

Article

Localized Sustainable Development Goals Changes and Their Response to Ecosystem Services—A Case of Typical Southern Hilly Regions in China

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Abstract: Sustainability has become an indispensable core consideration when nations formulate their development policies. This study delves into the dynamic correlations between ecosystem services (ESs) and localized Sustainable Development Goals (SDGs) in a typical hilly region in southern China. Various ESs were computed using the InVEST model, while spatial econometric models were employed to assess ES responses to SDG targets at the county, sectoral, and overall spatial levels. The findings revealed the following. (1) From 2005 to 2020, there were differences in the development rates of various SDG targets in Ganzhou. Except for SDG 15, which declined, the development of the other targets showed an overall increasing trend. The development of the various SDG targets was relatively balanced, but SDG 9 and SDG 7 had the highest growth rates, ranging from 9.4% to 10.7% and 9.4% to 10.3%, respectively. The comprehensive SDG assessment index exhibited significant spatiotemporal variation, with a general trend of higher values in the north and lower values in the south. (2) The local ES showed a delayed response to SDG 1 and SDG 2, but there was a significant positive response to SDG 3, SDG 4, SDG 6, SDG 8, and SDG 9. However, responses to SDG 7, SDG 11, SDG 13, and SDG 15 showed regional differences. This study not only provides valuable insights for sustainable development in Ganzhou and other regions of China but also offers Chinese perspectives and experiences that may inform global efforts towards SDG implementation. This study fills the gap in existing research by constructing a localized SDG indicator system and quantifying each SDG indicator, further exploring the response of the ES to each SDG in the region. Looking ahead, we anticipate further research to deepen the understanding of the relationship between ESs and SDG targets on a broader geographical scale and over longer timeframes, aiming to provide a more robust scientific foundation for building a harmonious coexistence between humans and nature in the future.

Keywords: localization; sustainable development goals; ecosystem services; southern hilly regions

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1. Introduction

On a global scale, the localization of Sustainable Development Goals (SDGs) has emerged as a crucial step towards realizing the vision of global sustainable development [1]. These goals, encompassing a wide range of social, economic, and environmental dimensions, include No Poverty (SDG 1), Zero Hunger (SDG 2), Good Health and Well-being (SDG 3), Quality Education (SDG 4), Gender Equality (SDG 5), Clean Water and Sanitation (SDG 6), Affordable and Clean Energy (SDG 7), Decent Work and Economic Growth (SDG 8), Industry, Innovation, and Infrastructure (SDG 9), Reducing Inequalities (SDG 10), Sustainable Cities and Communities (SDG 11), Responsible Consumption and Production (SDG 12), Climate Action (SDG 13), Life Below Water (SDG 14), Life on Land (SDG 15), Peace and Justice Strong Institutions (SDG 16), and Partnerships for the Goals (SDG 17) [2]. Each goal is designed to address specific challenges and contribute to the overall objective of sustainable development. Integrating the 17 global SDGs, as outlined by

the United Nations, with specific local circumstances is essential for developing implementation strategies that are tailored to local conditions and needs [3]. This localization process is pivotal in achieving the vision of global sustainable development because it ensures the practical effectiveness and long-term sustainability of development strategies, aligning each goal with the unique challenges and opportunities present in diverse regional contexts [4]. Localization goes beyond merely translating global goals into local languages; it involves a deep understanding of local social, economic, cultural, and ecological contexts, as well as how these factors interact to formulate actionable plans [5]. Ecosystem services (ESs) refer to the various benefits provided by the natural environment to humans, including but not limited to food production, water purification, climate regulation, and cultural services [6]. These services are the foundation of human well-being and are crucial for achieving localized, sustainable development goals. For instance, a region's water resource management strategy must take into account local climatic conditions, hydrological cycles, ecosystem health, and socio-economic needs [7]. By studying how ESs respond to and support localized sustainable development goals, we can better understand the complex relationship between ecosystems and human societies, thereby formulating more effective conservation and utilization strategies [8]. The practical significance of localized sustainable development goals lies in enhancing human well-being. By aligning global goals with local needs, development outcomes can ensure more equitable benefits for all populations, especially the most vulnerable and marginalized groups [9]. This not only helps reduce poverty and inequality but also contributes to building more harmonious social and environmental relationships [10]. Through in-depth research on the relationship between ESs and localized sustainable development goals, we can formulate more effective regional development strategies, protect biodiversity, enhance human well-being, and ultimately realize the grand blueprint of global sustainable development.

In recent years, there has been extensive discussion within the academic community regarding the relationship between the SDGs and ESs. Various scholars have approached this topic from multiple angles, investigating the role of ESs in supporting the achievement of SDGs, including, but not limited to, assessments of ESs, the formulation of management strategies, and the construction of policy frameworks. Reyers et al. (2020) proposed a shift from individual social and ecological goals to socio-ecological goals by utilizing a social-ecological framework to address the interdependence between global biodiversity, ESs, and sustainable development objectives [11]. Qiu et al. (2022) explored the supply-demand relationship of ESs in Inner Mongolia, discussing the landscape ecosystem and its impact pathways against the backdrop of sustainable development goals, combining the millennium ecosystem assessment and the United Nations SDGs [12]. Sitoula et al. (2023) studied the impact of policy coherence on achieving sustainable development goals, especially in the global south and least developed countries. They also constructed a consistency analysis framework to assess the consistency of ES concepts in 20 documents [13]. Vasseur et al. (2017) highlighted the importance of ecosystem governance in achieving sustainable development goals and proposed methods to ensure efficient consideration of ESs, reflecting on how these methods could be incorporated into policies to strengthen the sustainable development agenda [14]. Dai et al. (2024) analyzed the changes in ESs on the Qinghai-Tibet Plateau and their contributions to sustainable development goals, exploring the role of different types of ESs and climate in this process [15]. Cooper et al. (2023) interviewed a range of researchers involved in biodiversity science, conservation, and policy implementation, collectively discussing action priorities for future land conservation and sustainable development of freshwater ecosystems to achieve sustainable development goals [16]. Fei et al. (2021) provided a conceptual framework and methods to identify a pathway for studying agricultural land use and environmental changes that align with concepts of ESs, planetary boundaries, and sustainable development goals [17]. Yang et al. (2022) measured the correlation between sustainable development and ESs based on the increasingly prominent contradictions between ecosystems and sustainable development in Shanxi Province [18]. Yin et al. (2023) clarified the contribution of ecosystem carbon sequestration

services to sustainable development goals based on the downscaling of sustainable development indicators, regression methods, and mechanism analysis [19]. Although scholars have made progress in studying the relationship between ES and SDGs in regions like the Tibetan Plateau, the response characteristics and mechanisms of ES under the specific geographical and ecological conditions of the southern hilly areas of China have not been fully explored. This research conducted empirical studies in Ganzhou, a typical southern hilly area, aiming to reveal the realization of different SDGs in the region and their response characteristics to ES, providing the scientific basis and decision support for the sustainable development of the southern hilly areas in China and other similar regions.

