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# Rural Effectiveness Evaluation: A New Way of Assessing Village Development Status

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**Abstract:** China is currently at a crucial stage of rural revival and transformation growth. Accurate measurement of rural development status is able to provide decision-making services for rural revitalization plan implementation. To address this issue, combining with effectiveness concepts and on the basis of the widely recognized "production–living–ecology" perspective of rural development in the world, this study proposes an innovative technical evaluating system for rural effectiveness. We constructed a rural effectiveness evaluation index system and measurement model, as well as a four-quadrant approach to identify the effectiveness of villages, selecting Xintai county, a typical resource-depleted city, for empirical analysis to verify the evaluation technical system. The results show that (1) 220 villages had comprehensive effectiveness, accounting for 27.8% of the total; the amount of effectiveness for villages in terms of the production, living, and ecological dimensions were 204, 229 and 195, respectively, and they clearly displayed heterogeneity in terms of spatial distribution. (2) The following are village effectiveness dominant types: the function dominates the comprehensive effectiveness. For each dimension, there is a functionally dominant type. (3) Bivariate Moran's I analysis revealed the relationships' internal effectiveness. In the same dimension, there was a conflict between efficiency and function. In each dimension, trade-offs were found between the production function, ecological function, living efficiency, as well as production efficiency, ecological function, and efficiency. Synergies were found among the production function and ecological efficiency. Living efficiency had synergies with production efficiency and ecological efficiency. This research enriched the theoretical approach of assessing rural development status and can help guide the rational conversion of village elements to achieve village transformation and sustainability development, as well as providing technical assistance for the implementation of the rural revitalization strategy.

**Keywords:** village development status; effectiveness evaluation; super-efficient DEA model; four-quadrant method; rural revitalization; rural sustainability; Xintai county



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## 1. Introduction

A rural region, as the most fundamental regional system, is a composite individual that performs production, living activities, and ecological environment [1,2]. Rural development in China is under enormous strain as a result of rapid urbanization and industrialization, with the rural population migrating to cities for better livelihoods and quality of life, resulting in issues such as industrial and economic decline, lagging infrastructure development, abandonment of agricultural land, and ecological security in rural areas due to population loss [3–5]. In this case, the Chinese government has suggested a rural revitalization policy since 2017 in order to save villages that are rapidly deteriorating. Village revitalization, on the other hand, should not merely comprise putting resources into rural regions; it should be done in accordance with local conditions, or otherwise it will result in input redundancy and bad output [6–8]. Consequently, we can only lead the execution of rural revitalization methods and the input of resource components if we properly and appropriately identify village problems and measure the status of rural development.

Current studies on assessing the status of village development have primarily focused on village functions or efficiency, with the goal of determining the status and background circumstances of the flow of the village's many aspects [9–11]. The village functions are a visible depiction of the village's elements and reflect the village's underlying conditions for development [12]. The elements of the village have been enriched as the village's economic and social development has progressed, and study on the village's function has gradually shifted from its early agricultural production function to its multi-functionality [13]. Due to the complexity of village systems, scholars have frequently summarized the numerous functional parts of villages from an economic, social, and ecological standpoint, as well as from a production, living, and ecological standpoint, to highly generalize the function types and simplify their complexity. The land use structure, the design of the village's functional typology, the prominent types of village functions, and the relationships between the functions are all key to the research. As it represents the status of the flow of elements and resource inputs and outputs, efficiency is an implicit reflection of a village's status. There has been much research on the efficiency of village development, such as ecological efficiency, agricultural production efficiency, and public service infrastructure allocation efficiency; however, few studies look at rural habitat as a whole [11,14,15]. There are fewer studies on micro scales in rural areas than there are on macro town and city scales [16]. Due to a lack of micro-scale research, there is a disconnect between the implementation level of rural revitalization methods and research findings, such as defining village features and development orientations, which are difficult to apply on a village-by-village basis [6].

We conducted an in-depth analysis of current research on the state of village development and discovered that measuring the status of village development in terms of village development efficiency and village function alone for a complex system with various variables is inaccurate. The ultimate purpose of the system can only be achieved if it has the right direction and goals in conjunction with efficiency [17]. A system or organization unable to be one-sided in its pursuit of efficiency. Efficiency does not mean that the purpose will be achieved; the ultimate purpose of the system can only be achieved if it has the right direction and goals in conjunction with efficiency—this is what effectiveness means [18,19]. Effectiveness is a recurring subject in the study of organizational management, as opposed to the partial and non-systematic character of system effectiveness and efficiency research, where effectiveness evaluation provides a more comprehensive assessment of the system's status [19,20]. However, academics now lack a scientific and quantitative indicator system for measuring village effectiveness, and the notion of effectiveness evaluation is still in the early stages of development.

We have extended previous research in the context of rural revitalization by gaining a better understanding of theories related to the multifunction and development efficiency of rural areas, and we have proposed an important topic based on a thorough examination of rural development issues: how to assess the development status of villages in a scientific and objective manner. On the basis of academic research findings on the notion of effectiveness, we developed the concept of village effectiveness evaluation. The specific purpose of this study comprised the following objectives: (1) constructing an evaluation indicator system and method for village effectiveness; (2) obtaining the results of regional effectiveness evaluations and their spatial distribution characteristics; (3) investigating the relationship between indicators of each effectiveness evaluation dimensions. By examining the relationship between village function and development efficiency, we can learn more about whether villages have the capacity for sustainable development, which is an obvious guideline for villages revitalization and sustainable development. This allows villages to make land use, policy formulation, and financial investment decisions based on their development status and eventually achieve urban–rural integration in terms of production, living, and ecology [21].

## 2. Theoretical Framework

The interaction of various factors, such as the restructuring of the rural economy, the rise of the rural service sector, the movement of people between urban and rural areas, and the continuous enrichment of various social development factors, have contributed to the transformation and spatial reconfiguration of rural development, having reshaped the socio-economic structure of rural areas with industrialization and urbanization [22–24]. The efficiency of rural development is primarily an assessment of the village's many aspects and the method through which each element flows [25]. The evaluation approach for village effectiveness should be from explicit and implicit two perspectives (Figure 1). The village function, as a key feature of rural space, is an explicit depiction of the village's current degree of development. The village's function system is largely reliant on both rural population and land resources, with land resources contributing to attracting population gather and people's demand affecting land resource utilization [2,26,27]. The various combinations of natural, economic, social, cultural, and ecological elements also define the differences in village functions, which are better defined by spatial differences in the countryside, the diversity of regional development goals, the diversity of social needs, and the diversity of land uses, all showing significant geographical differences and temporal evolution variability. External to the village, the implicit system consists of the national and regional environment, urban–rural relations, and so on, and is dominated by all levels of government, policy environment, investment institutions, talent and technology, and markets, with efficiency evaluation describing the state of the flow of factors [28,29]. The capacity to achieve the goals of management decisions in the process of the flow of various elements in the village is measured by village development efficiency, which is an implicit representation of the status of village development [30]. It is an implicit representation of the state of village development, as it measures the level of inputs (natural resources, human resources, social capital) and outputs (economic outputs, human facilities, ecological environment) of villages to assess the level of positive effects and benefits obtained from village resource inputs, reflecting the size and strength of villages and towns' ability to achieve effects and benefits [31]. Village function and village development efficiency are inextricably intertwined, with village function referring to the amount and kind of resource as well as the use of village elements. Village efficiency represents the size and strength of an organization's capacity to accomplish realistic and possible impacts and benefits and is a key driver of village function and a driving force behind long-term village sustainable development. Village function and efficiency are a vital basis for measuring a village's effectiveness from both explicit and implicit perspectives, and the two cannot be separated. The duplication of resource inputs can only be avoided, and optimal development can achieved by matching the objectives of village development with the same efficiency [11,15].

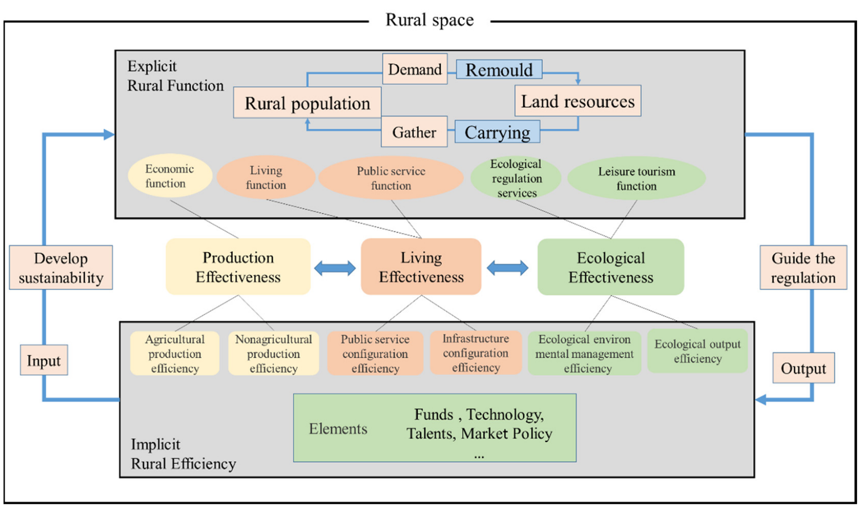


**Figure 1.** Rural effectiveness system theoretical framework.

## 3. Materials and Methods

### *3.1. Study Area*

Xintai county (35°37′–36°07′ N, 117°16′–118°02′ E) is a county-level city in eastern China that is under the authority of Taian prefecture-level city, Shandong Province (Figure 2). Xintai is located in the hilly region of central Shandong has a diverse geography, with high hills to the north, east, and south; low terrain in the center; and a river plain to the west. With a total land area of 1946 square kilometers with 18 towns and 818 villages, Xintai county is 68 km long from east to west and 53 km long from north to south. It has a continental monsoonal semi-humid climate with four distinct seasons and is located in the northern temperate zone. There are 28 types of minerals found and 22 types of proven minerals in the region, as well as 134 significant mineral production regions and 83 proven mineral production areas. Mining has been around for about 60 years. It has been leading overall economic and social growth with transformation and transforming its economic development mode since 2011, when it was designated as a resource-depleted city. In addition to the original center city, Xintai county has developed two urban sub-administrative centers, comprising Loude Town, Yucun Town, and Xizhangzhuang Town, Yangliu Town, and Guodu Town.

