# The Study of Coupling Coordination Between Urbanization and Ecosystem Service Value-Taking Shandong Province as an example

Yu Pan[a], Chang You[b*]

a School of Foreign Studies, Shandong University of Finance and Economics, Jinan 250014, China
b School of Ethnology and sociology, Minzu University of China, Beijing 100081, China
*Correspondence: 22400130@muc.edu.cn

**Abstract.** In line with the overarching theme of fostering interdisciplinary dialogue and promoting sustainable urban development, this study delves into the intricate nexus between urbanization and ecosystem service value (ESV) in Shandong Province.Shandong Province has significantly impacted ecosystem services value (ESV) due to its rapid economic growth and urban expansion. This study focuses on the changes in ESVs during the urbanization process. By employing a coupling and coordination degree model, it explores the dynamic relationship between urbanization and ESV. The study reveals a significant increase in the urbanization index from 1990 to 2020 in Shandong Province, with high-value urban areas expanding. Concurrently, changes in the spatial distribution of ESV were observed, with increases in certain regions, indicating a complex interplay between urbanization and ESV. Utilizing the coupling and coordination degree model, the study not only unveils the state of coordinated development between urbanization and ESV but also, through spatiotemporal analysis, exposes the dynamics and spatial differences in their coupling and coordination. The results indicate: (1) Shandong Province saw a significant rise in urbanization index from 1990 to 2020, with rapid expansion in central urban areas such as Jinan and Zibo, reflecting the swift urbanization process. (2) The value of ecosystem services (ESV) also increased during the same period, especially in northwestern cities like Dezhou and Binzhou, where the coordination between urbanization and ESV noticeably improved, demonstrating effective synergistic development between urban areas and ecosystems. The research underscores the importance of incorporating ecosystem service conservation and enhancement in urban planning and development to achieve a win-win strategy for economic development and ecological protection.

**Keywords:** Urbanization; Ecosystem Services; Coupling and Coordination Degree; Sustainable Urban Development


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# 1 Introduction

Over the past few decades, urbanization, as one of the most significant geographical and socio-economic phenomena globally, has drawn extensive attention. The process of urbanization profoundly affects the ecological environment, especially the supply capacity of ESV, which contributes to human societal well-being through air and water purification, climate regulation, food provision, and biodiversity conservation[1]. With the rapid progression of urbanization, issues such as ecosystem degradation, and the overexploitation of natural resources have become increasingly prominent, causing concern over the negative impacts on ESV among the scientific community and policymakers. Recent studies have focused on exploring the mechanisms and patterns of urbanization's impact on ESV[2]. For example, some research has assessed the effects of urban expansion on biodiversity, revealing a downward trend in ESV due to urbanization[3]. Other studies have concentrated on evaluating specific ESV, such as air purification and water regulation, during urbanization[4]. These studies provide important insights into the complex relationship between urbanization and ESV. Current research, while offering quantitative analyses on the impacts of urbanization on ESV, often focuses on specific regions or types of ESV, lacking comprehensive studies on the dynamic relationships between the entire urbanization process and various ESVs. Additionally, analyses of the coupling and coordination between urbanization and ESV are typically superficial and fail to fully reveal how policies and management can effectively promote harmonious development at different stages of urbanization.

Addressing these gaps, this study aims to systematically analyze the coupling and coordination dynamics between urbanization and ESV in Shandong Province from 1990 to 2020. It explores how urbanization influences ESV at different stages and analyzes the main mechanisms and pathways involved. Based on the results of the coupling coordination, targeted policy recommendations are proposed to promote sustainable development of urbanization and ecosystem services. The significance of this study lies in providing a new perspective on the complex mechanisms of the impact of urbanization on ESV and its practical value in formulating scientific urban planning policies and promoting sustainable urban development.

# 2 Materials and Methods

## 2.1 Data Sources

In this study, the land use data, population density, GDP , night light index were obtained from Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (http://www.resdc.cn/). The spatial resolution is 1km×1km. Grain output, price and planted area were respectively from the Shandong Rural Statistical Yearbook for 1990, 2000, 2010 and 2020.

### 2.2 Study Area

Shandong province is situated in the eastern part of China, with approximate latitude and longitude coordinates ranging from 34°22'N to 38°24'N latitude and 114°36'E to 122°43'E longitude. Shandong's high level of economic development and rapid urbanization pace have notably impacted its ecological environment. Due to its unique geographical location and economic characteristics, Shandong serves as an ideal case study for examining the effects of urbanization on ESV. The province's natural environment, comprising plains, mountains, rivers, and seas, provides a favorable condition for assessing the impact of urbanization on various types of ESV.