Ganzhou is situated in the southern hilly region, characterized by its remote geographic location and relatively underdeveloped infrastructure. The level of social development is comparatively low. Despite its large population, the available land for development is restricted to narrow river valleys, posing significant challenges to sustainable development [20,21]. The innovation of this article lies in its focus on how ESs in this typical region respond to localized sustainable development goals. Through a comprehensive analysis of the spatiotemporal trends of various localized sustainable development goals and ESs within the study area, it reveals the response of ESs to localized SDG targets at the county level, neighborhood scale, and overall spatial context. This fills a gap in the current research and holds significant theoretical and practical importance for guiding sustainable development practices in Ganzhou and similar regions. The aim is to provide new insights and strategies for the localization of ESs and sustainable development goals.

2. Materials and Methods

2.1. Study Area

Ganzhou, located in the southern part of Jiangxi Province, China, sits at the upper reaches of the Gan River and is the largest in the area and the most populous prefecture-level city in Jiangxi Province (Figure 1). It boasts abundant natural resources, with high forest coverage and rich biodiversity. Its economy is based on agriculture, with industry as the leading sector and rapid development in the service industry. With a long history and profound cultural heritage, Ganzhou is home to rich historical relics and unique folk customs [22]. Geographically advantageous, it serves as a crucial hub city connecting the Yangtze River Delta, Pearl River Delta, and the western coastal economic zone. Ganzhou features diverse topography and complex climatic conditions characterized by a distinct subtropical monsoon climate. Spring is warm and rainy, summer is hot and humid, autumn is cool and dry, and winter is mild and rainy [23], making it an ideal place for studying climate change and environmental protection in the region [24]. In recent years, Ganzhou has been actively integrated into the national “Belt and Road” initiative and the development strategy of the Yangtze River Economic Belt, accelerating industrial transformation and upgrading and promoting new urbanization construction. Its development experience holds valuable lessons for other regions of central and western China. Additionally, Ganzhou has achieved significant results in poverty alleviation, ecological civilization construction, and other areas, providing valuable practical cases for studying local governance and social development in China.

2.2. Data Sources

Statistical Data: The SDG indicator data and various control variables in the difference-in-differences method are all sourced from the “China County Statistical Yearbook”, “Jiangxi Statistical Yearbook”, and “Ganzhou Statistical Yearbook”. Remote sensing data: Annual average rainfall is sourced from the National Meteorological Science Data Center (<http://data.cma.cn/>, accessed on 15 March 2024). DEM data mainly come from the Geographic Spatial Data Cloud (<http://www.gscloud.cn/>, accessed on 15 March 2024). Soil texture data originate from the Cold and Arid Regions Science Data Center (<http://bdc.casnw.net/index.shtml>, accessed on 15 March 2024). Potential evapotranspiration data are from the “Global Aridity Index and Potential Evapotranspiration (ET0) Climate Database v2”

(<https://figshare.com/>, accessed on 15 March 2024). Land use data and NDVI are sourced from the Chinese Academy of Sciences Resource and Environment Science Data Center (<http://www.resdc.cn>, accessed on 15 March 2024). All geographic information data are resampled to a 100 m accuracy.

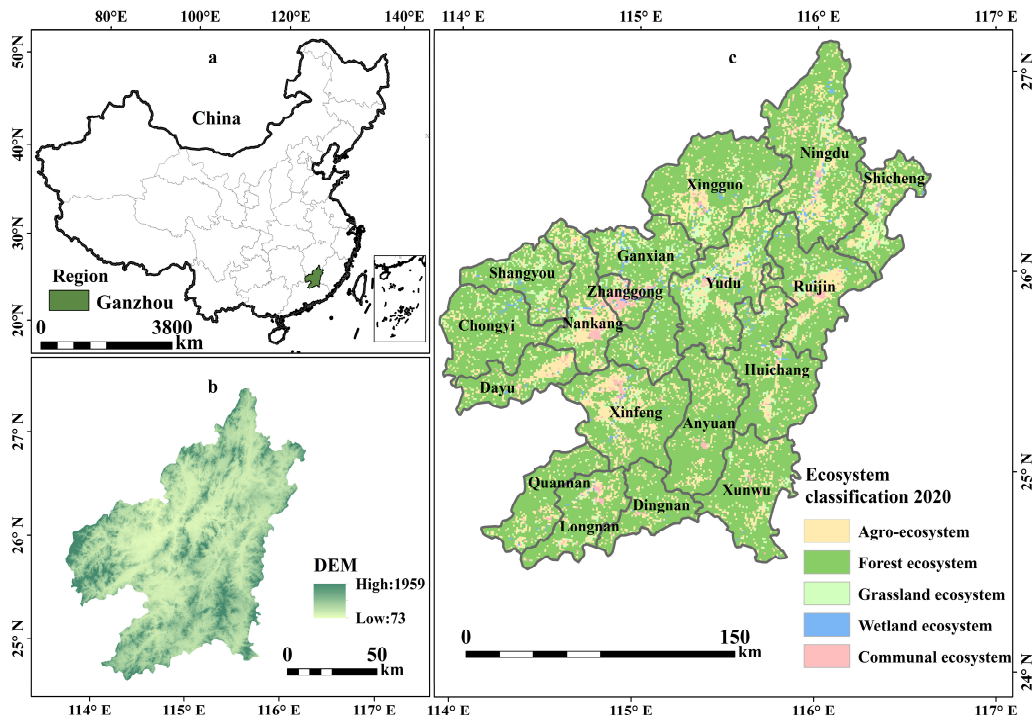


Figure 1. Study area. Note: Agro-ecosystem: paddy fields and drylands. Forest ecosystem: dense forests, shrublands, sparse forests, and other woodland areas. Grassland ecosystem: high-coverage grasslands, medium-coverage grasslands, and low-coverage grasslands. Wetland ecosystem: swamp-land, river channels, lakes, reservoirs, glaciers, permanent snow, and beach areas. Communal ecosystem: urban areas, residential areas, and industrial and mining lands.

2.3. Construction of SDG Assessment Indicator System

Guided by the framework of the United Nations SDGs, we have developed an SDG assessment indicator system (Table 1) that combines global guiding principles with the localized context of Ganzhou. The selection of indicators not only aligns with the overall objectives of the SDGs but also resonates with the characteristics of the southern hilly regions in China while also being inspired by the existing literature [25–27]. During the selection process, we focused on various aspects such as economic conditions [28], food security [29], medical resources [30], educational resources [31], water resource management [32], clean energy usage, economic growth, industrial innovation, urban sustainable development, climate action, and ecosystem health [28,32,33]. Through these processes, we have constructed a representative and locally distinctive SDG evaluation index system. This system ensures comprehensiveness, scientific rigor, and local applicability, enabling an effective assessment of the progress and challenges faced by Ganzhou in achieving the SDGs.

Table 1. SDGs indicators system.

Target	Indicators	Direction
SDG 1: No poverty	Per capita disposable income of farmers/yuan	+
	Savings balance/billion yuan	+
SDG 2: Zero hunger	Food production per capita/kg/person	+

Table 1. Cont.

