 | 17.48 | 17.36 | -0.48 | -2.71 % |
| | **total** | 429.94 | 416.03 | 410.44 | 403.17 | -26.77 | -6.23 % |

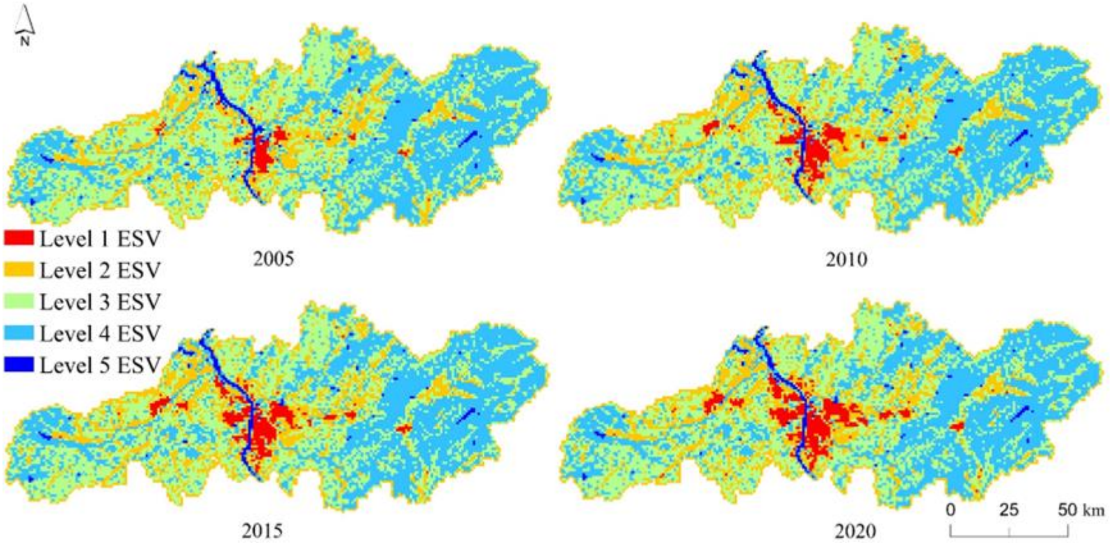

**Figure 3.** Distribution of ecosystem service value in Changsha from 2005 to 2020.

with change rates of -2.9% and -7.86%, respectively.

The ESV functions of Changsha from 2005 to 2020 were rated in Table 6 from the standpoint of ecosystem service functions as regulation service > support service > cultural service > supply service. More than 70% of ESV was made up of regulation services, while hydrologic regulation in secondary function contributed ¥14.107 billion or more than 32% of ESV, due to the research region's substantial water area. The second was climate regulation, which, during the study period, totaled over ¥10 billion or 24% of ESV, and was mostly influenced by forested areas. The supply service made up the smallest portion, and the secondary function's provision of water resources was usually negative and declining year over year. In terms of the changes in ecosystem service functions, the value of each function decreased, and the supply of water resources decreased the most with a decrease of ¥766 million and a change rate of -46.86%. This decrease was caused by the expansion of paddy fields, dry land, and construction land. Due to the shrinkage of grassland and forest land, all functions of the regulating service experienced a fall of more than ¥300 million. Food and raw

