Postprint: Prediction of Ecosystem Service Value and Driving Forces in the Poyang Lake Ecological Economic Zone

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Abstract

The Poyang Lake Ecological Economic Zone is China' s first ecological economic zone elevated to national strategic status. Utilizing MODIS data for the Poyang Lake Ecological Economic Zone from 2004, 2008, 2012, and 2016, land use/cover data for four corresponding periods were acquired. Based on a revised equivalent factor table of ecosystem service value per unit area and the grey GM(1,1) model, ecosystem service value data for 2016-2024 (at 2-year intervals) were projected, and the driving forces underlying changes in ecosystem service value were analyzed. The results demonstrate that during 2004-2016 in the Poyang Lake Ecological Economic Zone, the area of grassland, construction land, and unused land increased, whereas the area of cultivated land, forest land, and water bodies decreased. However, the projected change rate for 2016-2024 is merely -0.17%, suggesting that the ecosystem service value of the study area is approaching a relatively stable state. Driving force analysis indicates that anthropogenic comprehensive disturbance is predominantly characterized by medium-impact intensity disturbance in spatial distribution. Urbanization rate constitutes the primary driving force for the decline in total regional ecosystem service value, followed sequentially by non-agricultural population, population density, primary industry GDP, secondary industry GDP, fixed asset investment, total GDP, and tertiary industry GDP. It is recommended that land use planning and regulation be strengthened, expansion of construction land for urbanization be controlled, industrial structure be adjusted, pollution be reduced, and the enhancement of total ecosystem service value in the Poyang Lake Ecological Economic Zone be promoted.

Full Text

Preamble

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Ecosystem Services Value Prediction and Driving Forces in the Poyang Lake Eco-economic Zone

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Abstract: The Poyang Lake Eco-economic Zone represents China's first ecological economic zone elevated to national strategy status. Using MODIS data from 2004, 2008, 2012, and 2016 for the Poyang Lake Eco-economic Zone, we obtained land use/cover classifications for these four corresponding periods. Ecosystem services value data at 2-year intervals from 2016 to 2024 were predicted according to the revised equivalent value table of ecosystem services per unit area and the grey GM(1,1) model. The driving forces behind changes in ecosystem services values were subsequently analyzed. The results revealed that from 2004 to 2016, the area of grassland, construction land, and unused land increased, while the trends for arable land, forest land, and water area were opposite. With the predictive change rate of ecosystem services value being only -0.17% between 2016 and 2024, it indicated that the regional ecosystem services value would enter a relatively stable state. Driving force analysis showed that human activity interference remained at a moderate intensity level in spatial distribution. Urbanization rate was the primary driving force decreasing regional total ecosystem services value, followed by non-agricultural population, fixed asset investment, and tertiary industry GDP. We recommend strengthening land use planning and regulation, controlling urban construction land expansion, adjusting industrial structure, and promoting the enhancement of total ecosystem services value in the Poyang Lake Eco-economic Zone.

Keywords: ecosystem services value; land use structure; grey forecast model; driving force; Poyang Lake Eco-economic Zone

Ecosystem services refer to the products and services that natural or artificial ecosystems provide directly or indirectly to support human life through their structures, processes, and functions. The value of ecosystem services is a core indicator for measuring whether a region can achieve sustainable development. Land constitutes the basic element of ecosystems, and land use/cover changes have decisive impacts on regional ecosystem service functions and values. Quantitative assessment of regional ecosystem service functions and values through land use changes has become a hot topic in ecological research. Most evaluations of ecosystem service functions and values are static assessments based on observational or statistical data from a specific period, while dynamic predictions and studies on driving factors of ecosystem service functions and values are relatively scarce. Since ecosystem service functions and values are influenced by numerous natural and socioeconomic factors with complex interrelationships, studying the evolution patterns and driving forces of regional ecosystem service functions and values holds important scientific significance.

The Poyang Lake Eco-economic Zone, approved by the state in 2009 as China' s first ecological economic zone elevated to national strategy, has become an important economic growth pole in central China. It also serves as a vital ecological function protection area in China and a globally important ecological region designated by WWF, bearing multiple ecological functions such as flood regulation, water storage, and pollution degradation. This study takes the Poyang Lake Eco-economic Zone as the research object, using land use/cover change data from 2004 to 2016 and employing a grey prediction model to forecast the region' s ecosystem services value, aiming to provide scientific basis for future development planning and sustainable development of the Poyang Lake Eco-economic Zone.