Target	Indicators	Direction
	Fertilizer application per unit of cultivated area/(t/ha)	–
SDG 3: Good health and well-being	Number of health facility beds per 10,000 persons/units	+
	Number of community hospitals/units	+
SDG 4: Quality education	Number of secondary schools/units	+
	Nine-year compulsory education penetration rate/%	+
SDG 6: Clean water and sanitation	Average annual rainfall/mm	+
	Water supply/m ³ /hm ²	+
SDG 7: Affordable and clean energy	Wind power generation/kwh	+
	Energy efficiency/kWh/ton of standard coal	+
SDG 8: Decent work and economic growth	Share of secondary and tertiary industries/%	+
	GDP per capita/(yuan/person)	+
	Total retail sales of consumer goods per capita/(yuan/person)	+
SDG 9: Industry, innovation, and infrastructure	Value added of industry/billion yuan	+
	High-tech output/billion yuan	+
SDG 11: Sustainable cities and communities	Proportion of population without safe living conditions/%	–
	Land use efficiency/%	+
SDG 13: Climate action	Renewable energy use rate/%	+
	Greenhouse gas emissions/tons	–
SDG 15: Life on land	Area of forest land/km ²	+
	Number of wildlife populations/10,000 units	+
	Biodiversity index	+

2.4. Calculation of Individual SDG Indices

The comprehensive assessment model is utilized to calculate various SDG indices with the following formula [34,35]:

$$P_{ij} = (X_{ij} - \min(X_i)) / (\max(X_i) - \min(X_i)) \quad (1)$$

$$P_{ij} = (\max(X_i) - X_{ij}) / (\max(X_i) - \min(X_i)) \quad (2)$$

$$e_i = -k \sum_{j=1}^n Z_{ij} \ln Z_{ij}, \quad k = 1/\ln 16, \quad Z_{ij} = \frac{P_{ij}}{\sum_{j=1}^n P_{ij}} \quad (3)$$

$$h_i = 1 - e_i, \quad W_i = \frac{h_i}{\sum_{i=1}^n h_i}, \quad 0 < W_i < 1, \quad \sum W_i = 1 \quad (4)$$

$$H_j = \sum W_i P_{ij} \quad (5)$$

Formulas (1) and (2) respectively represent the standardization of positive and negative indicators, where i and j denote the order of indicator rows and columns, $\min(X_i)$ and $\max(X_i)$ represent the minimum and maximum values of the indicators and P_{ij} denotes the standardized value. In Formula (3), e_i represents the entropy value calculated by the entropy weight method [36], W_i represents the indicator weight, and H_j represents the various SDG indices.

2.5. Calculation of the SDG Composite Index

Based on the SDG index values calculated using the TOPSIS model in Formula (5), further computation is conducted to obtain the comprehensive evaluation index of the SDGs. The calculation formula is as follows [37,38]:

$$Z = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & Z_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ Z_{m1} & Z_{m2} & \cdots & Z_{mn} \end{bmatrix} = \begin{bmatrix} Z_{11} * w_1 & Z_{12} * w_1 & \cdots & Z_{1n} * w_1 \\ Z_{21} * w_2 & Z_{22} * w_2 & \cdots & Z_{2n} * w_2 \\ \vdots & \vdots & \vdots & \vdots \\ Z_{m1} * w_m & Z_{m2} * w_m & \cdots & Z_{mn} * w_m \end{bmatrix} \quad (6)$$

$$Z^+ = \{ \max_{1 \leq j \leq m} Z_{ij} | j = 1, 2, \dots, m \} = \{ z_1^+, z_2^+, \dots, z_m^+ \} \quad (7)$$

$$Z^- = \{ \min_{1 \leq j \leq m} Z_{ij} | j = 1, 2, \dots, m \} = \{ z_1^-, z_2^-, \dots, z_m^- \} \quad (8)$$

$$D_j^+ = \sqrt{\sum_{i=1}^m (z_{ij} - z_j^+)^2} \quad (9)$$

$$D_j^- = \sqrt{\sum_{i=1}^m (z_{ij} - z_j^-)^2} \quad (10)$$

$$C_j = \frac{D_j^-}{D_j^+ + D_j^-} \quad (11)$$

In Equation (6), Z represents the weighted decision matrix, where Z_{mn} denotes the standardized value of the m row and n column. w_m signifies the indicator weights calculated using the entropy weight method (4). Here, $i = 1, 2, \dots, n$; $j = 1, 2, \dots, m$. In Equations (7) and (8), Z^+ is the optimal value of the indicator, and Z^- is the worst value of the indicator. D_j^+ is the difference between the indicator vector for each year and the best value, and D_j^- is the difference from the worst value. C_j stands for the comprehensive evaluation index of the SDGs.

2.6. Calculation of Ecosystem Services

In order to comprehensively assess the value of ES, we employed the InVEST model for a detailed analysis. The calculation of various ESs (Table 2) based on the InVEST model is as follows:

Table 2. Calculation formula for each type of ES.

Classify	Equation	Explanation
Habitat quality [39,40]	$Q_{xj} = H_j \left(1 - \left(D_{xj}^2 / (D_{xj}^2 + k^2) \right) \right)$	Q_{xj} —represents the habitat quality index of grid x in land use type j , which is dimensionless; H_j —habitat suitability of land use type j ; D_{xj} —the habitat stress level of raster x in land use type j ; k —the half-saturation constant.
Grain supply [41,42]	$G_x = (NDVI_x / NDVI_{sum}) \times G_{sum}$	G_x —the food production of grid x ; G_{sum} —the total grain output; $NDVI_x$ —the NDVI value of grid x ; $NDVI_{sum}$ —the sum of NDVI values of cropland in the study area.
Water yield [43,44]	$Y_{xj} = \left(1 - \frac{1 + w_x R_{xj}}{1 + w_x R_{xj} + \frac{1}{R_{xj}}} \right) P_x$ $w_x = Z \frac{W_x}{P_x}, R_{xj} = \frac{k_{xj} ET_{ox}}{P_x}$	Y_{xj} —the water yield of grid x in the j^{th} land use type; P_x —the water yield of grid x in the j^{th} land use type; w_x —the ratio of plant water availability to annual rainfall; R_{xj} —the dimensionless dryness index of grid x in the j^{th} land use type; Z —the seasonal factor; W_x —the quantity available; k_{xj} —the evapotranspiration coefficient of vegetation of grid x in the j^{th} land use type; ET_{ox} —the possible evapotranspiration of grid x .

Table 2. Cont.

Classify	Equation	Explanation
Water purification [45,46]	$ALV_x = HSS_x * pol_x$ $HSS_x = \alpha_x / \bar{\alpha}_x$	Where: ALV_x is the nutrient output of grid x , HSS_x is the hydrologic sensitivity score of grid x , pol_x is the output coefficient of grid x , α_x is the runoff index, and $\bar{\alpha}_x$ is the average runoff index.
Carbon storage [47,48]	$Cij_storage = Cij_above + Cij_below + Cij_soil + Cij_dead$	$Cij_storage$ —the carbon storage of grid i use type; Cij_soil —the soil carbon storage per unit area of grid i in the j^{th} land use type; Cij_dead —carbon storage per unit area of raster i in the j^{th} land use type.
Soil retention and erosion [49]	$SEDRET_x = RKLS_x - USLE_x$ $USLE_x = R \times K \times LS \times C \times P$	$SEDRET_x$ —soil retention of grid x ; $RKLS_x$ —the potential soil erosion of grid x ; $USLE_x$ —the actual soil erosion amount of grid x ; R —rainfall erosion factor; K —soil erosion factor; LS —the slope length-slope factor; P —water and soil conservation factor; C —the vegetation cover factor.
Index of total ES [50,51]	$ES_i = (hH_i + gG_i + wW_i + cC_i + sS_i) / 5$	ES_i —the standardized ES; H_i, G_i, W_i, C_i , and S_i respectively represent the normalized values of habitat quality, grain supply, water yield, carbon storage, and soil retention, h, g, w, c, s denote the weights of each type of ES calculated by the entropy weighting method [36,52], respectively.