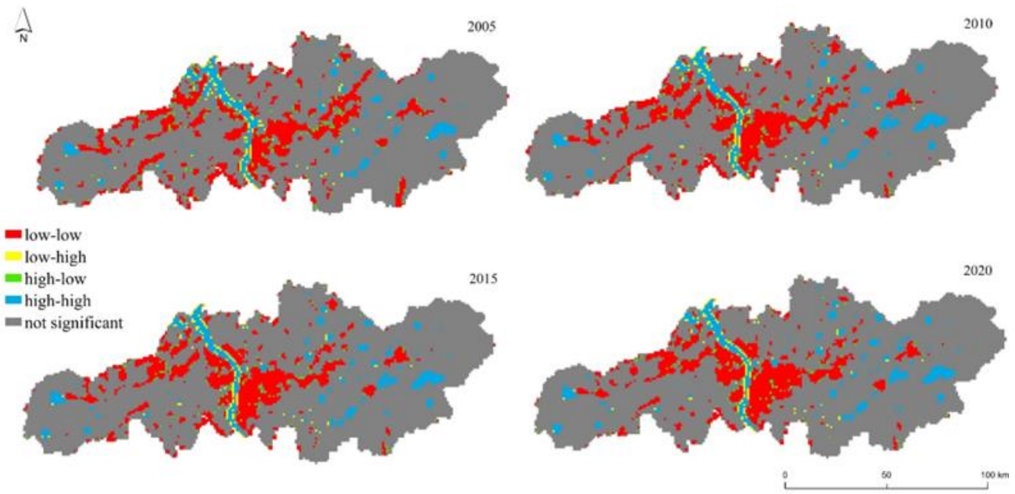

**Figure 4.** The local indicators of spatial association (LISA) cluster graph of ecosystem service value in Changsha from 2005 to 2020.

material output fell primarily because of the shrinkage of arable land. A small reduction in the support and aesthetic services was made, which was inextricably linked to the shrinking amount of grassland and forest land.

Figure 3 demonstrated that fishing nets were created by using ArcGIS and the natural break was used to grade ESV with the first level ESV being the lowest and the fifth level ESV being the highest. According to the spatial distribution of ESV, the overall ESV in Changsha from 2005 to 2020 was high in the east and west, high at the river penetration, and low in the middle. The reason may be that the high terrain can be found in the Xuefeng Mountains in the west and the Luoxiao Mountains in the east. Due to the land use type in this region being mainly forest land and the vegetation coverage rate being high, the ESV is high. The rivers are primarily the Xiangjiang River system with developed water systems and high hydrological regulation values. The center region is a flat, transitional area between the hills and the plains that is ideal for human activity. ESV is low in this location since construction land is the predominant type of land use. As a result of urbanization and population increase, the Level 1 ESV area expanded from the center to the surroundings in terms of ESV spatial alterations. The majority of Level 1 ESV regions were found in Changsha City's metropolitan area with administrative districts corresponding to Furong, Yuhua, Tianxin, Yuelu, and Kaifu Districts, as well as Level 4 and 5 ESV areas, which correspond to Liuyang City and Ningxiang City.

### Spatial autocorrelation of ecosystem service values

As shown in Table 6, the global Moran's I of ESV in 2005, 2010, 2015, and 2020 were 0.46, 0.475, 0.474, and 0.485, respectively, with an overall increasing trend and *P*-values less than 0.001, indicating that ESV in the study area had a positive spatial correlation and an increasing degree of autocorrelation. Figure 4 showed that the distribution of high-high agglomerations in Changsha was stable during the study period, mainly located at rivers, lakes, and reservoirs with a sparse population and good ecological environment. Low-low agglomerations were primarily distributed in the central plains and relatively flat areas with land types dominated by construction land, densely populated, and constantly expanding around. High-low agglomerations were less common and scattered in the central region, close to the confluence of water and construction land. Low-high agglomerations were located primarily along rivers, close to the junction of water and construction land.