### 2.3 Calculation of Urbanization Index (UI)

To comprehensively reflect the degree and characteristics of urbanization, construction land area, population density, GDP, and nighttime light index were selected as indicators for calculating the urbanization index. Each indicator was normalized to eliminate dimensional impacts[5], and the entropy weight method was used to calculate their weights and the overall urbanization index[6].

$$U_k = \sum_{j=1}^{m} X_{kj} W_{kj} \tag{1}$$

where Uk denotes the urbanization index, Xkj denotes the weight of the jth indicator, and Wkj denotes the jth indicator after normalization.

### 2.4 Calculation of the ESV

The ESV was calculated by using the standard equivalent factor value method, taking the net profit of grain production per unit area of agricultural ecosystems as a standard equivalent factor for ESV. Considering the fluctuations in value and planting area of the four major grains (rice, wheat, corn, and soybean) over different years, this paper uses the average net profit of these grains from 1990 to 2020 as the standard equivalent factor value. The calculation formulas for ESV assessment reflect the economic value of crops per unit area, with adjustments made for the fluctuating values and planting areas of major grains over time[7].

$$V_a = \frac{1}{7} \sum_{i=1}^{n} \frac{a_i p_i q_i}{A} (i = 1,2,\cdots,n) \tag{2}$$

$$VE_{ij} = C_{ij} V_a \ (i, j = 1,2,\cdots,n) \tag{3}$$

$$ESV = \sum A_k E_k \tag{4}$$

Va denotes the economic value of crops per unit area in China; I denotes the crop type and pi indicates the current price of the ith crop. qj denotes the yield of the jth crop on 1 unit area; ai denotes the total planted area of ith crop. A denotes the total planted area of the four crops. $\mathbf{VE_{ij}}$ denotes the ESV coefficient of the jth ESV function contained in the ith ecosystem; Cij denotes the economic value of the jth service function

contained in the ith ecosystem with respect to 1 unit of farmland; Va is the economic value of one crop per unit of area of a. Ak denotes the area of the kth class of land kth, and Ek denotes the ESV of the kth class of land corresponding to the k land class of the 1 unit of area.

### 2.5 Degree of Coupling Coordination

Given the multi-layered and multidimensional nature of the interactions between urbanization and ESV, this study employs a coupling coordination model to quantitatively analyze their relationship. The model integrates multiple indicators to reveal the interplay and coordination between urbanization and ESV at various stages. The coupling and coordination degree model calculates the dynamic relationship between urbanization indices and ESV. The calculation results were categorized into four classes using the natural breakpoint method[8], which are dissonance (0.0-0.3), low coupling (0.3-0.4), medium coupling (0.4-0.5), and high coupling (0.5-1.0). The coupling coordination degree model is calculated as follows[9]:

$$C_n = \{U_1 \times U_2 \times \cdots U_n / \sum_{i=1}^{n} U_i\}^{1/n} \tag{5}$$

$$T\_c = \partial U\_h + \beta U\_p + \delta U\_a + \varepsilon U\_m, \quad D\_c = \sqrt{(C\_c \times T\_c)} \tag{6}$$

$\mathbf{C_n}$ indicates the degree of coupling between multiple systems and $\mathbf{U_i}$ represents the combined level of development of the systems and subsystems. $\mathbf{T_c}$ is the assessment index of each system and subsystem. $\mathbf{D_c}$ is the coupling coordination degree between systems, taking the value range of [0,1], in this study $\boldsymbol{\partial = \beta = 0.5}$.

## 3 Results

### 3.1 Characteristics of the Spatial and Temporal Evolution of the UI

From 1990 to 2020, the UI in Shandong Province showed characteristics of spatial and temporal distribution differences (Figure 1). Between 1990 and 2000, the high-value areas of the UI in Jinan and Zibo cities increased. By 2010, the UI across Shandong Province as a whole showed a clear upward trend. Besides the concentrated high-value areas in Jinan and Zibo, more clusters of high UIs emerged in Weifang, Yantai, Qingdao, and Linyi. From 2010 to 2020, the areas with high UIs in Shandong Province further increased, indicating that urbanization in Shandong has progressed very rapidly over the span of 10 years. This indicates that effective measures have been implemented during urbanization to maintain or enhance the provision of ESV, such as greening projects and the establishment of ecological reserves. As the economy grows, urban residents and policymakers have become increasingly concerned about environmental quality.