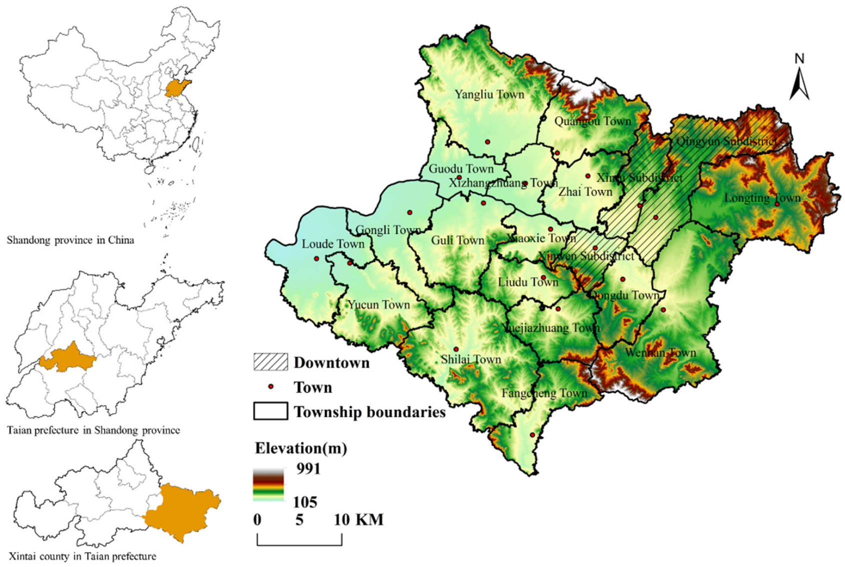


**Figure 2.** Location of study area.

### *3.2. Data Sources*

Due to the relative lack of statistical data at the village level in China, the quantitative data in this study are derived from field research data, which includes village demographic background, land resources, industrial development, residential base status, infrastructure configuration, and ecological environment. In May 2021, members of the research team collected questionnaire data from 818 administrative villages in Xintai, with village branch secretaries or village clerks filling in the research data. The Shandong Urban and Rural Planning and Design Institute also provided village boundary vector data, DEM data, and remote sensing image data.

### *3.3. Construction of Function Measurement Indicator System*

On the basis of the theoretical underpinning laid out in this article, village effectiveness evaluation is divided into two components: village function and efficiency evaluation. A village effectiveness evaluation index system was constructed from the three dimensions of "production, living, and ecology", aiming for universality and applicability of the effectiveness evaluation system; this form is still a widely accepted classification form for its direct interaction with rural development [32]. The analysis and deconstruction of the development tasks and core elements of each type of village was based on the discussion results of six experts in the field (Table 1).

**Table 1.** Village effectiveness evaluation indicator system.

| Target Layer | Indicator Attributes | Indicator | Indicator Explanation | Type of Indicator |
|---|---|---|---|---|
| Production effectiveness | Function | Agricultural land area per capita | Total area of land used for agricultural production/total population of the village | + |
| | | Number of non-agricultural industries | The number of all type enterprises and individual businesses | + |
| | | Percentage of the village labor force | Number of people working in the village/total population of the village | + |
| | | Disposable income per capita | Average level of the sum money spent and saved by villagers | + |
| | Efficiency | Agricultural production land area | Area of agricultural land in a village | Input |
| | | Scale of land for non-agricultural industries | Total area of non-agricultural industrial land | |
| | | Total agricultural production output value | Total agricultural production output value in a village | Output |
| | | Total nonagricultural production output value | Total nonagricultural production output value in a village | |
| Living effectiveness | Function | Population density | Resident population of the village/total area of the village | + |
| | | Average household dwelling size | Total area of homestead/total number of households in the village | + |
| | | Residential quality | Proportion of masonry, brick and steel bungalows, self-built buildings, collective construction buildings, and commercial buildings | + |
| | | Transport accessibility | Total road mileage in the village area | + |
| | | Degree of locational advantage | Distance from village center to town center | − |
| | Efficiency | Financial expenditure funds for the amenities | Financial expenditure funds for the amenities of the village | Input |
| | | Living convenience | Average proportion of households with piped water, natural gas to households, central heating, and hardened roads | Output |
| | | Infrastructure, public service enrichment | Number of types of facilities such as fitness facilities, parks, places of worship, and public services provided by the village | |
| Ecological effectiveness | Function | Natural or geological hazards | Number of geological hazards in 5 years | − |
| | | Percentage of ecological land | Total area of ecological land in the village, including woodland, grassland, and water/total area of the village | + |
| | | Ecologically harmful industries | Number of industries in the village that are harmful to the ecological and residential environment | − |
| | Efficiency | Village environmental management costs | Village investment funds for ecological and village environmental management | Input |
| | | Proportion of flush toilets | Number of flushing toilets owned by households in the village/total number of households | Output |
| | | Village greenery coverage | Ratio of village green area/total residential area | |

#### 3.3.1. Production Effectiveness

The effectiveness of rural production is evaluated from both an agricultural and non-agricultural perspective. The background circumstances of the village's production factors are assessed by the village function aspect [24]. Agricultural production is the most fundamental kind of production in rural regions, and it plays a critical role in ensuring food security and employment. Furthermore, when the countryside's socio-economic development progresses and all elements are enriched, non-agricultural output is able to meet the demands of the population and is more indicative of a village's growth potential. To reflect the nonagricultural function of the village, we chose the number of nonagricultural production industries and the value of nonagricultural production output. They all provide stable work and a source of income for the village's residents [9]. As a result, the agricultural land area per capita, the number of non-agricultural industries, labor force, and disposable income per capita were chosen to assess the village's agricultural production function.

The efficiency aspect is mainly measured by the input of human and material resources and the output of the value [29]. For agricultural production, it mainly refers to the area of economically productive land (including arable land, garden land, economic forestry, pasture land, and agricultural land for facilities). The nonagricultural sector is expressed in terms of the area of nonagricultural production land. Production output indicators are expressed in terms of agricultural and nonagricultural output value.

#### 3.3.2. Living Effectiveness

The living effectiveness is primarily concerned with the village's facilities and the residential environment. Population density is used as a measure of the state of public services and infrastructure in villages, and the higher the population density, the higher the degree of configuration [16]. The residential environment and ease of living are represented by the residential environment, which includes the quality of the homes and the area of dwellings per capita, while the ease of living is represented by road coverage and the village's location [25]. The grassroots village organizations represent the majority of input in terms of village efficiency, which is indicated in financial expenditure funds for village amenities. The comfort of living, as well as the availability of public services and infrastructure, define the output side [21]. The average proportion of villages with running water to households, natural gas to households, central heating, and hardened roads reflects the convenience of life, whereas the number of infrastructure and types of public services provided by villages, such as fitness facilities, parks and green spaces, and places of worship, representing an abundance of public services and infrastructure.

#### 3.3.3. Ecological Effectiveness

The village's ecological effectiveness takes into consideration the village's natural ecological condition as well as the village environment. The ecological function is primarily expressed by the ecological land and the stability of the local ecological environment, as well as specific natural or geological hazards that occur in the village, the area of ecological land, and the number of environmentally hazardous industries in the village [33,34]. The ecological efficiency metric measures how well humans manage and protect the environment. The cost of village habitat management is used to assess the input dimension, while the proportion of running toilets and the proportion of village green space are used to estimate the amount of habitat output [14].

### *3.4. Effectiveness Measurement Methodology*

#### 3.4.1. Standardization of Data for Function Evaluation Indicators

Different relevant indicators are required for the assessment process, each of which may differ in type, size, order of magnitude, and other features, making it difficult to calculate them directly to analyze the characteristics and patterns of the object of research. To normalize data such that it falls within a tiny, defined interval, we employed data normalization [35]. It is frequently used in the comparison and assessment of specific indicators to remove unit limitations from data and transform it into dimensionless, pure values that allow indications of different units or magnitudes to be compared and weighted. The formula for data standardization is shown below:

$$\text{Positive indicators}: \ y'_i = \frac{y_i - Miny_i}{Maxy_i - Miny_i} \tag{1}$$

$$\text{Negative indicators}: \ y'_i = \frac{Maxy_i - y_i}{Maxy_i - Miny_i} \tag{2}$$

Among them, $y'_i$ is the normalized value of the indicator and $y'_i$ is the original value of the indicator.

#### 3.4.2. Functional Measurement Model

The calculation of factor weights is the first step in evaluating village functions. The techniques of establishing weights are generally the subjective assignment method and the objective assignment method. Indicator weights may be used to quantify the relative relevance of evaluation indicators and improve the reliability and realism of the evaluation outcomes [13]. This study used the entropy weight method model to assign values to each dimension of the village function assessment indicators, and the calculation formula is shown below.

$$w_i = \frac{1 - e_i}{\sum_{i=1}^{n} 1 - e_i} \tag{3}$$

$$e_i = -k \cdot \sum_{i=1}^{n} (p_{ij} \ln p_{ij}) \tag{4}$$

$$k = \frac{1}{\ln(m)} \tag{5}$$

$$p_{ij} = \frac{y'_i}{\sum_{i=1}^{n} y'_i} \tag{6}$$

where $w_i$ is the weight of the ith indicator; $e_i$ is the entropy value of the $i$th indicator; $p_{ij}$ is the weight of the $j$ indicator in the $i$ village; $k$ is the scale factor; $m$ is the number of villages in the study area; and $n$ is the number of indicators.

$$F(P) = \sum_{i=1}^{n} w(p)_i \cdot y(p)_i \tag{7}$$

$$F(L) = \sum_{i=1}^{n} w(l)_i \cdot y(l)_i \tag{8}$$

$$F(E) = \sum_{i=1}^{n} w(e)_i \cdot y(e)_i \tag{9}$$

$$F(C) = F(P) + F(L) + F(E) \tag{10}$$

where $w_i$ and $y_i$ represent the weights and the normalized values of the indicators, respectively. $F(P)$, $F(L)$, $F(E)$, and $F(C)$ represent the Village Production Function Index, the Village Living Function Index, the Village Ecological Function Index, and the Village Comprehensive Function Index, respectively. The values range from 0 to 1, and the higher the value, the more functional the village is, and vice versa.