**Table 7.** Factor detection for the spatial heterogeneity of ESV in Changsha from 2005 to 2020.

| | 2005 | | 2010 | | 2015 | | 2020 | | 2005-2020 |
|---|---|---|---|---|---|---|---|---|---|
| | q-value | P | q-value | P | q-value | P | q-value | P | q-value |
| **DEM** | 0.256 | 0 | 0.252 | 0 | 0.262 | 0 | 0.287 | 0 | 0.264 |
| **slope** | 0.261 | 0 | 0.120 | 0 | 0.125 | 0 | 0.147 | 0 | 0.163 |
| **annual temperature** | 0.243 | 0 | 0.230 | 0 | 0.222 | 0 | 0.221 | 0 | 0.229 |
| **annual precipitation** | 0.153 | 0 | 0.136 | 0 | 0.152 | 0 | 0.168 | 0 | 0.152 |
| **NDVI** | 0.010 | 0 | 0.028 | 0 | 0.030 | 0 | 0.030 | 0 | 0.025 |
| **HAI** | 0.650 | 0 | 0.657 | 0 | 0.668 | 0 | 0.704 | 0 | 0.670 |
| **total retail sales of social consumer goods** | 0.043 | 0 | 0.072 | 0 | 0.063 | 0 | 0.133 | 0 | 0.078 |
| **population density** | 0.094 | 0 | 0.118 | 0 | 0.123 | 0 | 0.102 | 0 | 0.109 |
| **per capita income of urban and rural residents** | 0.092 | 0 | 0.087 | 0 | 0.117 | 0 | 0.137 | 0 | 0.108 |
| **the proportion of primary industry** | 0.059 | 0 | 0.097 | 0 | 0.095 | 0 | 0.110 | 0 | 0.090 |
| **average land GDP** | 0.094 | 0 | 0.074 | 0 | 0.078 | 0 | 0.102 | 0 | 0.087 |

## Driving force analysis of spatial differentiation of ecosystem service value

ESV changes are influenced by several variables, which can be categorized as natural and social forces. Among which, the social influences can include additional variables like economic activity, human behavior, and so forth. According to previous studies [18, 20, 25, 26] and the availability of data, two categories including 11 representative driving factors were proposed as (1) natural driving factors (DEM, mean annual temperature, annual precipitation, NDVI, slope) and (2) social and economic driving factors (human impact index (HAI), mean land GDP, population density, per capita income of urban and rural residents, total retail sales of social consumer goods, and proportion of primary industry). By using the ArcGis (version 10.3), the natural driving factors and socio-economic driving factors were discretized by using the natural break. According to the average q value of driving factors in descending order, Table 7 showed the sequence of HAI > DEM > mean annual temperature > slope > annual precipitation > population density > per capita income of urban and rural residents > proportion of primary industry > mean land GDP > total retail sales of social consumer goods > NDVI. The average q-value of HAI was 0.67, which demonstrated that human activities had a significant impact on the ecosystem and were the primary cause of ESV spatial differentiation. The average q-value of mean annual temperature and DEM both approached 0.22, which were powerful factors in explaining the regional variance of ESV. Both the annual precipitation average q-value and the slope average q-value were greater than 0.15, making them moderate drivers of the spatial variation of ESV. Average q-values for population density and per capita income in urban and rural areas were both higher than 0.1, indicating that they were only minor drivers of ESV spatial differentiation. The average q-value of the proportion of the primary industry, mean land GDP, total retail sales of social consumer goods, and NDVI were all less than 0.1, which had little power to explain the spatial differentiation of ESV.

Based on the change in driving factor q-value across the study period, the mean annual temperature and slope's q-value both showed a downward trend over time. The annual precipitation and DEM q-values were both steady and slightly rising. From 2005 to 2010, the q-value of the NDVI climbed from 0.009 to 0.028 before stabilizing. The q-value of HAI continued to rise, while the q-values of total retail sales of consumer goods, population density, urban and rural per capita income, the proportion of primary industries, and mean land GDP showed little variation but rather grew overall. This illustrated that, while natural driving factors had a decreasing impact on spatial disparities in ESV, socio-economic driving factors had a rising impact. Therefore, it is essential to decrease the detrimental effects of human activity on the environment, adhere to the ecological protection red line, and scientifically manage human activity.