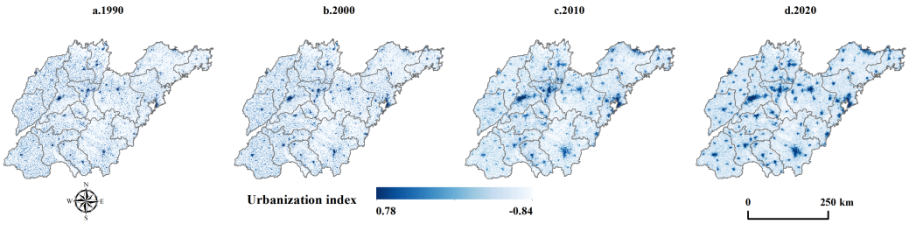


**Figure 1.** Characteristics of spatial and temporal distribution of UI in Shandong Province

### 3.2 Spatial and Temporal Distribution of ESV

In Shandong Province, the ESV for most regions falls between $-0.0010 billion to $0.0017 billion and $0.0017 billion to $0.0038 billion (Figure 2). Between 1990 and 2000, ESVs in northern Binzhou, southwestern Jining and Heze increased significantly. By 2010, the ESVs across Shandong were relatively stable, with minor changes compared to 2000. From 2010 to 2020, there was a noticeable growth in ESV in Dezhou, Binzhou, and Dongying in the northwest. Areas with ESVs ranging from $0.0207 billion to $0.0306 billion became more concentrated in Dezhou and Dongying in the north, Weihai in the east, and Heze in the south.

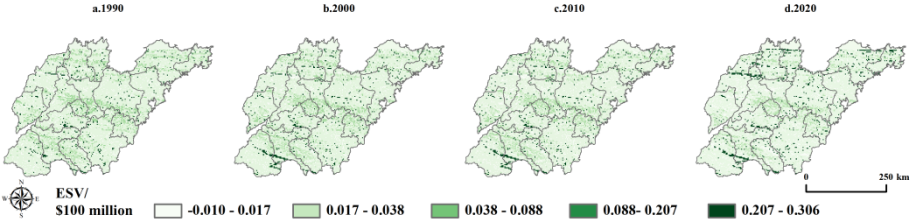


**Figure 2.** Characteristics of spatial and temporal evolution of ESV in Shandong Province

### 3.3 Characteristics of the Coupling Between the UI and ESV

Overall, in Shandong Province, the UI and the ESV exhibit low coupling (0.3-0.4) across most regions (Figure 3). From 1990 to 2000, cities in western Shandong, such as Jinan and Binzhou, experienced an upward evolution in their coupling and coordination levels. By 2010, more areas of high coupling (0.5-1.0) emerged across various cities in Shandong Province, indicating a remarkable improvement in the coupling between urbanization and ESV. Between 2010 and 2020, there was a notable progression from areas of low coupling (0.3-0.4) to areas of moderate (0.4-0.5) and high coupling (0.5-1.0), demonstrating noteworthy achievements of Shandong Province in coordinating urban development with ecosystem health. The improved coupling and coordination between urbanization and ESV results from multiple factors, including a balance between economic development and environmental protection, advancements in technology and environmental management, and increased public participation and environmental education. These factors interact to collectively enhance the protection and promotion of ESV in Shandong Province during its urbanization process.

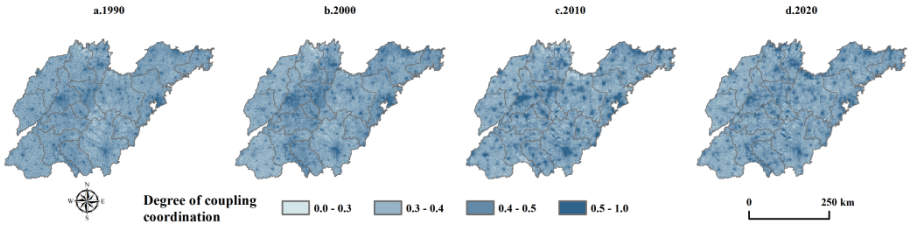


**Figure 3.** Coupling characteristics of UI and ESV in Shandong Province

## 4 Conclusion

Research from 1990 to 2020 in Shandong Province showed significant changes and developments in the spatiotemporal distribution characteristics of the UI and ESV. High-value areas of the UI were primarily concentrated in cities like Jinan, Zibo, Weifang, and Linyi. Over time, these high-value areas gradually expanded, especially since 2010, the process of urbanization has advanced rapidly, covering more cities. Meanwhile, the distribution of ESV also showed certain changes, with an increasing trend particularly in the northwestern cities like Dezhou, Binzhou, Dongying, as well as in Laiwu, Jining, and Weihai. The study of the coupling and coordination between the UI and ESV found that, in most areas, the coupling is low, but cities like Jinan and Zibo exhibit better coordination. This indicates that Shandong Province has achieved many achievements in urban development and ecosystem maintenance, especially in certain cities through effective policies and management, realizing better coordination between urbanization and ESV. Future research could delve deeper into the specific mechanisms of impact between urbanization and ESV, particularly how these mechanisms operate in different types of cities and ecosystems. This includes a systematic analysis of how policies, economic, and social factors influence this relationship.

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