#### 3.4.3. Efficiency Measurement Methods

The super-efficient DEA model is based on the DEA model and is intended to address the problem of comparing the efficiency values of effective decision units, which prevents further comparison of differences when evaluating the efficiency of decision units with multiple units at the production frontier [17,35,36]. Below are the main formulas for the super-efficient DEA model. The calculation procedure is based on the Python programming language and the PyDEA calculations package (package source: http://araith.github.io/pydea/ accessed on 10 June 2021).

$$E(\theta),\ \ s.t. \begin{cases} min\theta \\ \sum\limits_{i=1}^{n}\sum\limits_{j\neq 1} X_j\lambda_j + S^- = \theta X_0 \\ \sum\limits_{i=1}^{n}\sum\limits_{j\neq 1} Y_j\lambda_j - S^+ = Y_0 \\ \lambda \geq 0,\ j = 1,2,\ldots,k-1,k,\ldots,n \\ S^- \geq 0, S^+ \geq 0 \end{cases} \tag{11}$$

In the formula, $E(\theta)$ denotes the efficiency value of the evaluation unit; X and Y denote the input and output variables, respectively; $\lambda$ denotes the proportion of combinations in the effective decision unit, which is used to discern the returns to scale of the decision unit: $\sum\lambda < 1$, $\sum\lambda = 1$, and $\sum\lambda > 1$ that denote increasing scale efficiency, constant scale efficiency, and decreasing scale efficiency, respectively. $S^-$ and $S^+$ denote the slack and residual variables, respectively. When $\theta < 1$, it means that the decision unit does not reach the optimal efficiency; when $\theta > 1$, it means that the decision unit reaches the optimal efficiency.

$$E(\theta)_C = E(\theta)_P + E(\theta)_L + E(\theta)_E \tag{12}$$

In the formula, $E(\theta)_C$ is the village comprehensive efficiency index; $E(\theta)_P$, $E(\theta)_L$, and $E(\theta)_E$ represent the Village Production Efficiency Index, the Living Efficiency Index, and the Ecological Efficiency Index. The higher the index, the more efficiency the village is in terms of development and vice versa.

### 3.4.4. Village Effectiveness Matching Model

When this dimension of effectiveness is combined with the concepts related to village effectiveness discussed above, a village can be defined as having this dimension of effectiveness when its function and efficiency are congruent in the evaluation dimension and in the evaluation results, i.e., when both function and efficiency values are high in the same dimension. To match village effectiveness, we employed a four-quadrant analytical approach. The "village function" index is on the horizontal axis, while the normalized "village efficiency" index is on the vertical axis. The cut-off points between the high and low indices, i.e., the intersection of the four quadrants, is the midpoint value of the "function" and "efficiency" scores.

The planar coordinate system is divided into four quadrants, as illustrated in Figure 3, namely, the "high-function high-efficiency zone (HF-HE)", "low-function high-efficiency zone (LF-HE)", "low-function low-efficiency zone (LF-LE)", and "high function low efficiency (HF-LE)". According to this article, villages that reach the first quadrant of the HF-HE zone are defined as having effectiveness units. Using this procedure, the evaluation units are further filtered.

### 3.4.5. Classification Model for Effectiveness Dominant Types

In order to reveal the action mechanisms of effectiveness, we should differentiate the types of effectiveness dominance using the formula shown below:

$$T_{ij} = F(ij) - E(\theta)_{ij} \tag{13}$$

In the formula, $T_{ij}$ is the dominant type of effectiveness for the $j$ dimension in $i$ village; $F(ij)$ is the function index for the $j$ dimension in $i$ village; and $E(\theta)_{ij}$ is the dominant type of effectiveness for the $j$ dimension in $i$ village. If $T_{ij} > 0$, the village is function dominant type; if $T_{ij} < 0$, the village is efficiency dominant type.

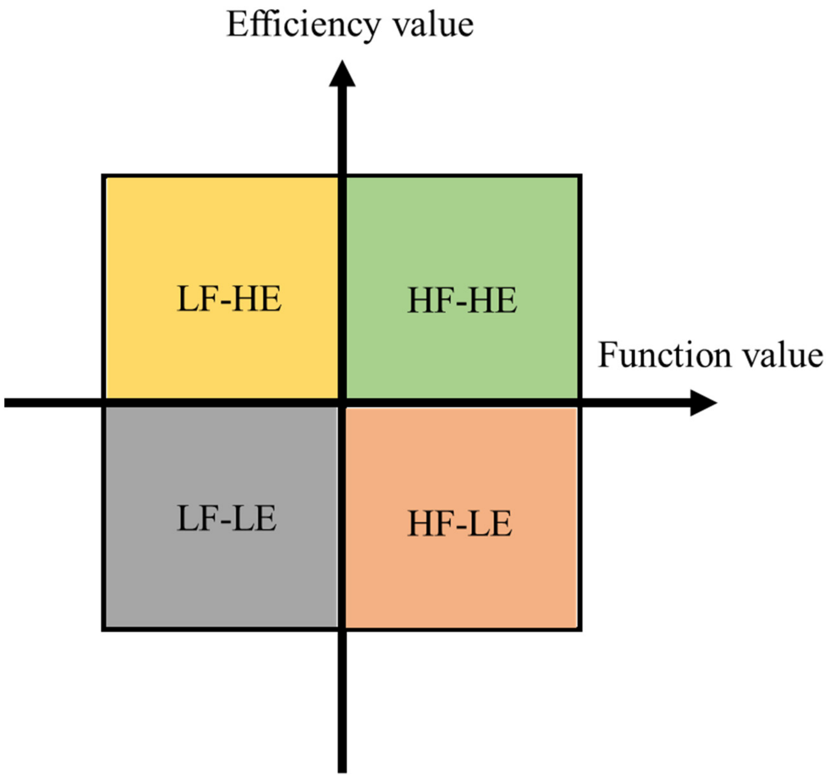


**Figure 3.** A four-quadrant analysis model for high-value function.

#### 3.4.6. Quantitative Evaluation Model of Effectiveness Intensity

The village can be described as more effective if the "function and efficiency" indexes are greater and the disparity between them is less. This theory underpins a quantitative examination of the intensity of village effectiveness, which is quantified using two indicators: the high and low function and efficiency values, as well as the difference. We introduce the notion of linked coordination, which describes how two or more systems affect each other as a result of numerous interactions between them and the outside environment [37]. The coupling coordination model calculates the coupling index by measuring the coupling between systems and the coupling index, where the coupling index represents the strength of the interactions between systems [38]. The coupling index calculates model as follows:

$$D = \sqrt{C \times T} \tag{14}$$

$$C = \left\{ \frac{\mathrm{S1} \cdot \mathrm{S2}}{\left[\frac{(\mathrm{S1} + \mathrm{S2})}{2}\right]^2} \right\} \tag{15}$$

$$T = \alpha \mathrm{S1} + \beta \mathrm{S2} \tag{16}$$

where $D$ is the degree of coupling and coordination of village function and efficiency in each dimension; $T$ is the score of village function and efficiency in each dimension; $\alpha$ and $\beta$ are the coefficients to be determined for production, living, and ecological functions in the context of the coordination of "production living and ecological" efficiency, with reference to relevant expert opinions and literature, $\alpha = 1/2$, $\beta = 1/2$; and $C$ is the degree of coupling. When $C$ is large, it means that the two systems are optimally coupled; when $C$ is small, it means that the elements within the system are not related to each other, and the system is developing towards disorder. However, if both system indices are low and the difference is small, the coupling is also judged to be high, so the village efficiency value is further analyzed by the smallest of the two values.

#### 3.4.7. Evaluation Model of Effectiveness Internal Relationship Analysis Model

To understand the complicated relationship of trade-offs and synergies between each village effectiveness dimension, we used Bivariate Moran's $I$ to analyze the mechanisms [13,39,40]. The specific formula was calculated as follows:

$$I_i = \left[ \frac{Z_i}{\left( \frac{\sum_i z_i^2}{n} \right)} \right] \tag{17}$$

$$Z_i = x_i - \overline{x} \tag{18}$$

where $x_i$ and $y_i$ are the different index values among production, living, and ecology in village $i$ and $j$, respectively. $n$ is the number of villages, and $w_{ij}$ is the spatial adjacent weight matrix between each village $i$ and $j$. In this study, all these operations were implemented by Geoda 1.14 software.

## 4. Results

### *4.1. Village Function and Efficiency Evaluation Results*

#### 4.1.1. Village Function Evaluation Results

According to the aforementioned data processing method, the weight of each function index is listed in Table 2.

