

Article

Research on the Evaluation and Spatial Distribution Optimization of the Field Intensity Effect of Rural Basic Education Infrastructure in Wuhan's New Urban District: A Case Study of Liji Township

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Abstract: Education infrastructure is a critical public service facility in rural areas. The evaluation of rural education infrastructure could have important implications for the spatial distribution optimization of public educational services in countryside regions. Based on the elementary education data and survey data of Liji Town in 2022, this paper built an index evaluation system for Liji Township to explore the optimized spatial distribution mode of rural education infrastructure using models of MCR and field intensity. This system consisted of the potential energy of rural basic education infrastructure, as well as district and service thresholds. The results show the following: (1) The resistance of the rural education infrastructure in Liji Township was lower in the eastern and western parts of the township, as well as along the northern–southern county highway; however, the resistance was higher in the southern and northeastern areas. (2) There were significant differences in the potential energy component of education field intensity, showing a gradual decreasing tendency from the central villages to the peripheral villages. The spatial distribution of the central villages' potential energy component was consistent with the component of the service threshold. However, the components of both district and service thresholds showed higher values for the suburban villages and lower values for the peripheral villages. (3) The rural basic education infrastructure can be divided into three types, and the corresponding development path is proposed in combination with different types. The optimization result is easy to explain and has potential applications in public education evaluation and facility layout planning. These modes can facilitate the allocation and spatial distribution optimization of basic education infrastructure in rural regions of metropolitan areas.

Keywords: rural basic education infrastructure; field intensity; minimum cumulative resistance model; spatial distribution and optimization; Wuhan



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1. Introduction

With the advent of the era of the knowledge economy, education is becoming increasingly important in social development. The spatial distribution and allocation of

educational resources are crucial for educational equity and have far-reaching significance for the realization of the sustainable development of society [1]. The call for equity and quality in the educational system has become a global agenda. The United Nations, through the Sustainable Development Goals (SDGs), requires nations to “ensure inclusive and equitable quality education and promote lifelong learning opportunity for all”. One of the indicators of this objective is building and upgrading inclusive education facilities to ensure effective learning environments for all [2]. This reiterates the important role equitable infrastructure is deemed to perform in the educational process. Many countries are currently experiencing urbanization due to economic and social development [3]. Rapid urbanization has led to a boom in urban economies and expansion in urban spaces, but it has also resulted in a global rural economic downturn [4,5]. A prevalent global trend in urbanization is to prioritize cities at the expense of towns, leading to an expanding gap between urban and rural regions and the sustained neglect of rural concerns in the long run [6,7]. It is crucial that educational services and social benefits be equally accessible to residents of both rural and urban areas. The basic urban–rural educational infrastructure is an important factor in promoting educational equity. Its accessibility and equity are closely related to social livelihood, social equity, and the overall situation of new urbanization. This has always been a research hotspot in geography, education, and other disciplines [8].

In recent decades, China has implemented rural revitalization strategies to modernize the country’s rural development, and optimizing rural education infrastructure has become a key component [9,10]. As a basic human right, education is critical to achieving sustainable development. The scientific planning and development of rural schools can provide equal opportunities for the rural population. With the rapid advancement of urbanization, urban and rural residents are demanding higher-quality public service resources. The “14th Five-Year Plan” outline proposes to achieve the equalization of basic education service infrastructure so that urban and rural residents have access to education. Moreover, the “2022 Work Points of the Ministry of Education of the People’s Republic of China” further emphasizes the need to promote the revitalization of rural education and the development of high-quality and balanced compulsory education. The above laws and policies all indicate that rural revitalization is one of the most important strategies in China [11]. Due to the dynamic evolution of urban–rural relations with the dominance of the dual structure in China, rapid urbanization and industrialization have had a profound impact on rural areas [12]. There is a structural imbalance between the supply and demand of public service infrastructure in rural areas, which severely restricts urban–rural integration and fairness. According to education statistics from Wuhan, the proportion of children and adolescents (under 14 years old) in Liji Township has decreased from 19.8% in 2016 to 13.2% in 2022, a decrease of 6.6% in the past six years [13]. On the one hand, the birth rate is gradually decreasing, and on the other hand, some children are accompanying their parents to study in the city. Therefore, it is necessary to adjust the layout and scale of schools in the entire township. The urban–rural transition, boundary instability, and dynamic changes in rural areas of new urban districts are significant. Surrounding rural areas continue to be integrated into urban areas, leading to the evolution of rural development towards urbanization and the emergence of new spatial differentiation [14]. New urban areas in cities generally exhibit rapid development but have little public service infrastructure. The problems of an insufficient supply of educational infrastructure and the mismatch between supply and demand are particularly prominent in new urban areas [15]. In addition, the low agglomeration and driving effects of urban and rural areas, coupled with the further hollowing out of the countryside, have exacerbated the outflow of students. The negative impact of the accessibility requirements of transportation and the low-threshold effect have led to the inefficient and scattered layout of rural basic education infrastructure, resulting