2.7. Calculation of the Response of Total Ecosystem Services to Each SDG

To explore the response of ES to various SDG targets, spatial econometric models are constructed. These include the Ordinary Least Squares (OLS) [53,54], Spatial Lag Model (SLM) [55], Spatial Error Model (SEM) [56], and Spatial Durbin Model (SDM) [57,58]. The calculation formulas for the models are as follows:

$$CP_{it} = \beta x_{it} + \rho \sum_{j=1}^n W_{ij} Cp_{ij} + \varphi \sum_{j=1}^n W_{ij} x_{it} + u_i + v_t + \varepsilon_{it} \quad (12)$$

In the equation, CP_{it} represents the dependent variable, namely the total ES index of region i in year t ; x_{it} stands for the independent variables, namely various SDG indices; β denotes the coefficients of various SDG indices; ρ and φ represent the spatial regression coefficients of total ES and various SDG indices, respectively; W_{ij} is the spatial weight matrix (second-order rook matrix); u_i and v_t are spatial and time-fixed effects; ε_{it} stands for the random error term. The SDM model is the general form of both the SLM and SEM models. When $\varphi = 0$, Equation (12) simplifies to the SLM model; when $\varphi = -\rho\beta$, Equation (12) simplifies to the SEM model.

2.8. Calculating the Impact of Ecological Protection and Restoration Policies on SDGs

The difference-in-differences (DID) method is widely used for evaluating the effects of policies [59]. This study employs the DID method to analyze the impact of the ecological protection and restoration projects implemented in Ganzhou from 2016 to 2019 on the achievement of SDG targets, with the calculation formula as follows [60]:

$$SDG_{i,t} = \beta_0 + \beta_1 did_{i,t} + \beta_2 x_{i,t} + \gamma_t + \theta_i + \varepsilon_{i,t} \quad (13)$$

where i is the district and county, t is the year; SDG denotes the total SDG index; did is the ecological protection and restoration projects implemented in Ganzhou in 2016–2019; x is the set of control variables, including average temperature, number of extreme weather events, air quality index, urbanization rate, and population density; θ denotes individual fixed effects; γ denotes year fixed effects; ε denotes a random error term.

3. Results

3.1. Variation in SDG Targets across the Study Area

From 2005 to 2020, Ganzhou exhibited different evolutionary characteristics in achieving various SDG targets (Figure 2). The SDG 1 (No Poverty) index showed a slight decline from 2005 to 2010, followed by a gradual increase from 2010 to 2020. The SDG 2 (Zero Hunger) index displayed a yearly increasing trend from 2005 to 2020. The SDG 3 (Good Health and Well-being) index generally increased year by year, with a significant acceleration in growth observed from 2010 to 2015. The SDG 4 (Quality Education) index hit a turning point in 2010, after which the rate of increase slowed down. The SDG 6 (Clean Water and Sanitation) index experienced a slight decline from 2005 to 2010, followed by a significant rise, and then a minor decline again from 2015 to 2020. The indices for SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), and SDG 9 (Industry, Innovation, and Infrastructure) all showed steady yearly increases from 2005 to 2020. The SDG 11 (Sustainable Cities and Communities) index first increased and then decreased from 2005 to 2015 but continued to rise until 2020. The SDG 13 (Climate Action) index increased year by year. The SDG 15 (Life on Land) index experienced a notable decline from 2005 to 2010, followed by a modest increase from 2010 to 2020. Ganzhou has shown a year-on-year increase in overall SDG achievements.

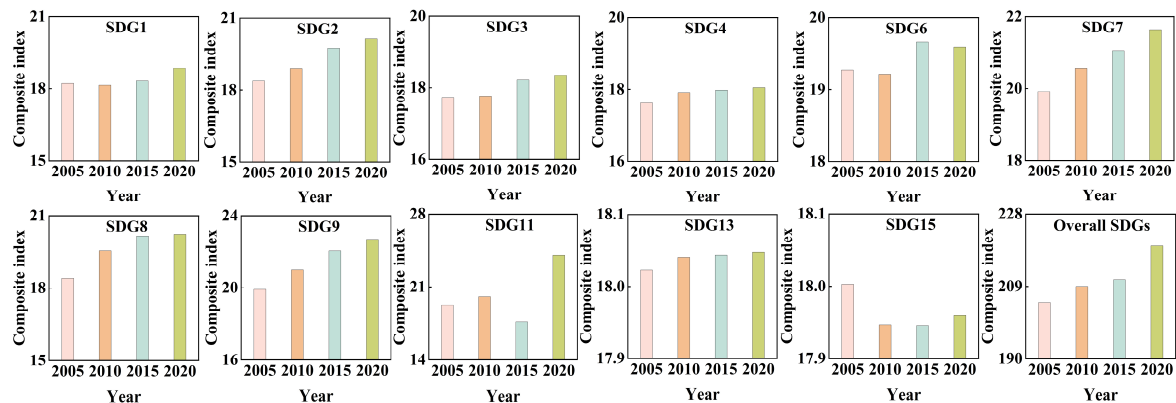


Figure 2. Time-series changes of each SDG index in Ganzhou.

3.2. Temporal Changes in Each SDG

From 2005 to 2020, overall, Ganzhou showed relatively balanced development across various SDG targets (Figure 3). Overall, SDG 9 (9.4%~10.7%) and SDG 7 (9.4%~10.3%) had the highest development ratios. The development ratios for SDG 4 (8.3%~8.7%), SDG 13 (8.5%~8.7%), and SDG 15 (8.4%~8.7%) were relatively lower. From 2005 to 2020, the proportions of SDG 2, SDG 4, SDG 8, and SDG 11 in the development of all targets showed an increasing trend. Conversely, the proportions of SDG 1, SDG 7, and SDG 9 in the development of all targets during the study period showed a decreasing trend.

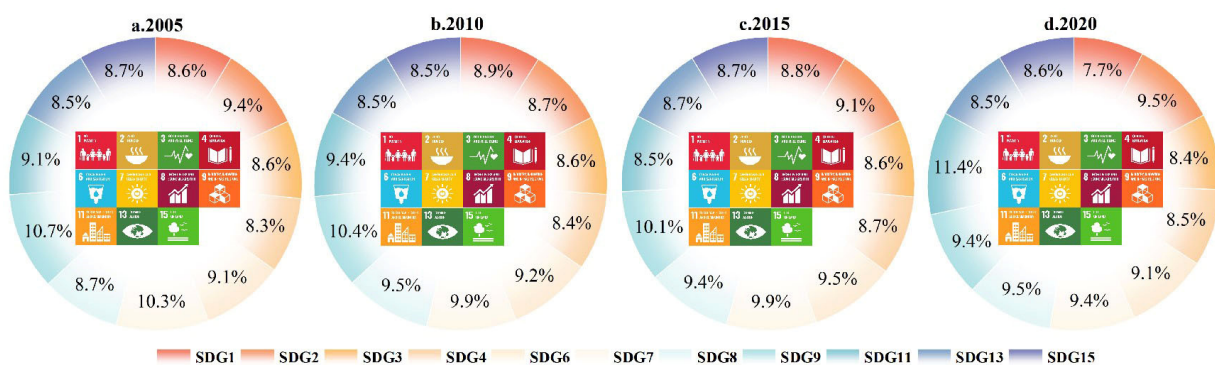


Figure 3. Time-series changes in the share of each SDG index in the total SDG for Ganzhou.