**Table 2.** Results of village function evaluation indicator weights.

| Target Layer | Indicator | Indicator Explanation | Type of Indicator | Weight |
|---|---|---|---|---|
| Production function (0.3706) | Agricultural land area per capita | Total area of land used for agricultural production/total population of the village | + | 0.0912 |
| | Number of non-agricultural industries | The number of all type enterprises and individual businesses | + | 0.0901 |
| | Percentage of the village labor force | Number of people working in the village/total population of the village | + | 0.1079 |
| | Disposable income per capita | Average level of the sum money spent and saved by villagers | + | 0.0814 |
| Living function (0.3695) | Population density | Resident population of the village/total area of the village | + | 0.0735 |
| | Average household dwelling size | Total area of homestead/total number of households in the village | + | 0.0786 |
| | Residential quality | Proportion of masonry, brick and steel bungalows, self-built buildings, collective construction buildings, and commercial buildings | + | 0.0663 |
| | Transport accessibility | Total road mileage in the village area | + | 0.0781 |
| | Degree of locational advantage | Distance from village center to town center | − | 0.0730 |
| Ecological function (0.2599) | Natural or geological hazards | Number of geological hazards in 5 years | − | 0.0582 |
| | Percentage of ecological land | Total area of ecological land in the village, including woodland, grassland, and water etc./total area of the village | + | 0.1308 |
| | Ecologically harmful industries | Number of industries in the village that are harmful to the ecological and residential environment | − | 0.0709 |

The function values of the 791 villages in the region were computed using the function assessment technique and visualized by ArcGIS 10.2 software. The mean value of the production function was found to be 0.4576, the mean value of the living function was 0.5091, the mean value of the ecological function was 0.2301, and the mean value of the comprehensive function was 0.3438.

As seen in Figure 4, in each dimension of comparative advantage, the geographic visualization of the village function values revealed a distinct spatial concentration of villages. The zone of comparative advantage in production function is concentrated in the central city of Xintai and the urban sub-administrative center, Loude and Yucun town; areas of comparative advantage for living functions are concentrated in west of the county; ecological function high-value areas are concentrated in the mountainous areas in the north and the plains in the west; and the comprehensive functional advantage area are distributed in the in the central city of Xintai and the two urban sub-administrative centers.

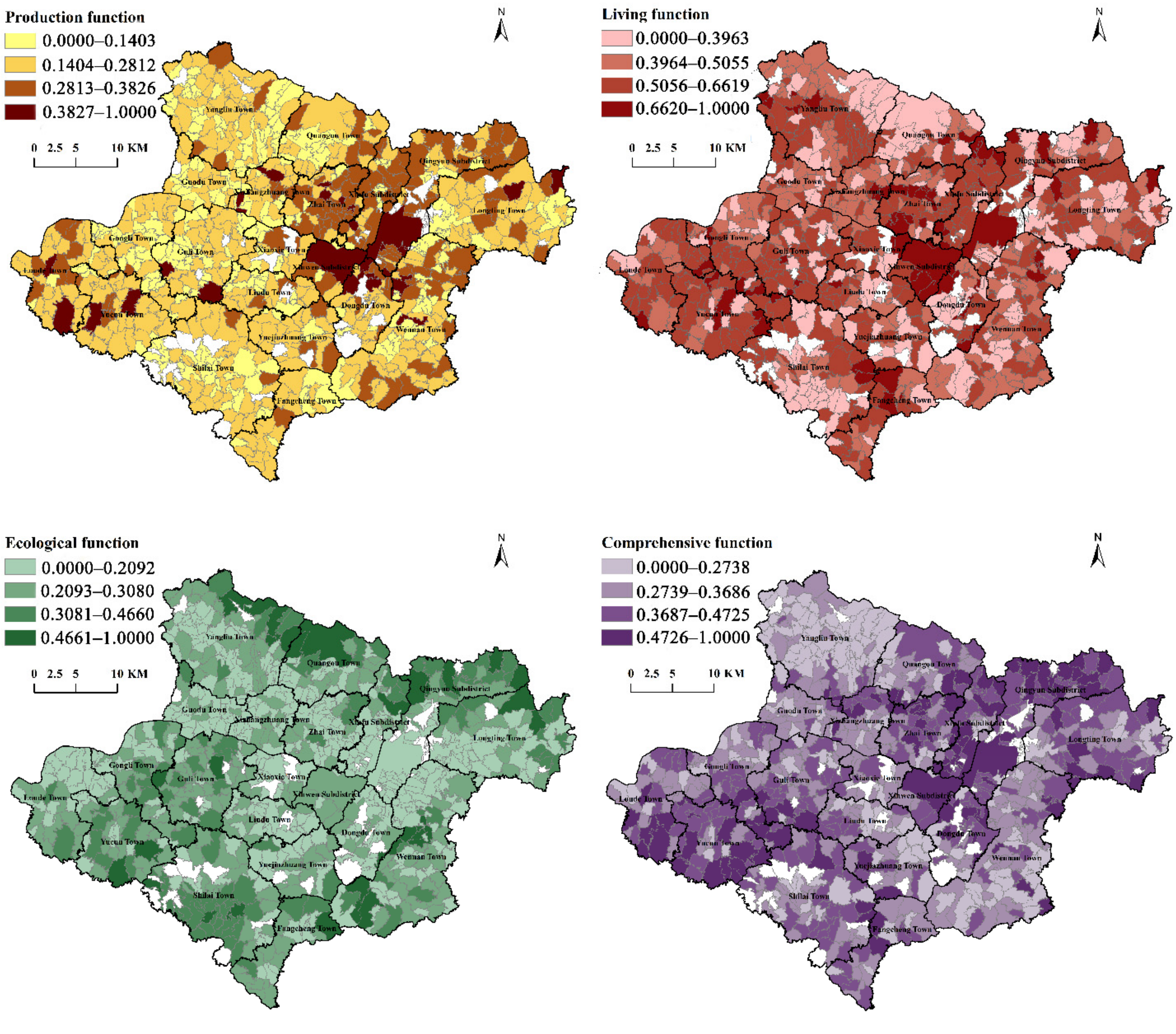


**Figure 4.** Spatial pattern of the rural function in Xintai.

#### 4.1.2. Village Efficiency Evaluation Results

The above-mentioned village efficiency assessment technique based on the super-efficient DEA model was used to calculate and normalize the village efficiency results. The average production efficiency in Xintai was found to be 0.3005, whereas the average living efficiency was 0.2392, the average ecological efficiency was 0.2428, and the average total efficiency was 0.2525.

According to Figure 5, it can be observed from the results of the spatial visualization of village efficiency that village efficiency has a clearly concentrated distribution in space. The advantageous areas for production efficiency are concentrated in the central city of Xintai and the western sub-administrative center of the city; the advantageous areas for living efficiency are concentrated around the central city; the advantageous areas for ecological efficiency are concentrated in the northern mountainous area and the western Loude and Yucun Town; and the comprehensive efficiency is concentrated and distributed in the central city and the sub-administrative center, Loude Town.

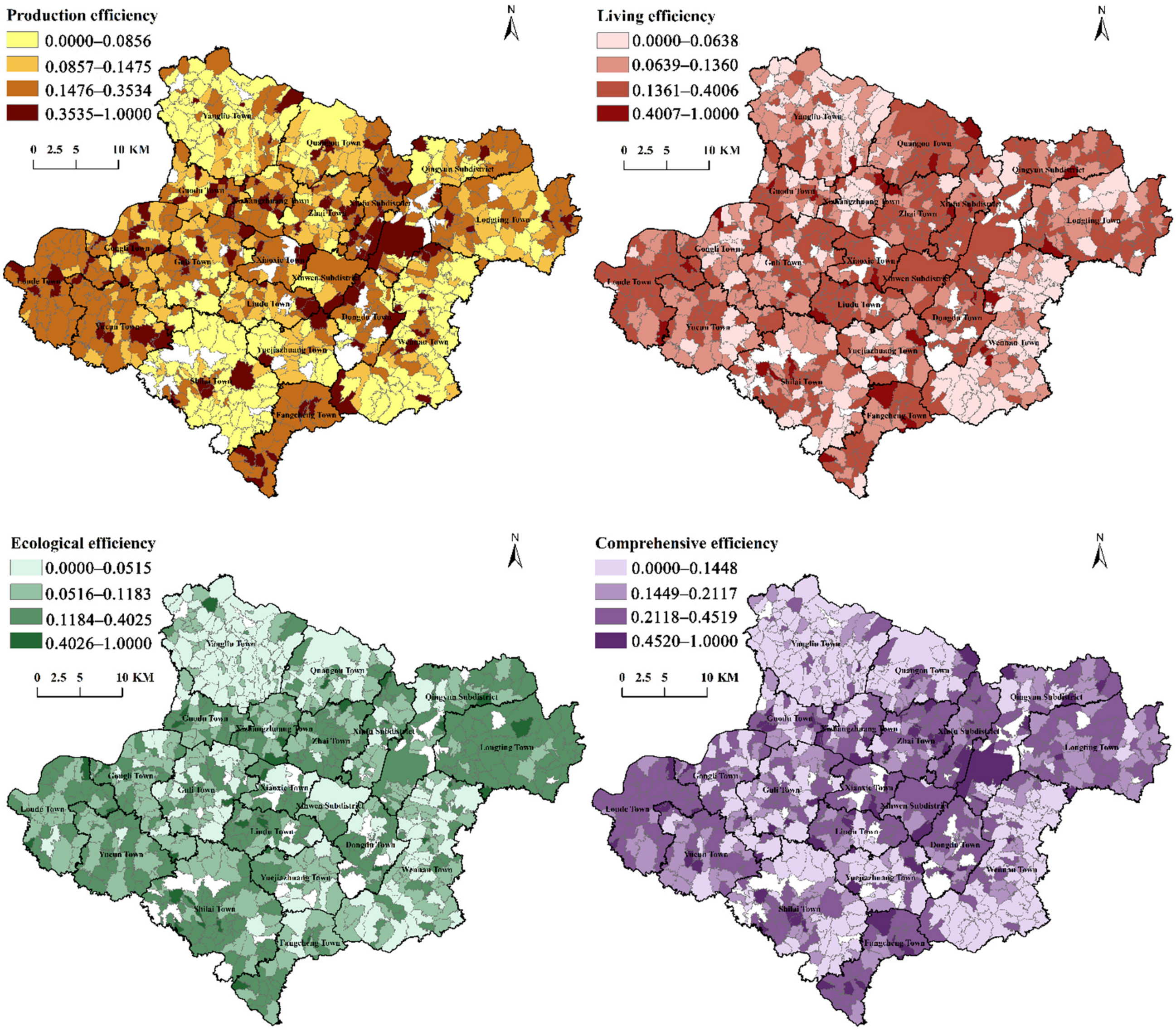


**Figure 5.** Spatial pattern of the rural efficiency in Xintai.

### *4.2. Effectiveness Matching Results*

A village will have effectiveness if its "function" and "efficiency" values are in the first quadrant, according to the four-quadrant effectiveness evaluation technique described above. Figure 6 depicts the results of the four-quadrant analysis. The effectiveness matching results were visualized in space by ArcGIS 10.2 software (Figure 7). As shown in Figure 6, there are 204 villages in the HF-HE region, being least numerous in the LF-LE region with only 190 villages in the production dimension; in the living dimension, the HF-HE region has the most villages (229), and others are more evenly distributed in the LF-HE, LF-LE, and HF-LE regions. In terms of ecological dimension, this is mainly concentrated in the LF-HE and the HF-LE zone. The comprehensive dimension is mainly concentrated in the HF-HE regions.