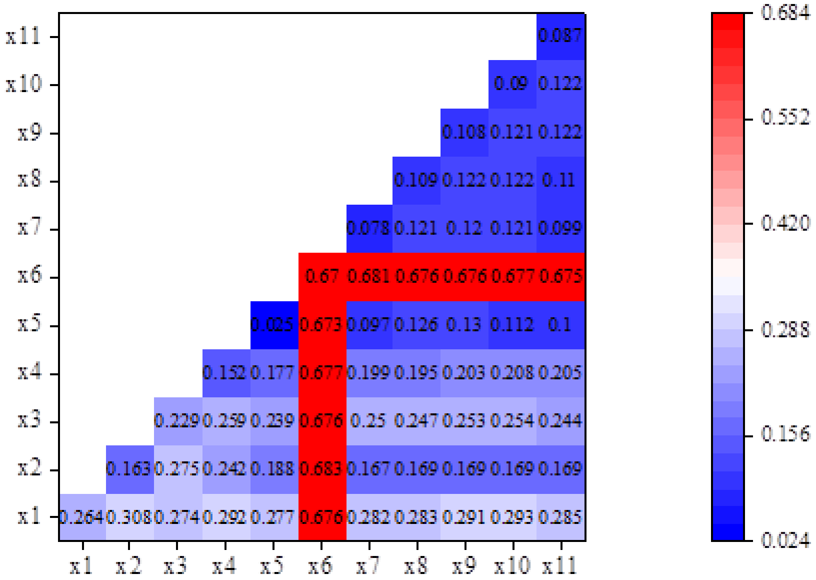

**Figure 5.** Interactive results of drivers of spatial heterogeneity of ESV in Changsha from 2005 to 2020. x1: DEM. x2: slope. x3: annual temperature. x4: mean annual precipitation. x5: NDVI. x6: HAI. x7: total retail sales of social consumer goods. x8: population density. x9: per capita income of urban and rural residents. x10: the proportion of primary industry. x11: mean land GDP.

According to the results of interaction detection, the interactions between various factors were all stronger than the explanation of ESV spatial difference by a single factor, and all belonged to the bivariate enhancement and non-linear enhancement. Figure 5 demonstrated that the average q value of the interaction between HAI and other driving factors was more than 0.67. An average q-value of 0.683. The interaction between HAI and slope provided the strongest explanatory force for ESV spatial differentiation. The average q-value of the other factors' interactions was less than 0.3, yet it was still greater than each single factor's explanatory power. Taken together, the spatial differentiation of ESV in Changsha during the study period was influenced by the joint action of natural driving factors and social and economic driving factors. Therefore the characteristics of each driving factor and how they interacted to improve different driving factors should be taken into account in the management of ecosystem services and ecological risk control in the future, and, according to local conditions, land use development patterns that were compatible with the natural and socio-economic environments should be chosen to prevent harm to the ecosystem brought on by unreasonable human activities and the synergistic effects of nature and society.

The findings demonstrated that, as cities grow, land use changed resulting in a steady decline in ESV and that an increase in unused land also represented irrational land usage, which resulted in land abandonment. According to studies, Changsha's non-construction land will continue to decline over the next ten years while its construction land will expand quickly, and ESV will generally be on the decline [27]. This illustrates how Changsha is currently and in the future in a conflict between economic development and ecological preservation. In 2021, Changsha issued the Master Plan for Territorial Space of Changsha (2021-2035), which gives play to the advantages of integration of natural resources and spatial planning and management in terms of strategic guidance, realizes the full coverage of territorial spatial planning and management and the control of all factors, continuously promotes the "smart growth" of the city, and enhances the citizens' sense of gain. The ensuing development must therefore rigorously regulate the unplanned growth of building land, design the urban functional space logically, enhance the amount of green construction in the urban core, and produce an urban ecological landscape. We shall uphold the red line for arable land, protect non-construction land, forbid mountain-clearing and deforestation, and harshly penalize unauthorized encroachment on water and wetlands. Geodetector was used in this study to look at the socio-economic and natural driving factors that influenced ESV spatial variance in Changsha between 2005 and 2020. The findings demonstrated that socio-economic driving factors increasingly became more influential. Future construction and development must take into account how various factors interact, choose a land use strategy that is appropriate for the region's natural conditions as well as its stage of economic and social development, and avoid ecological risks while enhancing the ecosystem's ability to sustain itself. Among them, HAI, population density, and per capita income of urban and rural people are three of them that are becoming increasingly important influencing factors and interact with one another. The influx of people brings economic benefits to the city. Additionally, it will unavoidably result in waste and contamination entering the natural system, escalating the conflict between humans and nature. Raising the population's standard of living and civilization as well as increasing public awareness of environmental protection are both necessary. It's crucial to continue researching the best methods for putting in place a reliable ecological compensation system.