3.3. Variation in the SDG Composite Assessment Index

The overall SDG comprehensive evaluation index in Ganzhou exhibits a spatial-temporal differentiation characteristic of being higher in the north and lower in the south (Figure 4). The districts and counties with the highest SDG comprehensive index values are located in the northern part of Ganzhou, with values ranging from 0.3 to 0.998. The lowest SDG comprehensive index values are mainly concentrated in the southern part of Ganzhou, with values ranging from 0.022 to 0.096. From 2005 to 2020, the SDG comprehensive evaluation index showed varying degrees of decline in both the southern and northern parts of Ganzhou. There was an upward trend in the western part of central Ganzhou.

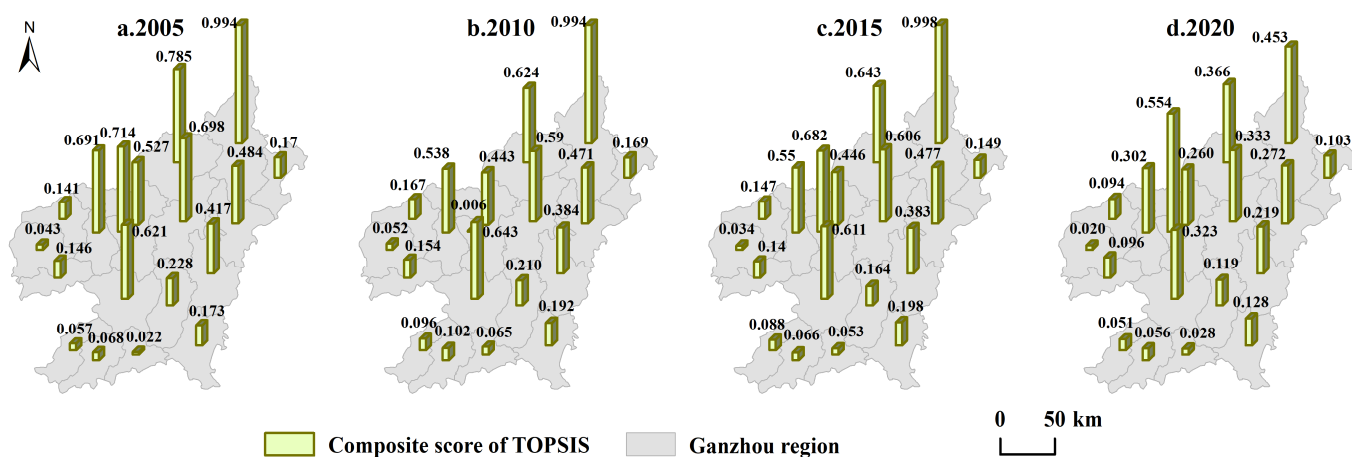


Figure 4. Spatiotemporal variation in the SDG composite index.

3.4. Spatial and Temporal Changes in Ecosystem Services

The overall ecosystem services index in Ganzhou shows high values in the southern and northern parts, with low values in the central region from 2005 to 2020. There are a few low-value clusters in the central-western area, and the aggregation of these low values expanded. The water yield index displays a distribution characteristic of being higher in the north and lower in the south (Figure 5). The water purification index is relatively higher in the western and north-central regions of Ganzhou. The habitat quality index presents spatial heterogeneity, being higher in the central and northern parts and lower in the south. The soil retention index is higher in the eastern part of Ganzhou compared to the west, though it is generally low across the board. The soil erosion index reveals a pattern of being lower in the city center and higher in the surrounding areas. The carbon storage index is generally high, with a few low-value areas concentrated in the central-western region. The grain yield index is overall higher in the central-western parts, showing a trend of initial increase.

3.5. Ecosystem Service Responses to the SDGs

We further examine the response of ES to localized SDGs through the analysis of spatial econometric models. From 2005 to 2020, Moran's I index of ES in each district of Ganzhou was significantly positive ($p < 0.01$), indicating a significant positive spatial correlation between ES and suitability for spatial econometric analysis. Further model testing led us to select the appropriate model under a 2nd order rook matrix (Table 3). At a significance level of 1%, we rejected the null hypothesis of the Hausman test, selecting fixed effects. Additionally, at a significance level of 1%, we rejected the null hypothesis of the LR and Wald tests, indicating that the Spatial Durbin model (SDM) does not degrade to a spatial lag model (SAR) or spatial error model (SEM).