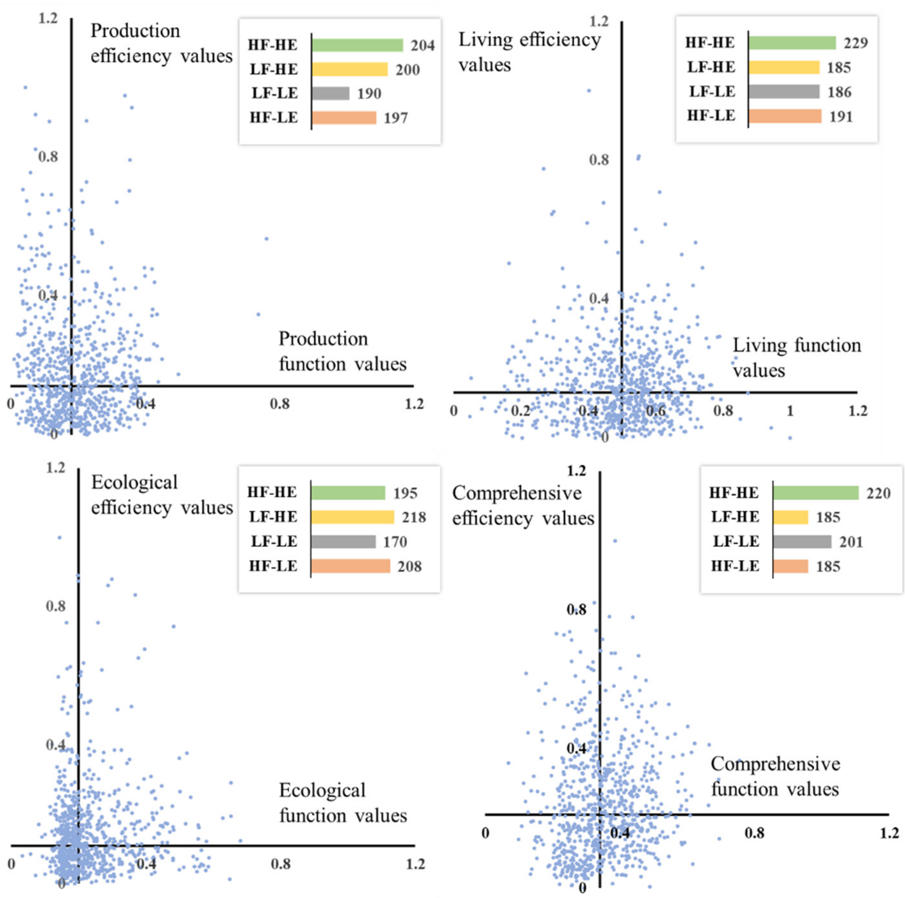


**Figure 6.** Four-quadrant evaluation results of villages.

The geographical distribution is seen in Figure 7. The majority of HF-HE is located in Xintai's main urban area, as well as the urban sub-administrative centers Yucun Town and Loude Town. All of them have a dense concentration of well-integrated industries with a high degree of industrial activity. The LF-HE villages are mostly found in the west of Xintai, Xizhangzhuang Town, and Guodu Town, reflecting strong transformation development. Because of the steep topography and poor natural background conditions, LF-LE villages are predominantly located in Wennan Town, Shilai Town, and Yangliu Town, with these places focusing mostly on primary industries, resulting in low industrial efficiency. The HF-LE villages are largely located in Quangou Town, Shilai Town, and the southern half of Wennan Town; the topography is slightly sloping and is a typical agricultural production site with favorable production conditions, but its efficiency is impeded by labor loss.

The villages of HF-HE are primarily concentrated in the central plain region and the central city of Xintai city in terms of living dimension. The plain region is an agricultural production and developed area, allowing for population gathering and facility allocation. As an old town, urban area has good conditions for infrastructure and public services. The LF-HE villages are mostly distributed around the urban area. Showing a trend towards outward urban expansion, LF-LE villages are predominantly found in Wennan Town, in which they primarily develop agroforestry with low industrial production and are located in high-altitude mountainous terrain, limiting resource allocation for living facilities. Yangliu Town is the location to the bulk of HF-LE villages. Despite the fact that the living quarters are nearly flawless, there remains an unbalance in the distribution of facilities.

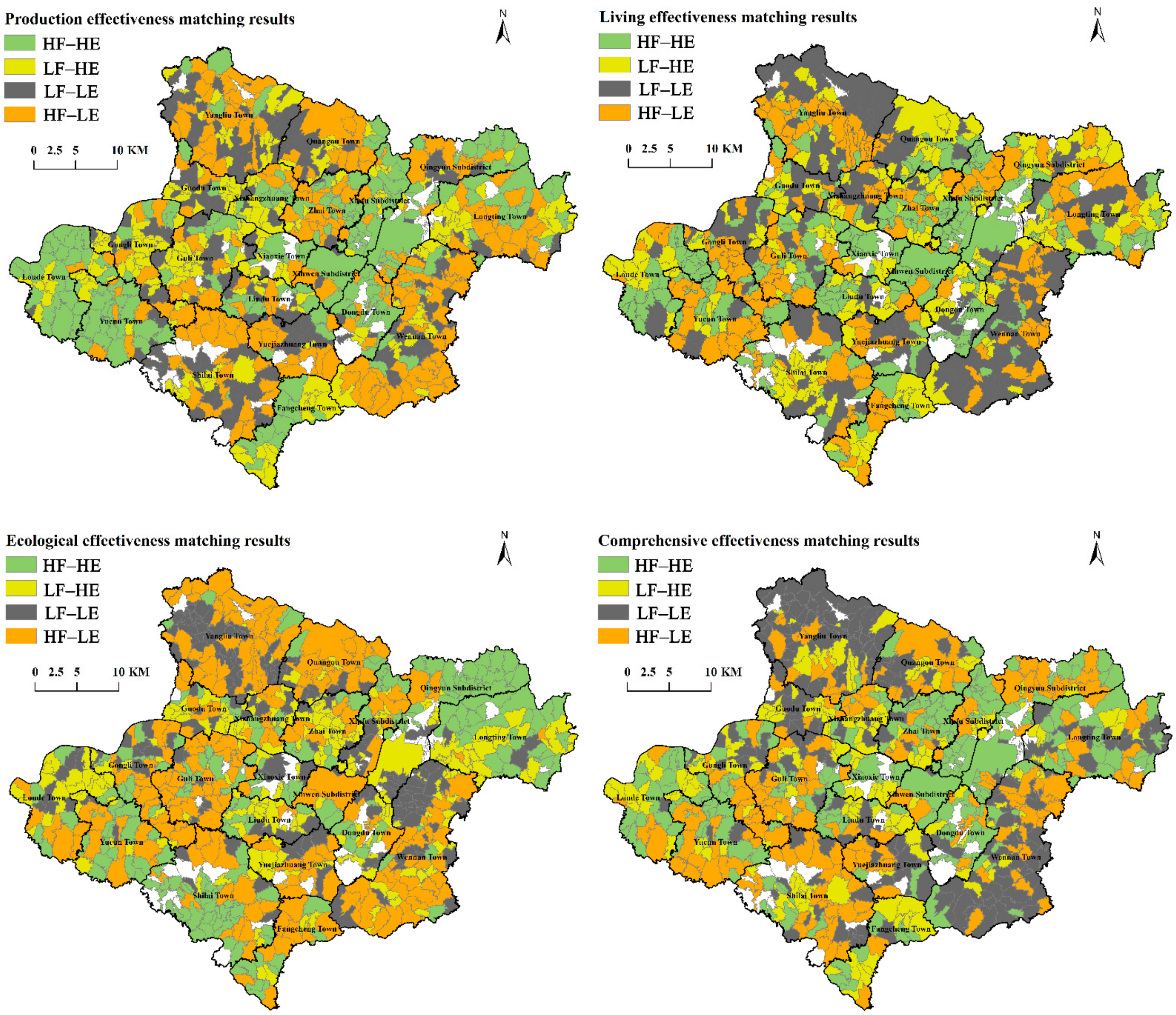


**Figure 7.** Spatial pattern of the rural effectiveness matching results in Xintai.

In the ecological dimension, HF-HE is mostly located in northern Longting Town and Qingyun district, which is Xintai's main ecological tourism district with great environmental conditions. The presence of LF-HE villages, evenly distributed in the urban area, demonstrates the region's ability to shift to an ecological society. The LF-LE-type villages are predominantly located in Yangliu Town's central part, which is the major grain-producing area, implying a conflict between agricultural productivity and ecological protection. The bulk of the steep and mountainous terrain corresponds to the HF-LE-type villages, which are generally found on the outskirts of Xintai's central city.

In the comprehensive dimension, the geographical distribution of HF-HE is mostly in Xintai' s central urban region, which has great potential for sustainable development, whereas LF-HE villages are dispersed and are the key transformation development sites with high development potential. Villages of the LF-LE type are found in Yangliu Town and Wennan Town, the countryside's hinterland and hilly areas, showing that village growth is constrained by topography and location. HF-LE-type villages are mostly found in the southwestern section of Xintai, Shilai Town, and the surrounding area, all of which are experiencing a decline in growth momentum and should focus on improving resource allocation efficiency.