1. Study Area

The Poyang Lake Eco-economic Zone is located on the south bank of the middle and lower reaches of the Yangtze River, covering northern Jiangxi Province with Poyang Lake as its core. Comprising cities and counties surrounding Poyang Lake, it spans 114°28 28 -117°28 20 E, 27°29 54 -30°04 N, with a total area of 51,081.6 km^2 (30.7% of Jiangxi Province' s total land area). The lakefront area includes Jiujiang urban district, Xingzi, Duchang, Poyang, Yugan, and Nanchang counties, while the peripheral area includes Nanchang urban district, Jinxian, Fengcheng, Gao'an, Fengxin, Jing'an, Xiushui, Wuning, Dexing, Leping, Jingdezhen urban district, Dongxiang, Yujiang, Yichun urban district, Fengxin, Jing' an, Shanggao, Yifeng, and Wanzai. By the end of 2013, the regional population reached 20.018 million (44.7% of Jiangxi's total), and GDP totaled 845.26 billion yuan (59.0% of Jiangxi' s total). Climate data from 1953–2013 for representative meteorological stations (Nanchang, Jiujiang, and Jingdezhen) show a decreasing precipitation trend (-33.18 mm/10a) and increasing temperature trend (0.244°C/10a), indicating a clear warming-drying trend that has led to reduced water area and weakened water conservation functions.

2. Data Sources and Processing

Given the large study area, it was difficult to obtain quality TM/ETM+/OLI imagery for the same period that could meet land use interpretation requirements. Therefore, this study used MODIS data (http://ladsweb.nascom.nasa.gov) for 2004 (October 5), 2008 (November 13), 2012 (November 13), and 2016 (March 3) to interpret land use/cover. To avoid interference from seasonal water surface changes, all selected data were from clear, cloud-free days in October–November. Data processing involved: (1) reconstructing multi-source datasets including MOD09A1 (500 m surface reflectance), MOD09Q1 (250 m), MOD13Q1 (250 m), and DEM (30 m$×$30 m); (2) using MODIS Reprojection Tool (MRT) for reprojection and uniform resolution adjustment to 250 m; (3) selecting training sample Regions of Interest (ROI) and using decision tree classification to classify the study area into arable land, forest land, grassland, water area, construction land, and unused land; (4) obtaining land use areas for four periods through statistical analysis of classification maps.

Accuracy assessment and field verification showed overall classification accuracies of 96.7%, 98.9%, 94.1%, and 95.5% for 2004, 2008, 2012, and 2016, respectively, with Kappa coefficients of 0.9572, 0.9856, 0.9327, and 0.9423, indicating high classification reliability. Socioeconomic data were sourced from Jiangxi Statistical Yearbooks and industry statistical yearbooks.

[Figure 1: see original paper] Location of the Poyang Lake Eco-economic Zone
[Figure 2: see original paper] Climate change characteristics in the Poyang Lake Eco-economic Zone from 1953–2013
[Figure 3: see original paper] Land use classification maps in the Poyang Lake Eco-economic Zone from 2004–2016

Land use structure and ecosystem services value changes in the Poyang Lake Eco-economic Zone from 2004–2016

3. Grey Prediction Model

The grey prediction model GM(1,1) (Grey Dynamic Model) processes original data sequences through mathematical methods to establish dynamic differential equations describing the intrinsic characteristics of the original system, creating abstract system dynamic evolution prediction models. It offers unique advantages for predicting objects and process systems with small datasets and unclear data structure relationships and operational mechanisms. Considering the fuzzy and uncertain characteristics of ecosystem services value changes and the impacts of industrial transformation, ecosystem services value prediction represents a typical grey evaluation process. Therefore, this study adopted the GM(1,1) model to predict ecosystem services value in the Poyang Lake Eco-economic Zone. The specific calculation methods are detailed in reference [14]. The GM(1,1) model is simple, highly accurate, and suitable for short-term predictions of regional ecosystem changes without requiring land use structure distribution patterns or transfer probabilities.