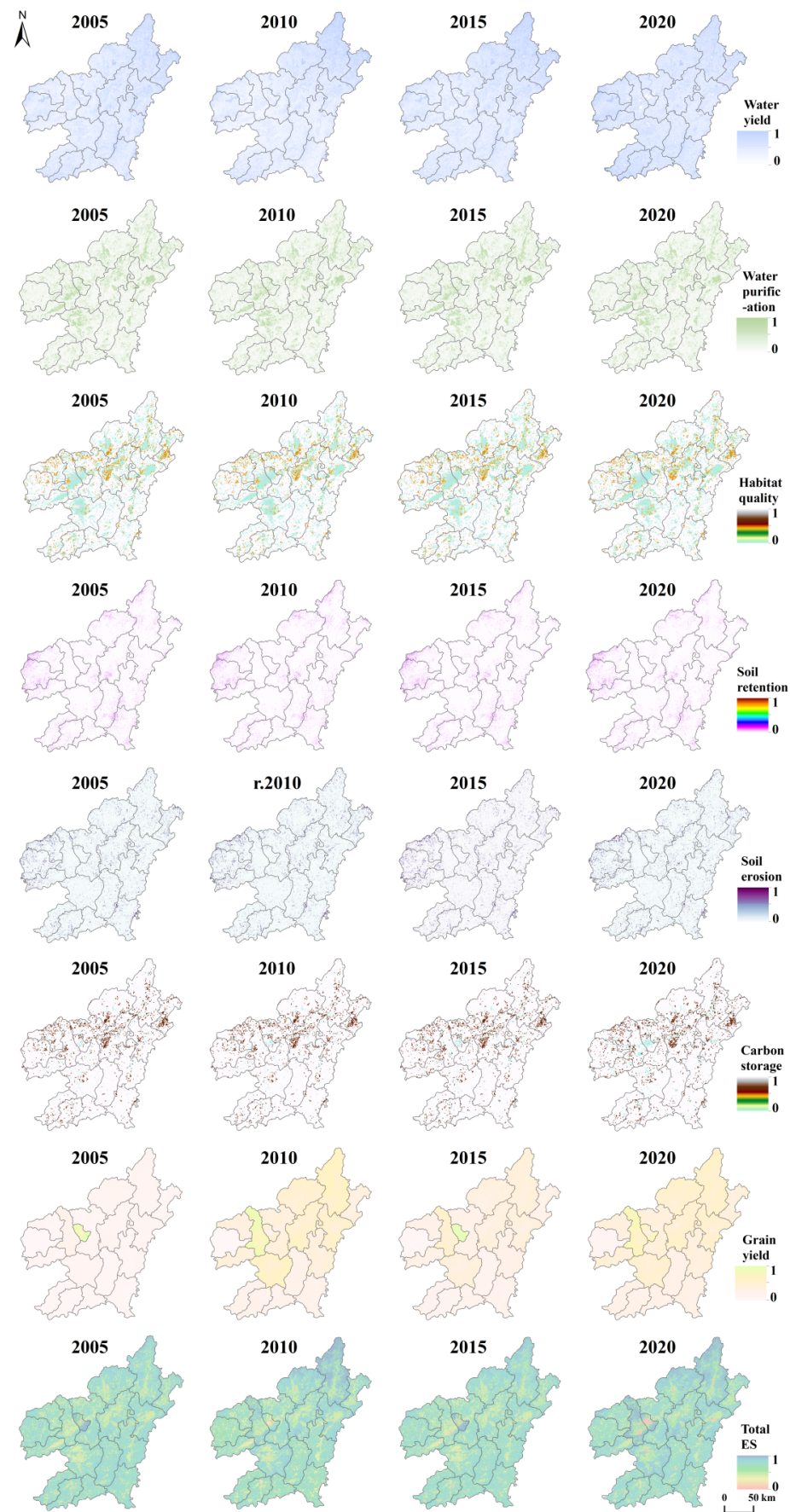


Figure 5. Spatiotemporal variations in ESs in Ganzhou.

Table 3. Results of model testing.

Spatial Weighting Matrix	Test Methods	Statistic	p-Value	Applicable Models
2-order rook matrix	LM_error	19.932	0.0000	Spatial Durbin model with fixed effects
	Robust LM_error	30.457	0.0000	
	LM_lag	19.864	0.0000	
	Robust LM_lag	30.516	0.0000	
	Hausman	−16.28	0.0000	
	LR(SDM vs. SAR)	40.17	0.0000	
	LR(SDM vs. SEM)	40.51	0.0000	
	Wald	53.73	0.0000	

The spatial econometric results display the response of ES to various SDG targets (Table 4). This outcome aligns with the model testing results (Table 3), further validating the superiority of the SDM model under fixed effects. The SDM model results indicate that ES in Ganzhou exhibit negative responses to SDG 1 and SDG 2 at significance levels of 5% and 10%, respectively, while showing significant positive responses to SDG 4, SDG 6, SDG 7, SDG 8, SDG 9, and SDG 11. However, ES did not significantly respond to SDG 3 and SDG 15. Among these, the response coefficients of Ganzhou ES to SDG 13 (0.727), SDG 6 (0.358), and SDG 8 (0.110) are the highest, indicating the strongest response of ES to these three targets.

Table 4. ES response to each SDG.

Variant	OLS	SEM	SAR	SDM	Variant	OLS	SEM	SAR	SDM
SDG 1	−0.039 *	−0.026 *	−0.049 *	−0.027 **	SDG 13	−0.12	0.122	0.113	0.727 **
SDG 2	−0.042 *	−0.031 *	−0.061 *	−0.036 *	SDG 15	0.218	0.282 ***	0.255 ***	0.053
SDG 3	−0.031 *	−0.045 *	−0.098 *	0.001	sigma2_e	\	0.000 ***	0.001 ***	0.000 ***
SDG 4	0.121 *	0.093 *	0.160 *	0.043 ***	rho	\	\	−0.246 ***	0.086 *
SDG 6	0.069 *	0.028	0.094 *	0.358 ***	lambda	\	0.797 ***	\	\
SDG 7	0.060 **	0.031 *	0.027 *	0.069 **	Log-likelihood	\	36.229	35.246	43.399
SDG 8	−0.026 *	−0.008	−0.004	0.110 ***	_cons	0.362 ***	\	\	\
SDG 9	−0.046 *	−0.031 *	−0.002	0.050 **	R ²	0.786	0.856	0.843	0.911
SDG 11	−0.027 *	−0.106 **	−0.116 **	0.012 *	N	72	72	72	72

Note: *: significant at 10% level; **: significant at 5% level; ***: significant at 0.1% level.

To gain a more comprehensive understanding of the response of ES to SDGs, we further employed a partial differentiation method to decompose the estimated coefficients of the SDM model into direct response, spillover response, and total response. Direct response indicates the response of ES in individual districts to SDG, spillover response indicates the response of ES in adjacent areas to various SDG, and total response represents the response of ES across Ganzhou to various SDG. The results are shown in Table 5.

Table 5. Spatial spillover effects of ES on each SDG.

Variant	Total ESs			Variant	Total ESs		
	Direct Effect	Indirect Effect	Total Effect		Direct Effect	Indirect Effect	Total Effect
SDG 1	−0.015 **	−0.029 **	−0.044 ***	SDG 8	0.025 ***	0.121 ***	0.146 ***
SDG 2	−0.004	−0.041 *	−0.044 *	SDG 9	0.001	0.054 **	0.055 **
SDG 3	0.006 *	0.003	0.01	SDG 11	−0.003 *	0.014 *	0.011 *
SDG 4	0.041 ***	0.051 *	0.092 **	SDG 13	−0.026	0.775 *	0.749 *
SDG 6	0.013	0.386 ***	0.399 ***	SDG 15	0.183 ***	−0.04	0.143
SDG 7	−0.010 *	0.077 **	0.066 *	-	-	-	-

Note: *: significant at 10% level; **: significant at 5% level; ***: significant at 0.1% level.

The direct, indirect, and total responses of ES to SDG 1 and SDG 2 are all significantly negative, indicating a lagged response of ES in the district, adjacent areas, and the entire Ganzhou region to SDG 1 and SDG 2 targets. ES only exhibits a significant positive response to SDG 3 in the local district, with no significant response observed in adjacent areas or the overall study. Significant responses of ES to SDG 4 and SDG 8 are observed in the local district, adjacent areas, and across the entire region. ES demonstrates significant responses to SDG 6 and SDG 9 in adjacent areas and across the entire region. The direct response of ES to SDG 7 and SDG 11 is significantly negative, while the response in adjacent areas and across the entire region is significantly positive. ES shows only significant positive responses to SDG13 in adjacent areas and across the entire region. Significant positive responses of ES to SDG 15 are observed only in individual districts.