### *4.3. Results of the Classification of Effectiveness Dominant Types*

Figure A1 shows the results of the spatial distribution of the dominant types of effectiveness. The high degree of industrial dynamism in the region is shown by the production dimension, which includes 119 function-dominant villages and 85 efficiency-dominant villages. The function-dominant types are primarily found in the city center and urban sub-administrative center, confirming the excellent industrial basis. The efficiency-dominant is primarily found outside of the city center, confirming the impact of urban expansion and industrial transformation. The living dimension has 226 function-dominant villages and 3 efficiency-dominant villages, indicating that the region's background living conditions are good due to the region's original industrial base promoting the configuration of living facilities, but that the efficiency of the allocation of living facilities is generally low, indicating that the regional living environment is stable but resource allocation is unbalanced. There are 148 function-dominant villages and 47 efficiency-dominant villages in the ecological dimension. Function-dominant villages are mostly located in the northeast mountainous regions, where the ecological environment is in excellent nick status; moreover, efficiency-dominant villages are distributed cross the west, showing that the region has expanded its efforts to manage the ecological environment. A total of 176 function-dominant and 44 efficiency-dominant villages are clustered in the comprehensive dimension, being mainly concentrated in the central urban and surrounding areas.

### *4.4. Results of Effectiveness Intensity Measurements*

A linear regression analysis was carried out to verify that the degree of coupling coordination was significantly positively correlated with the minimum value, as shown in Figure A2, avoiding a situation where the "function and efficiency" values were both low and coordinated, indicating that the coupling coordination values could be used to quantify the effectiveness of the village.

Figure A3 depicts the intensity of each aspect of village effectiveness. The higher values of production effectiveness are located in the center city of Xintai, which is a former coal mining base with a solid industrial foundation and a high concentration of businesses. The Xinwen subdistrict, which is the urban area's location and provides greater living amenities, is where the effectiveness of living is mainly concentrated. Longting Town and the Xintai's southwest have the best environmental effectiveness. Longting Town is located in a hilly area with favorable ecological conditions, and the government has increased efforts to promote environmental management and forestation in the southwestern region. The central city and sub-administrative center regions of Xintai are where the comprehensive effectiveness is concentrated.

### *4.5. Analysis of Interactions within Effectiveness*

Bivariate Moran's I was used to analyze the three dimensions of village "function" and "efficiency" values in order to explain the internal interaction mechanism of effectiveness, and the results are shown in Table 3, with the LISA cluster map shown in Figure A4. Production and living functions have a substantial positive link, with the LISA cluster demonstrating that population concentration and the allocation of living facilities go hand in hand with industrial growth. The production function has a significant negative correlation with the ecological function, indicating that the expansion of rural production activities and the intensive distribution of industries result in the gradual encroachment of non-agricultural construction land and agricultural production land on ecological land, as well as a weakening of environmental protection. The gradual shift in farmers' predominant agricultural mode of production, as well as the goal of protecting arable land, has resulted in some conflicts between non-agricultural and agricultural production. Ecological protection requirements have limited the expansion of agricultural land. These occurrences point to a conflict between production and ecological functions. The production function has a negative relationship with production efficiency, suggesting the area has internal conflicts and decline in industry sustainability will be raised, and the LISA cluster map imbalances in function and efficiency occur in some agricultural production areas. The production function is inversely connected to living efficiency—communities with higher industrial expansion and living facilities face a shortage of inputs as well as a mismatch of resources. Unexpectedly, the production function and ecological efficiency have a positive correlation, showing that economic development is accompanied by a focus on ecological management in the area, wherein we can see the LISA cluster map was mainly showing agricultural growing areas.

**Table 3.** Moran's I correlation coefficient between different dimensions in Xintai.

| | Production Function | Living Function | Ecological Function | Production Efficiency | Living Efficiency | Ecological Efficiency |
|---|---|---|---|---|---|---|
| Production function | — | | | | | |
| Living function | 0.13 *** | — | | | | |
| Ecological function | −0.063 *** | −0.194 | — | | | |
| Production efficiency | −0.072 *** | −0.106 | −0.01 * | — | | |
| Living efficiency | −0.011 *** | −0.074 | −0.044 | 0.079 *** | — | |
| Ecological efficiency | 0.005 *** | −0.057 | −0.007 ** | −0.043 *** | 0.087 *** | — |

*: *p*-value < 10%; **: *p*-value < 5%; ***: *p*-value < 1%.

Ecological function is negatively related to production efficiency and ecological efficiency. These findings imply that regions with better ecological conditions have lower rates of economic output, with weakening inputs to ecological management. In the LISA cluster map, in the northern mountains, they are in a mutually reinforcing relationship, which has a lot to do with the development of tourism in the area.

Production efficiency promotes living efficiency but inhibits ecological efficiency. Better industrial development leads to better production conditions, attracting population concentration and configuration of living facilities. However, the residential development and facility distribution may all degrade the local ecological environment. In the LISA cluster map, we can see that in mountainous and ecologically important areas, local authorities have strengthened ecological protection to avoid this phenomenon

Living efficiency has a positive influence on ecological efficiency, and living efficiency reflects the state of transformation of the human living environment in the region, with a high intensity of land development, strong human activity, and a large proportion of non-ecological land use, all of which will have a negative impact on the local ecological environment as people invest more in ecological management to solve these problems.

## 5. Discussion

Over the last several decades, China's industrialization and urbanization has changed the economic and social structure of the rural areas, with most villages experiencing hardship and decline [41,42]. Villages, in particular, supply labor and land for urban expansion and industry development. The ecological and environmental issues are becoming more significant as a result of resource depletion and industrial decline, population loss, and industrial transition [43,44]. There is an increasing interest in how to assess the status of rural development, which is critical to long-term sustainable. By summarising the existing rural development evaluation methods in this paper, we discovered that current research on the status of development of villages is usually represented in terms of "efficiency" or "function type", which is unable to provide an objective and comprehensive picture of the development situation. Furthermore, the study scale focuses mostly on township or county, sometimes disregarding the specific issues that occur in village development, which has little point in guiding village development. To give a more complete assessment of the status of village development, this research presents a theoretical framework for evaluating the effectiveness of villages, taking into consideration the conception of "effectiveness" in management. We applied and evaluated this in the rural areas of Xintai county, a resource-declining city. The Geographic Information System (GIS) was used to visualize the village's space and further investigate the spatial differentiation pattern of village efficiency. We used the four-quadrant method to classify the types of village effectiveness and analyzed the mechanisms of interaction within rural effectiveness using the Spearman correlation coefficient in order to aid in the analysis of the mechanisms that lead to differences in effectiveness.

This study classified the forms of effectiveness to identify the development status of different villages and provides development recommendations for the various sorts of villages. For example, the HF-HE-type villages have a strong development potential due to the interaction between better ground conditions and high efficiency of output [45]. The higher output efficiency of LF-HE-type villages indicates a stronger state of transition, but care must be given to match the direction of transformation with local resource characteristics, otherwise resource input would be wasted. The LF-LE villages are investment priority regions, and because of their terrible resource background, they are a trigger for population loss, which leads to a lack of industry and a lag in the development of amenities, making them more prone to a vicious loop of low function and efficiency [46]. The HF-LE villages show a stable status of development and a decline in sustainability, with a number of issues arising for all types of villages, including the production dimension, inefficient industrial output, redundant resource inputs, and labor drain from the region; the living dimension, a mismatch between resources and population size, old and poorly maintained facilities; and the ecological dimension, a deterioration of the ecological environment.

The Bivariate Moran's I analysis revealed some useful information of linkages between effectiveness factors. In the same dimension, there is a negative correlation between function and efficiency, indicating that better resource background conditions tend to slow development efficiency and are more likely to occur in villages with stable development, which can also reflect a mismatch of resource factors and thus affect the village's long-term sustainability [47]. At the same time, communities with lower baseline circumstances have better development efficiency, showing the village's transformational development dynamics.

The three dimensions of production, living, and ecological effectiveness have synergies and trade-off relationships. There are trade-offs between production and ecological functions, and between living and ecological functions, as well as synergies between production and living functions. It shows that there is a conflict between the allocation of production and living factors and the ecological environment, and that production and living factors can be developed in synergy. For instance, the rapid expansion of regional industry will result in population concentration and hence support the allocation of residential amenities [48]. The deterioration of the countryside's landscape due to agricultural production activities and the invasion of ecological land prior to the construction of non-agricultural production facilities [49], as well as human activities and industrial growth in the region, will be limited if the area's ecological environment protection are prioritized [50,51].

Synergies exist between production and living efficiency as well as between living and ecological efficiency, but there are trade-offs between production and ecological efficiency. It demonstrates that high production output efficiency promotes efficiency gathering residents, living amenities, and public services, as well as improved living circumstances, attracting industries to the area and increasing regional economic output [52]. Higher economic growth, on the other hand, can have a negative influence on the environment, which is an issue that villages need to address urgently in the framework of transformational development [53]. The development of the living environment is inextricably related to the improvement of the ecological environment [54], and investments in ecological management will be accompanied by the need for a change in the living environment [55,56].