4. Ecosystem Services Value Calculation

Based on Xie Gaodi et al.' s [15-16] research on Chinese terrestrial ecosystem services values and Zhao Zhigang' s [17] determined characteristic regions and adjustment coefficients for six terrestrial ecosystem service values, we obtained baseline data for ecosystem services value per unit area in the Poyang Lake Eco-economic Zone. The ecosystem services value assessment method followed reference [2].

5. Human Impact Comprehensive Index Calculation

The human impact comprehensive index (HAI) describes the degree of human disturbance within landscape units, calculated as:

$$\text{HAI} = \frac{\sum_{i=1}^{N} A_i S_i}{TA}$$

where HAI is the human impact comprehensive index, N is the number of landscape types, A_i is the area of landscape type i, S_i is the human impact intensity coefficient for landscape type i, and TA is the total landscape area. Based on relevant research [18] and expert consultation, we determined the human impact intensity coefficients S_i for different land types.

Human impact intensity indices for different land types

Using ArcGIS 10.2, we performed Kriging spatial interpolation on HAI values calculated for 1 km$\times 1 km landscape units to obtain spatial distribution maps of human disturbance intensity for2
$very low (0 < HA$ 0.20), $low (0.20 < HA$ 0.40), $moderate (0.40 < HA$ 0.60), $high (0.60 < HA$ $0.80), and very high (HA>0.80).

6. Ecosystem Services Value Prediction Model

Using linear interpolation of land use/cover data from four periods, we obtained annual land use structure data from 2004–2016. With DPS 7.05 software, we constructed grey GM(1,1) models for each land type using data at 2-year intervals. Model accuracy was assessed using the following criteria: Grade I (C<0.35, P$ 0.95), $Grade II (C < 0.50, P$ 0.80), $Grade III (C < 0.65, P$ 0.70), $and Grade IV (C$ 0.65, P $0.70). All models achieved Grade II or better accuracy, indicating good predictive performance and high reliability. Prediction results were appropriately adjusted based on Jiangxi' s "cultivated land requisition-compensation balance" policy.

Grey dynamic models for various land use types in the Poyang Lake Eco-economic Zone from 2016–2024

7. Ecosystem Service Function and Value Prediction

Predicted ecosystem services values for each land type from 2016–2024 show minimal change in total value for the Poyang Lake Eco-economic Zone, with a change rate of only -0.17%. Forest ecosystem services value increased by 2.31%, while arable land and water area values decreased by 1.92% and 1.49%, respectively. Construction land and unused land values remained relatively stable. The trend indicates that environmental quality will first decline then improve, likely due to stabilizing population growth and emerging effects of ecological protection policies.

Changes in ecosystem services value of various land types in the Poyang Lake Eco-economic Zone from 2016–2024

Analysis of different ecosystem service functions shows increasing trends for gas regulation, climate regulation, and raw material production (value increase ratios of 0.97%, 0.90%, and 0.62%, respectively), while waste treatment and food production showed decreasing trends (-1.26% and -1.03%). The dominant service function is water conservation, accounting for over 50% of total value, followed by soil conservation (over 20%). Climate regulation and gas regulation each exceed 10% of total value.

Value changes of ecosystem service functions in the Poyang Lake Eco-economic Zone from 2016–2024

8. Driving Forces of Ecosystem Services Value in the Poyang Lake Eco-economic Zone

Human disturbance and socioeconomic factors cause regional land use structure changes, further affecting ecosystem service functions [19]. This study analyzed driving forces from both human interference and socioeconomic perspectives.

8.1 Human Impact Factors

To analyze human impacts, we divided the study area into 1 km$×$1 km landscape units, calculated HAI for each unit, and performed Kriging interpolation to obtain spatial distribution maps for 2004, 2008, 2012, and 2016. Spatial characteristics show: areas around Poyang Lake dominated by moderate impact intensity; central and southern areas by moderate to high intensity; northern areas by low to very low intensity. From 2004–2008, high-impact areas expanded significantly in the southwest; 2008–2012 saw continued southwest expansion in a belt pattern; 2012–2016 showed further expansion of high and very high impact areas in central, southern, and southwestern regions. The expansion of high-impact areas aligns strongly with urban construction expansion. Moderate to high impact areas correspond to arable land and construction land, with transitions mainly representing conversion from arable land to construction land.