## Conclusion

In Changsha, from 2005 to 2020, the ecosystem service value and its spatio-temporal characteristics were examined based on land use data, and the driving forces behind ESV geographical differentiation were investigated by using Geodetector. The following conclusions were reached: (1) The land use types in Changsha from 2005 to 2020 were dominated by forest land accounting for more than 60% of the total area; construction land expanded the fastest, and its transferred area primarily came from forest land and paddy field; the area of unused land, wetland, and construction land increased, the area of forest land, paddy field, grassland, and dry land decreased, and the area of water was relatively stable. (2) On a timeline from 2005 to 2020, Changsha's ESV demonstrated a decreasing trend, declining by ¥2.677 billion. Wetland's ESV increased by ¥30 million overall, while the ESV of other land use types decreased. All ecosystem services decreased to varying degrees, and the value of the water supply decreased by ¥766 million with the largest change range. (3) On a spatial scale, Changsha's ESV from 2005 to 2020 was typically high in the east and west, high in the river, and low in the center; the spatial agglomeration effect of ESV increased gradually; high-high aggregation areas were primarily distributed near rivers, lakes, and reservoirs; low-low aggregation areas were primarily distributed in the central plain and other regions with relatively flat terrain, and low-high and high-low aggregation areas were less common and dispersed. (4) Natural and socio-economic driving forces both had an impact on the spatial differentiation of ESV in Changsha City from 2005 to 2020. Among them, HAI had the greatest impact and was the main driving factor, while DEM, slope, and annual precipitation were important driving factors. Other factors had minimal power to explain the spatial differentiation of ESV. The trajectory of change indicated that socioeconomic driving forces had a growing impact on ESV geographical differentiation.

## References

1. Xie GD, Zhang CX, Zhang LM, Chen WH, Li SM. 2015. Improvement of the evaluation method for ecosystem service value based on per unit area. J Nat Resour. 30(08):1243-1254.
2. Costanza R, D'arge R, De Groot R. 1997. The value of the world's ecosystem services and natural capital. Nature. 387(6630):253-260.
3. Sannigrahi S, Bhatt S, Rahmat S, Paul SK, Sen S. 2018. Estimating global ecosystem service values and its response to land surface dynamics during 1995-2015. J Environ Manage. 223:115-131.