We strive for a balanced development of villages, but each village has its own set of circumstances. Because some objective conditions are often unattainable, village development should be based on the development status, location conditions, and resource endowment of the planning, rather than a model to copy, as this will result in redundancy in resource allocation and inefficient output problems [57–59]. As a result, on the basis of village development principles and trends, we should fully exploit the benefits of high-effectiveness villages while compensating for the faults of low-effectiveness villages. We should provide adequate policy assistance to these communities in order to increase development prospects, such as boosting the input of variables such as land, labor, and money. At the same time, the scale effect of village performance and the amount of resource invested in villages of various sizes and populations should be considered. In order to achieve a more balanced development of the region as a whole, attention should be directed to the resource input of distant settlements in the mountains. Industrial integration development could offer a larger benefit in efficiency enhancement for towns whose primary industries are the mainstay, which can also draw more labor and public resources to collect. In villages where secondary and tertiary industries are the main industries, more attention should be paid to improving the utilization rate of agricultural land while pursuing economic development [60,61]. At the same time, more attention should be paid to environmental management and protection in order to help improve comprehensive effectiveness. Moreover, attention should be paid to the scale effect of village effectiveness and the proportion of resources invested in villages of different size and population. In villages where secondary and tertiary industries are the main industries, more attention should be paid to improving the utilization rate of agricultural land while pursuing economic development. At the same time, more attention should be paid to environmental management and protection in order to help improve comprehensive effectiveness [62,63].

In addition to the effectiveness assessment variables discussed in this research, the indicator system has to be enhanced as China implements urbanization and rural modernization in detail. More research should be conducted to see how distinctive villages might increase their efficiency. It is possible to incorporate a big data platform, which is necessary for increasing data diversity, minimizing the use of people and material resources for data collection, as well as boosting assessment efficiency.

## 6. Conclusions

This study conducted a theoretical framework and assessment method for village effectiveness, using the notion of effectiveness, in order to solve the question of how to measure the condition of village development, and it further analyzed the variability of village effectiveness and internal influencing mechanisms. The main conclusions were achieved and drawn as follows:

(1) We evaluated a total of 791 villages in Xintai county, of which 220 villages were found to have comprehensive effectiveness, accounting for 27.8% of the total, and the high-value areas were found to mainly be distributed in the central urban and sub-administrative center of Xintai county. The number of villages with effectiveness in the production dimension was rather limited, with only 204 villages accounting for 25.7% of all assessment objects, and the high value of their location same as the comprehensive effectiveness. There were 229 villages with high living effectiveness, accounting for 28.9% of all villages, and the high-value geographical distribution was concentrated in the county center. The ecological dimension had the largest number villages, with 195, accounting for 24.7% of the total, and their high-value spatial distribution was mostly in eastern mountainous areas.

(2) The primary categories of village effectiveness were identified. In terms of production, 119 villages were function-dominant, and 85 villages were efficiency-dominant, suggesting that the region has a strong industrial basis. The efficiency-dominant type is primarily found outside of the central city, confirming the impact of industrial transformation and the urban sprawl; in the living dimension, there were

226 function-dominant types and 3 efficiency-dominant types, indicating that the region's background conditions for living facilities are good due to the region's original industrial base, but the efficiency of living facility allocation is generally low. There were 148 function-dominant type villages and 47 efficiency-dominant type villages in the ecological dimension, with the function-dominant type villages being more common. Loude Town was the region that has increased its efforts to manage the ecological environment. In the comprehensive dimension, there were 176 function-dominant type villages and 44 efficiency-dominant type villages.

(3) The study's findings revealed a negative association between function and efficiency in the same dimension, implying that a better resource background scenario frequently leads to an imbalance in resource allocation and a low output level, which has a detrimental influence on the village's long-term sustainability. At the same time, there are some trade-offs and synergies between the three dimensions of production, living, and ecology, such as the trade-offs between production and ecological function, and production function and living efficiency, as well as ecological function and production efficiency, and production and ecological efficiency, all of which indicate a contradiction between human activities and the ecological environment. There are synergies between production function and ecological efficiency, production efficiency and living efficiency, and living efficiency and ecological efficiency, indicating the transformation development of regional industries; as part of the process of economic growth, the residents have caused an increase in the renovation of habitats and the protection of the ecological environment.

Rural development is a complex reflection of environmental, social, and economic factors, as well as human activity. Rural development planning and resource investment can be aided by an accurate assessment of the status of rural development. Rural effectiveness evaluation can accurately reflect the coupling relationship between rural area function and development efficiency, as well as the distribution characteristics and role mechanisms of different development status in rural areas. Through empirical application, it is proven that this technical system has a certain universality, and to some extent it enriches the theoretical system and methods of rural development status evaluation, establishing a scientific foundation for bettering the architecture of rural resources and improving the logic of rural development research. It serves as a guide for making decisions on sustainable rural development and putting China's rural revitalization policy into action.