4. Discussion

4.1. Spatiotemporal Changes in Each SDG

Studying the spatiotemporal changes in SDGs in Ganzhou requires consideration of localized factors, namely the unique geographical, economic, social, and cultural contexts of Ganzhou. The evolution of SDG indices across different districts in Ganzhou is driven by the region's geographical disparities [61], economic development levels [62], resource allocation [63], and varying government policies [64]. For instance, areas with developed industries may perform better in terms of economic growth (SDG 8) [65], energy efficiency (SDG 7), and infrastructure development (SDG 9), while mountainous regions may face significant challenges in poverty (SDG 1) [22], education (SDG 4), and health (SDG 3) [66]. Specifically, the mountainous areas in the northwestern part of Ganzhou, due to their complex terrain and inconvenient transportation, may face challenges in infrastructure development, leading to relatively slow progress in SDG 9 [67]. Meanwhile, the north-eastern plains of Ganzhou, with flat terrain and abundant resources, may find it easier to develop agriculture and industry, thus performing better in SDG 2 (Zero Hunger) and SDG 8. Economically developed areas like central Ganzhou may perform well in SDG 1 and SDG 8 because of advanced industry, ample job opportunities, and a higher standard of living [68]. Conversely, agriculturally dominated regions like southern Ganzhou may face challenges in SDG 1 and SDG 2 due to high agricultural income reliance and susceptibility to seasonal and market fluctuations [69]. For industrially developed areas, the government may place greater emphasis on environmental protection and infrastructure development to promote the achievement of SDG 7 and SDG 9 [70]. The achievement of SDG targets can also be influenced by the population structure and cultural customs of the different regions. For example, mountainous areas in the western part of Ganzhou may see relatively slow progress in SDG 4 (Quality Education) due to inconvenient transportation and a lack of educational resources [71]. The local natural environment plays an important role in achieving sustainable development goals as well [72]. For instance, the ecological environment in mountainous regions might be more fragile, requiring more resources for ecological protection, which could impact the achievement of SDG 15 (Life on Land).

In response to the SDGs, Ganzhou implemented national ecological protection and restoration projects (NECP) from 2016 to 2019. We utilized a DID model to validate the effectiveness of these projects (Table 6). First, we conducted a parallel trend test, which indicated no significant difference in the overall SDG index between the treatment group (affected by the policy from 2015 to 2020) and the control group (unaffected by the policy from 2005 to 2010), thus meeting the precondition of maintaining parallel trends before the policy intervention. Result (1) shows the regression outcomes without considering the control variables, while result (2) includes the control variables. Specifically, after implementing the ecological protection policy (2015–2020), the overall SDG index showed a positive change, passing the 5% significance test. Among the control variables, the air quality index significantly promoted the achievement of the overall SDG. In contrast, the number of extreme weather events and the urbanization rate negatively impacted the overall SDG, while the increase in population density had a positive and significant effect.

Average temperature did not significantly affect the overall SDG. The results of this study passed the placebo test, indicating that other unobservable random factors did not influence the overall SDG index.

Table 6. Impact of the implementation of the NECP in Ganzhou on total SDGs.

Variables	(1)	(2)	Variables	(1)	(2)
	Total SDG	Total SDG		Total SDG	Total SDG
NECP	2.874 *** (−0.424)	1.767 ** (−0.466)	Population density	-	0.118 *** (−0.015)
Average temperature	-	−0.051 (−0.07)	_cons	13.031 *** (−0.195)	−3.305 (−10.848)
Number of extreme weather events	-	−0.200 * (−0.107)	Year effect	Yes	Yes
			Individual effect	Yes	Yes
Air quality index	-	0.369 *** (−0.139)	N	864	864
			R ²	0.161	0.448
Urbanization rate	-	−0.117 *** (−0.019)		-	

Note: Standard errors in parentheses. *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$.

In addition to the implementation of national-level projects, the Ganzhou municipal government has also formulated a series of policies in various districts and counties to promote the localized achievement of the SDGs. For instance, in 2018, counties in the western part of Ganzhou introduced a series of poverty alleviation policies, significantly reducing the poverty rate; whereas in 2020, the government might have intensified environmental protection efforts, facilitating the achievement of SDG 13 (Climate action). The economic cycles of different years also impact the realization of the SDG targets. During years of stable economic growth, such as 2019, regions may find it easier to achieve SDG 8. During economic downturns, regions face challenges in reducing poverty and boosting their economic growth. Natural disasters occurring in certain years can also affect the achievement of the SDG targets. For example, mountainous areas in Ganzhou might have been impacted by flooding in 2017, hindering the realization of SDG 2 and SDG 13. The trends in achieving specific SDG goals vary across regions in different years. For example, from 2016 to 2020, certain districts and counties in central Ganzhou showed a favorable growth trend in SDG 8, while neighboring counties faced challenges in achieving SDG 1 during the same period. To understand the temporal and spatial changes in sustainable development goals across various regions of Ganzhou, it is essential to consider factors such as specific years [21], policy adjustments [73], economic cycles [63], and natural disasters [20]. An in-depth analysis of these factors helps to better comprehend the trends in different SDG goals across regions in various years, enabling the formulation of more precise development strategies and promoting the realization of sustainable development goals.

4.2. Response of Ecosystem Services to Each SDG

Changes in ES are often influenced by natural environmental characteristics. For example, terrain, climate, and soil type in different areas of Ganzhou directly affect the types and supply of ESs. For example, the mountainous areas in the western and northern parts of Ganzhou may have abundant water resources and biodiversity, providing ES, such as water source protection and habitats for wildlife. Meanwhile, the plains in central Ganzhou are likely more suitable for agricultural production, offering rich food supplies and soil protection as ecosystem services. Human activities also directly influence the supply and quality of various ES. The processes of industrialization and urbanization may lead to changes in land use and increased pollutant emissions, thereby affecting the quality of water, soil, and other ecosystem services. Industrial parks located in central

Ganzhou might negatively impact the surrounding water quality, thus affecting the related ecosystem services. These human activities are often key reasons for spatial and temporal changes in ecosystem services. Government environmental policies and management measures play a crucial role in the supply and protection of ecosystem services. By establishing nature reserves, promoting sustainable land use planning, and implementing ecological compensation policies, the government can effectively protect and restore ES. For the mountainous areas in the northwestern part of Ganzhou, the government has taken measures to strengthen water resource protection and ecological restoration, aiming to enhance the supply capacity of the related ES. Therefore, the environmental management policies and enforcement intensity of different regional governments also directly affect the spatial and temporal variations in ESs. Additionally, climate change may lead to changes in precipitation patterns and more frequent extreme weather events, further impacting water supply, crop production, and other ESs. Finally, as urbanization and industrialization progress, land use types may change, such as a decrease in forest cover and an increase in cultivated land area, directly affecting services like soil and water conservation and biodiversity protection.

The response of ES to various SDGs involves the comprehensive influence of multiple factors. In terms of eradicating poverty (SDG 1), the negative response of ESs may stem from unequal resource utilization and distribution. The weakening of ESs in some areas of Ganzhou may have led to a decrease in agricultural output and job opportunities influenced by factors such as declining land resource quality and water scarcity. The negative response of ESs to zero hunger (SDG 2) may be related to the instability in agricultural production and food supply. The weakening of ESs may have resulted in reduced crop yields and an insufficient food supply, influenced by factors such as land degradation and water pollution. In terms of good health and well-being (SDG 3), ESs have not shown a significant response, reflecting the complex impact of Ganzhou ESs on human health. Although the weakening of ESs may lead to environmental pollution and frequent natural disasters, it can also enhance people's physical and mental health levels by providing suitable natural environments and biodiversity. ESs have a positive response to quality education (SDG 4), reflecting their support for educational resources. The beauty and richness of the natural environment may provide students with a better learning environment, while biodiversity and ecosystem stability may also provide a practical foundation for ecological education. The positive response of ESs to clean water and sanitation (SDG 6) is related to water resource management and protection. The maintenance and restoration of ESs help ensure the supply of water resources and the purification of water quality, thereby promoting the popularization of clean water and sanitation facilities. The positive response of ES to SDG 9 may be related to the support for infrastructure construction and industrial development. For sustainable cities and communities (SDG 11), the positive response of ESs reflects their support for urban planning and construction. ESs, such as urban greening, ecological landscapes, and nature reserves, help improve urban environmental quality and residents' quality of life and promote sustainable urban development. The positive response of ES to SDG 13 is related to the role of ecosystems in climate regulation and carbon storage. Through the absorption and storage of carbon by ecosystems such as forests and wetlands, ESs contribute to mitigating climate change and responding to its impacts.