[Figure 4: see original paper] Distribution of integrated intensity of human disturbance

8.2 Socioeconomic Factors

Based on county-level population and economic data, we standardized the data [20] and analyzed relationships between total ecosystem services value and socioeconomic indicators using OriginPro 9.1.

Population factors: Population density, non-agricultural population, and urbanization rate showed significant negative correlations with ecosystem services value (correlation coefficients: -0.894, -0.914, -0.900). Rapid population growth increases demand for food and raw materials, expands construction land, and increases waste emissions, all reducing ecosystem services value. However, population growth rate has slowed recently (6.9‰), moderating the decline in ecosystem services value.

[Figure 5: see original paper] Correlation between demographic factors and regional total ecosystem services value

Economic factors: Total GDP, primary industry GDP, secondary industry GDP, tertiary industry GDP, and fixed asset investment all showed significant negative correlations with ecosystem services value (correlation coefficients: -0.869 to -0.895). Increased income from food production and raw material extraction reduces ecosystem services value, while urban-industrial development drives construction land expansion. The negative impact order is: non-agricultural population > urbanization rate > primary industry GDP > secondary industry GDP > fixed asset investment > total GDP > tertiary industry GDP.

[Figure 6: see original paper] Correlation between economic factors and regional total ecosystem services value

9. Discussion and Conclusions

Previous studies have made progress in ecosystem services value assessment for different regions [21-25] and scales [26-28], but prediction research remains limited. Since ecosystem services value is an assessment rather than measurement, and influencing factors are numerous and complex, selecting appropriate models is crucial. This study confirms that the GM(1,1) model can effectively predict regional ecosystem services value with relatively small datasets, offering computational convenience and high accuracy compared to MARKOV, CLUE-S, and cellular automata methods [29-32]. Domestic scholars have applied GM(1,1) to predict ecosystem services value in Jiangsu, Shanghai, and Kashi [13-14, 34-36], with most showing continued declining trends stabilizing after 2020. This study found that while Poyang Lake Eco-economic Zone experienced declining value during initial construction (2004-2016), the predicted period (2016-2024) shows stabilization, with forest value increasing significantly and water conservation/waste treatment functions declining slightly.

Human activities and socioeconomic development significantly impact ecosystem services value [37]. Rapid urbanization has been the primary driver of value reduction in Poyang Lake Eco-economic Zone, with high-impact areas aligning with urban expansion. However, as urbanization slows, population and construction land growth reach control targets, and ecological protection measures are implemented (e.g., Jiangxi Ecological Public Welfare Forest Compensation Fund Management Measures, Jiangxi Main Functional Area Planning, Jiangxi River Basin Ecological Compensation Measures, Jiangxi Ecological Civilization Pilot Zone Construction Implementation Plan [38-41]), ecosystem services value will likely stabilize, with decreasing and increasing values balancing out.

This study confirms that arable land and forest systems, ranking first and second in area and value, play irreplaceable roles in maintaining stable ecosystem services value. Water systems are crucial for water conservation and waste treatment, and their protection is vital for medium-term development. The main conclusions are:

(1) From 2004–2016, land use/cover patterns changed significantly, with water area decreasing most notably and construction land increasing fastest, substantially altering the regional ecosystem services value pattern.

(2) Predictions for 2016–2024 indicate relatively stable total ecosystem services value (-0.17% change rate), with forest ecosystem services value increasing significantly (+2.31%) while arable land and water values declined noticeably.

(3) Gas regulation, climate regulation, raw material production, and entertainment-cultural functions are increasing, while waste treatment and food production are decreasing. Water conservation remains the dominant function.

(4) From 2004–2016, human interference expanded in both space and intensity, dominated by moderate impact intensity. Low-impact areas are mainly water and forest, while high-impact areas are arable land and construction land.

(5) Socioeconomically, population factors outweigh economic factors. Urbanization rate is the primary driver reducing total ecosystem services value, followed by non-agricultural population, fixed asset investment, and tertiary industry.

We recommend strengthening land use planning and regulation, controlling urban construction land expansion, adjusting industrial structure, and promoting enhancement of total ecosystem services value in the Poyang Lake Eco-economic Zone.

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