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# Appendix A

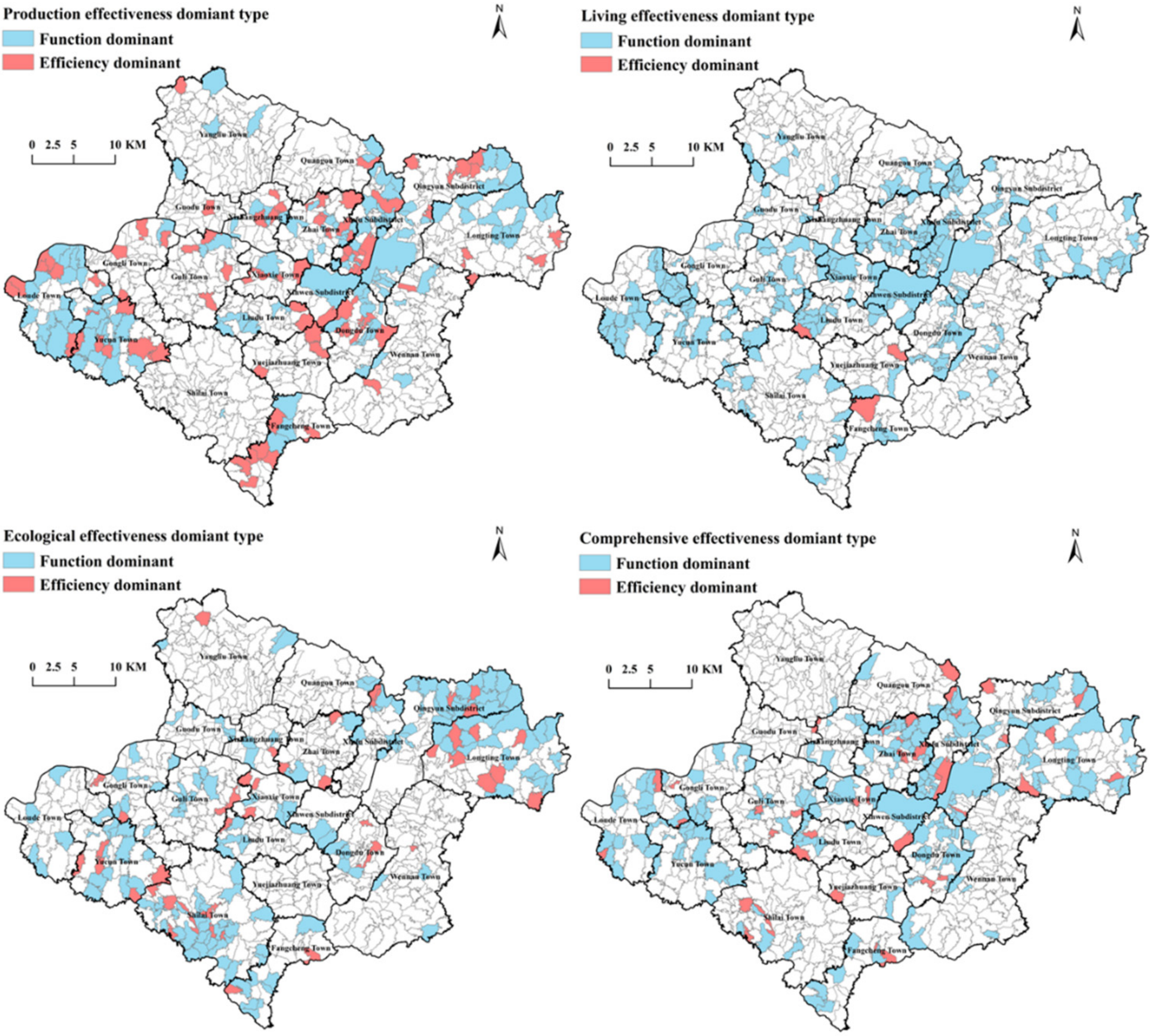


**Figure A1.** Spatial pattern of the rural effectiveness dominant type in Xintai.

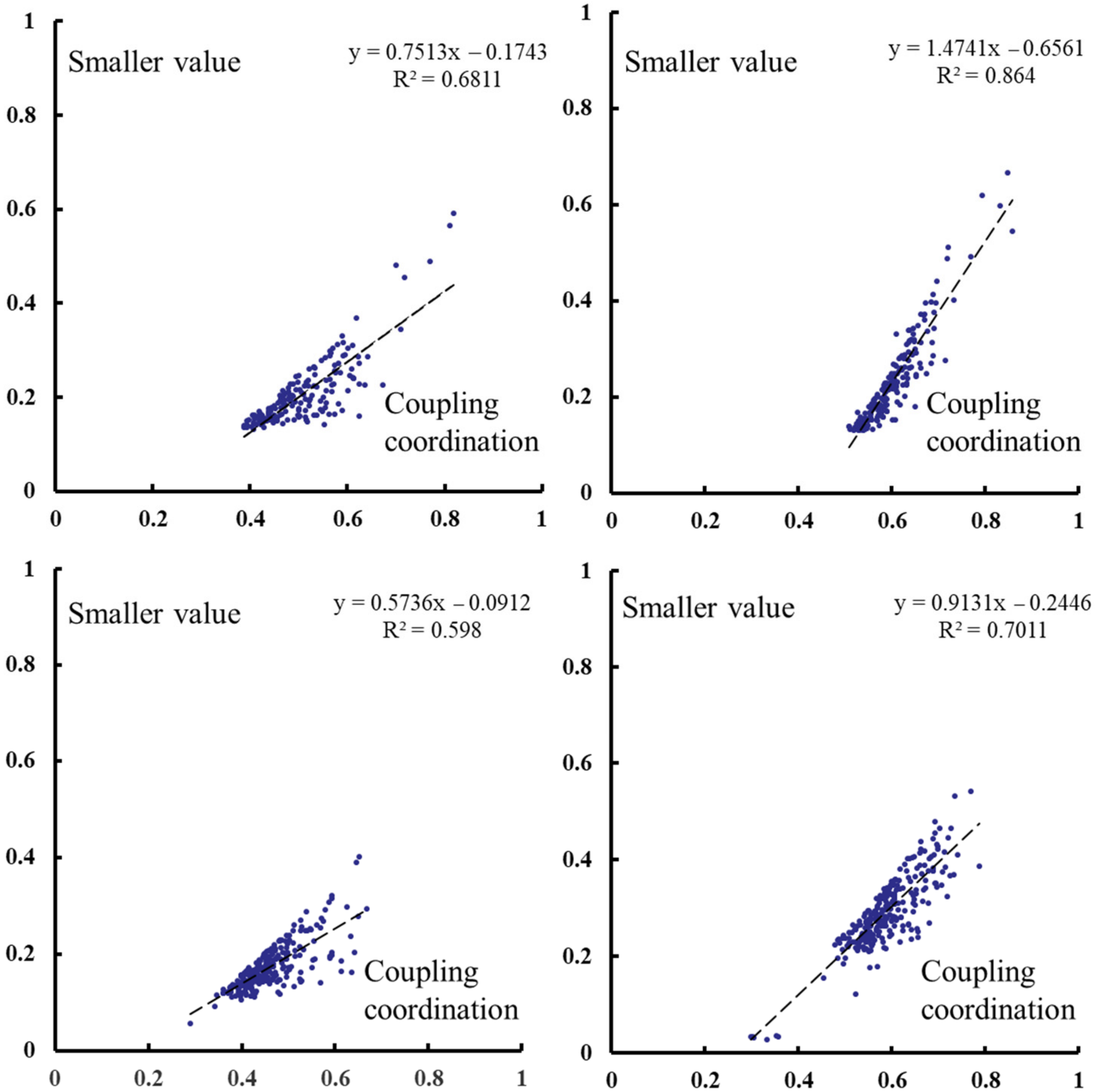


**Figure A2.** Linear regression model of coupled coordination and smaller values.

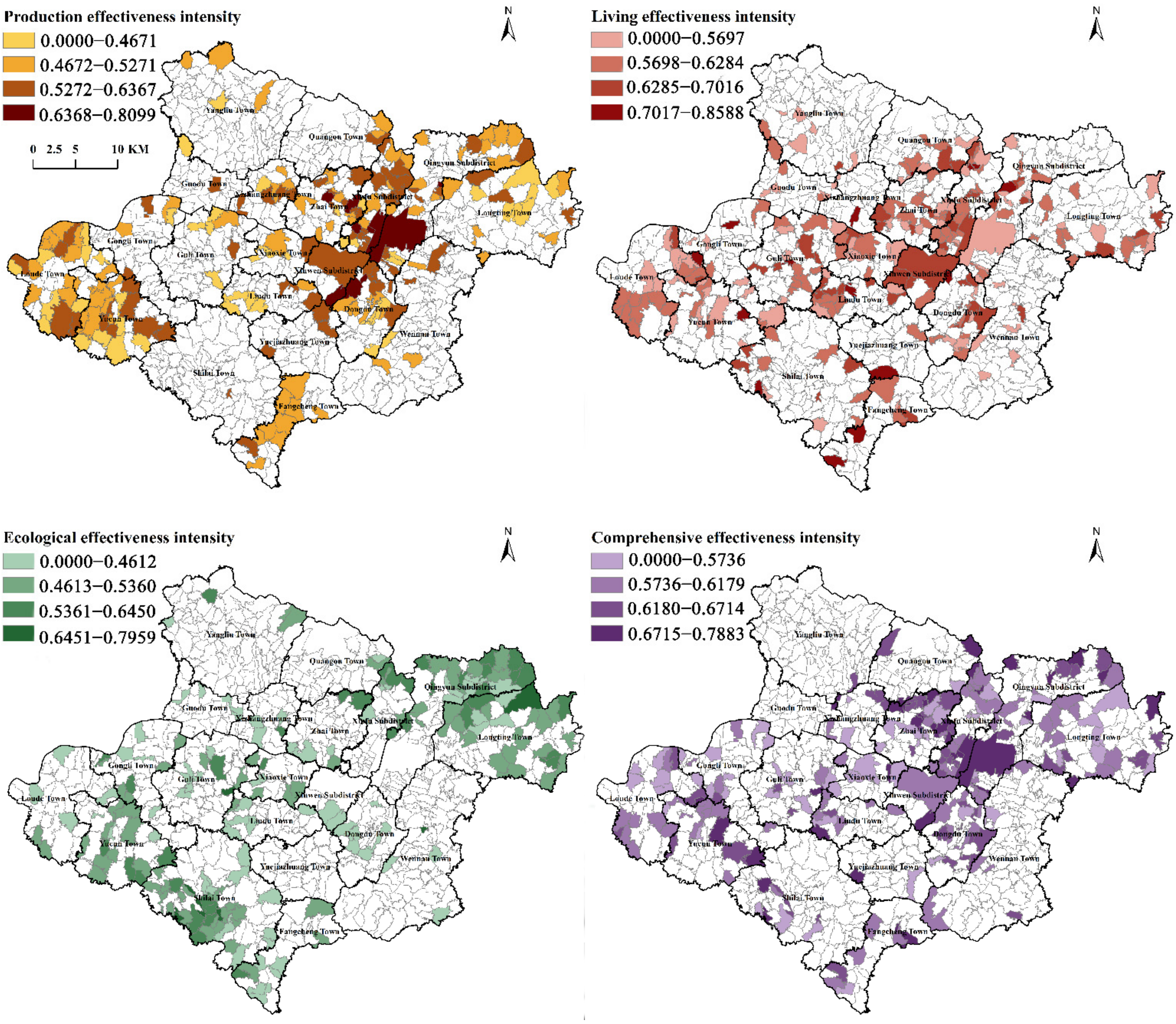


**Figure A3.** Spatial pattern of the rural effectiveness intensity in Xintai.

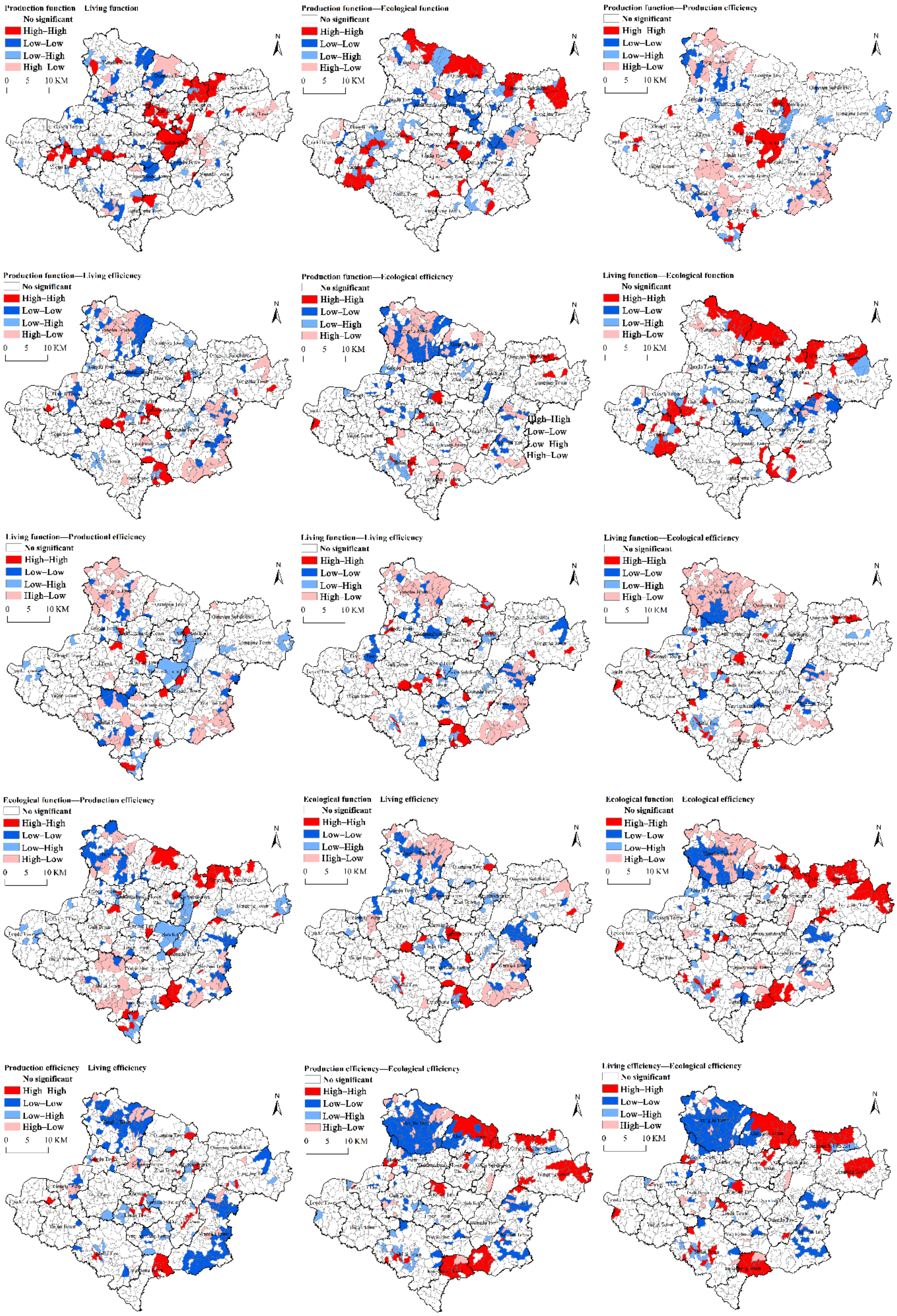


**Figure A4.** LISA cluster map of interaction in each effectiveness dimension.

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