Integrating the consideration of direct, indirect, and holistic responses is a vital approach to understanding the underlying reasons and mechanisms behind the response of ESs to the SDGs. In the case of SDG 1 and SDG 2, the direct negative response of ES indicates that a decline in the level of ESs within this district directly intensifies poverty and hunger issues. This may be due to the degradation of land resources and the scarcity of water resources, leading to a decrease in agricultural productivity, which in turn affects the alleviation of poverty and hunger. For SDG 4 and SDG 8, the positive response of ES in adjacent areas suggests that the improvement of ESs not only benefits this district but also has a positive impact on surrounding regions. For instance, the enhancement of ESs may promote the development of agriculture and industrial production, stimulate employment

and economic growth, and thereby influence the improvement of poverty and economic inequality issues. Regarding SDG 6 and SDG 9, the significant positive response of ES across the entire region may reflect the overall improvement in water resource management and infrastructure construction in Ganzhou, contributing to the sustainable use of water resources and economic development. This may be influenced by a combination of factors such as government policies, economic structure, and environmental management.

4.3. Recommendations and Outlook

To enhance the responsiveness of Ganzhou to localized SDGs, the following actions are required. Strengthen the protection and restoration of ecosystems. Establish more nature reserves and ecological restoration projects and enhance measures for water conservation, soil conservation, and vegetation recovery to improve the stability and sustainability of ESs. Consider the differences in ESs across regions and develop more comprehensive and localized development plans [74]. These plans should fully take into account the distribution of natural resources, ecological and environmental conditions, and socio-economic development needs to promote positive interaction between ecological, environmental protection and socio-economic development. Enhance cross-sectoral collaborative cooperation. Government departments, research institutions, enterprises, and social organizations should actively participate, establish joint working mechanisms, and jointly promote the construction of an ecological civilization and sustainable development [75]. Strengthen the capacity to address climate change. Strengthen the construction of monitoring and early warning systems, promote the implementation of adaptive measures, and advance carbon sink management and emission reduction efforts to counter the adverse effects of climate change on ecosystems. To achieve the sustainable use and protection of ESs, actively promote green development and resource recycling. Increase support for green technological innovation and environmental protection industries and promote the rational and economical use of resources to achieve a win-win situation for ecological, environmental protection and economic development [76]. Government departments, media, and social organizations should strengthen environmental education and popular science propaganda, promote the concept of ecological civilization, enhance public environmental awareness and action, and jointly advance the process of ecological, environmental protection and sustainable development [77].

This study also contrasts sharply with the existing literature in terms of methodology and research perspectives. Compared to Wang et al. (2024) [78], this research not only focuses on the balance and coordination of ES supply and demand but also incorporates an analysis of responses to SDGs, thereby examining the value and role of the ES within a broader framework of sustainable development. Additionally, in contrast to the studies by Wang et al. (2019) [79] and You et al. (2024) [80], this research employs a spatial econometric model to measure the responses of ESs to various SDGs, providing a new perspective on understanding the complex relationship between ESs and SDGs. Although studies by Li et al. (2021) [81] and Liao et al. (2023) [82] offer detailed analyses of land use and ES in Ganzhou, the innovation of this research lies in closely linking the responses of ESs with the realization of SDGs, revealing the critical role of ecosystem services in driving the achievement of SDGs. By comparing with existing research, this study systematically analyzes the responses of ESs to SDGs for the first time in Ganzhou, a typical southern hilly area, providing new theoretical foundations and practical guidance for the region's sustainable development. The combination of the InVEST model and spatial econometric models enhances the precision and reliability of the research. The findings not only offer valuable insights into the sustainable development of Ganzhou and other regions in China but also contribute to Chinese wisdom and solutions to the global realization of sustainable development goals.

Despite the valuable findings of this research, there are still limitations. The study area is relatively small, only representing, to a certain extent, the relationship between ES and SDGs in the southern hilly region. The natural, social, and economic conditions of

Ganzhou have certain particularities. Secondly, although the selected indicator system is as comprehensive and scientific as possible, it still cannot fully represent all SDGs. Some key areas may not be fully covered due to data access limitations or the limitations of indicator selection, affecting the overall assessment's comprehensiveness and accuracy. Although the spatial econometric model can reveal the response relationships within counties, across fields, and globally, it has not yet deeply explored local differences and micro-mechanisms at more detailed grid scales. Future research needs to conduct more detailed analyses at higher-resolution data and grid scales to more accurately reveal the complex interactive relationships between ecosystem services and SDGs. Comprehensive assessments and predictive simulations of the association mechanisms and influencing factors between ES and SDGs should be conducted to provide deeper theoretical support and practical guidance for the formulation of more scientific and reasonable environmental protection and sustainable development policies. Additionally, continuous strengthening of international cooperation and exchanges is necessary to jointly address global environmental challenges and make positive contributions to building a beautiful China and a community with a shared future for humanity.

5. Conclusions

Between 2005 and 2020, Ganzhou exhibited variability in the progress towards various SDGs across its different districts. Some areas made significant strides in eradicating poverty, addressing hunger, and improving education levels. However, challenges persist in areas such as health, access to clean water, and climate action. Overall, Ganzhou has achieved relatively balanced development across all SDG targets, with the southern regions lagging somewhat behind. ES in Ganzhou displays certain spatial distribution patterns. Water yield and grain yield are relatively lower in the south, while habitat quality and carbon storage are higher in the north. The ES in Ganzhou has shown significant responses to multiple SDG targets, with positive responses to goals such as quality education, clean water, and economic growth. Conversely, there have been negative responses to goals like poverty eradication and hunger alleviation. The impact of ES responses is not limited to individual districts but also extends to neighboring areas and the entire city, indicating a spillover effect.

While the findings are specific to Ganzhou, they offer valuable insights that can be generalized to other regions facing similar challenges in sustainable development. This research underscores the critical role of ecological conservation and improvement in promoting the realization of SDGs, with significant regional and holistic impacts. For other regions, the following recommendations can serve as a guideline for future research and policy-making. To achieve synergistic development between the ecological environment and the socio-economic sphere, it is essential to optimize land use planning to balance economic development with ecological conservation, enhance pollution control and environmental monitoring for improved environmental quality, and promote green industries to drive economic growth while minimizing environmental impact. Additionally, increasing social participation and education can raise awareness of and support for sustainable practices. Fostering regional cooperation can aid in sharing best practices and resources while integrating rural revitalization with ecological construction can balance rural development and environmental sustainability. Finally, establishing a comprehensive policy and regulatory framework is vital to guide and enforce sustainable practices, ensuring long-term compliance with the SDGs.

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