4. Sharma R, Rimal B, Baral H. 2019. Impact of land cover change on ecosystem services in a tropical forested landscape. Resources. 8(1):18.
5. Mengist W, Soromessa T, Feyisa GL. 2022. Estimating the total ecosystem services value of Eastern Afromontane Biodiversity Hotspots in response to landscape dynamics. Environmental and Sustainability Indicators. 14:100178.
6. Li J, Chen H, Zhang C, Pan T. 2019. Variations in ecosystem service value in response to land use/land cover changes in Central Asia over 1995-2035. Peerj. 7:e7665.
7. Rahman MM, Szabó G. 2021. Impact of land use and land cover changes on urban ecosystem service value in dhaka, bangladesh. Land. 10(8):793.
8. Tiando D S, Hu SG, Fan X, Ali MR. 2021. Tropical coastal land-use and land cover changes impact on ecosystem service value during rapid urbanization of Benin, west Africa. Int J Environ Res Public Health. 18(14):7416.
9. Lu CX, Xie GD, Xiao Y, Yu YJ. 2004. Ecosystem diversity and economic valuation of Qinghai Tibet Plateau. Acta Ecologica Sinica. 24(12):2749-2755.
10. Xie GD, Zhen L, Lu CX, Xiao Y, Chen C. 2008. Expert knowledge based valuation method of ecosystem service in China. J Nat Resour. 23(05):911-919.
11. Wang NN, Liu HY, Li Y, Wang YJ, Dong HY, Zhang Y, *et al*. 2022. Value evaluation of wetland ecosystem services in the Yellow River delta wetland. Shandong Agric Sci. 54(02):153-158.
12. Wang JL, Yang L, Zhang DH, Peng Q. 2016. Research on measurement of ecological benefit of water conservation forests in Beijing and Hebei Province: Based on the Theory of forest ecosystem service value. Ecol Econ. 32(01):186-190.
13. Zhang F, Yusufujiang R, Aierken T. 2021. Spatio-temporal change of ecosystem service value in Bosten Lake Watershed based on land use. Acta Ecologica Sinica. 41(13):5254-5265.
14. Li HM, Zhang AL. 2012. Quantitative analysis the driving factors of the ecosystem services values by land use change in the Qinghai Lake Basin. Issues of Forestry Economics. 32(04):323-328.
15. Pan Y, Wang J, Li JX, Liu M, Wei XY, Zhi LJ. 2022. Spatial and temporal evolution and driving analysis of green space ecosystem service value of urban agglomeration in central Yunnan. Res Soil Water Conserv. in press.
16. YaO ZQ, Chen S, Hu HW, Wu Q, Huang YL, Zhang Y. 2022. Evolution and driving analysis of ecosystem service values in the Wanjiang urban belt. Environ Sci Tech. 45(04):218-226.
17. Li KM, Wang XY, Yao LL, Shi Y. 2022. Spatio-temporal change and driving factor analysis of ecosystem service value in the Beijing-Tianjin-Hebei region. J Environ Eng Tech. 12(04):1114-1122.
18. Li JZ, Wang M, Feng WJ, Li B. 2022. Spatial-temporal characteristic and driving analysis of ecosystem service value in Xiangxi Autonomous. Remote Sens Nat Resour, in press.
19. Chen R, Yang C, Yang Y, Dong XZ. 2022. Spatial-temporal evolution and drivers of ecosystem service value in the Dongting Lake Eco-economic Zone. Chinese J Appl Ecol. 33(01):169-179.
20. Huang JY, Wang S, Deng C, Yang J, Huang P. 2021. Spatio-temporal dynamic analysis of ecosystem service value in Pingwu County. Southwest China J Agric Sci. 34(05):1113-1120.
21. Wang JF, Xu DC. 2017. Geodetector: Principle and prospective. Acta Geographica Sinica. 72(01):116-134.
22. Chen Z Q, Chen JF. 2008. Geostatistical analysis of human impact indexes for land use cover change in Fujian. Resour Sci. (11):1700-1705.
23. Shu B, Li Y Z, Wang L, He ZL, Wang M. 2022. Spatial and temporal dynamic changes of land use and ecosystem service value in Leshan City. Ecologic Sci. 41(1):159–168.
24. Hu S. 2020. Research on Ecosystem Service Value and Ecological Compensation Standard Based on Land Use Change (Thesis). China University of Mining and Technology.
25. Dong Y, Fu MC, Chen NG, Liu JL. 2022. Spatial differentiation of ecosystem service values in Tangshan City over the past 30 years using geographic detection. J Agric Resour Envir. in press.
26. Geng TW, Chen H, Zhang H, Shi QQ, Liu D. 2020. Spatiotemporal evolution of land ecosystem service value and its influencing factors in Shaanxi province based on GWR. J Nat Resour. 35(07):1714-1727.
27. Ji HY, Xiao JW, Liu C. 2021. Metrological analysis and trend prediction of ecosystem service value in Changsha based on land use change. J Central South University of Forestry & Technology (Social Sciences). 15(02):34-44.