in low-efficiency redundant construction and underutilization. However, rural and urban populations should be afforded equal access to educational services and social benefits [16]. Therefore, it is highly important to evaluate and optimize rural basic education infrastructure in new urban areas to achieve the equalization of education services between urban and rural areas.

2. Literature Review

Previous researchers took the spatial balance of efficiency and equity of allocation of educational facilities as the optimization goal [17]. They analyzed the relationship between education policy and the spatial layout of basic educational resources and measured residents' satisfaction with the spatial equity of basic educational resources [18]. On this premise, scholars have explored the physical infrastructure, spatial layout, location selection, supply mode, and efficiency of education resources [19–21]. When discussing the distribution of urban–rural education facilities, the concept of spatial equity can be divided into “horizontal spatial equity” and “vertical spatial equity” [22]. An increasing number of scholars have explored the location selection model of basic educational infrastructure based on the principle of spatial equity [23–25]. Talpur proposed that the distances between rural communities and education centers can be curtailed with the provision of education services according to the subregional population features in the subregion of Southern Pakistan [26]. Some studies have shown that the rational allocation of rural educational resources is conducive to personal growth and promoting regional balanced development [27,28]. With the rapid integration of geographic information technology and location-allocation models, the spatial distribution optimization means of basic education facilities have been greatly improved. This research mainly highlights the location selection and layout patterns of educational infrastructure [29,30] spatial equity and accessibility [31–33], social differentiation and its formation mechanisms in a spatial layout [34,35], the scope of educational services [36], the economic and social effects caused by changes in the scope and accessibility of educational service areas [37,38], and commuting-based school choice models [39,40] to solve the problem of educational equity in areas with mismatched educational infrastructure and underdeveloped areas.

The unique dual economic system in China has led to a concentration of basic education research in cities. These studies include aspects such as location selection [41,42], spatial distribution and external evaluation [43–45], accessibility analysis [46], social differentiation [47,48], supply-and-demand relationships [49,50], and influencing factors [51,52]. Among these, the accessibility analysis method has been integrated with models such as the minimum distance model [53], the potential model [54], and the two-step floating catchment area method and its improved models [55,56]. Han proposed an evaluation–optimization–validation framework for school location planning by integrating accessibility evaluations and an MCLP-CC optimization method used to optimize the maximum coverage of schools [57]. Zhai introduced a new method for measuring accessibility based on optimal supply-and-demand allocations, which is parameter-free, easy to calculate, and easy to explain [58]. Related studies have also focused on the external effects of educational spatial distribution, including the relationship between educational facility distribution and housing prices [59,60] and the Jiaoyufication caused by the uneven distribution of education facilities and social class stratification [61,62]. However, there is relatively little research on the evaluation and spatial distribution optimization of rural basic education infrastructure, and the research mainly focuses on the matching mode and influencing factors of rural basic education infrastructure [63–65], the analysis and layout adjustment of mergers and closures [66], matching policies, and implementation recommendations [67]. The evaluation and layout of rural basic education infrastructure have been discussed using methods

and techniques such as econometric modeling analysis [68], geographic information system (GIS) spatial analysis [69] and farmer household willingness questionnaires [70].

Although existing studies on the optimization of educational infrastructure are of great importance, there are some deficiencies. First, the current research fails to fully reflect the functional orientation and spatial characteristics of optimizing the layout of basic education infrastructure. Meanwhile, it ignores the actual needs of rural residents, resulting in a disconnect between the configuration of educational facilities and the needs of residents, and cannot scientifically and effectively guide the configuration of rural education service facilities. Second, due to the relatively small size, scattered distribution, and low density of rural populations, there are socioeconomic differences between villages. Therefore, the layout of rural education should not have a unified formulation model and can only be analyzed on a case-by-case basis [71]. Therefore, it is essential to deepen the research on diversified space optimization for rural basic education at the microscale.

Field potential theory describes the interaction and motion laws of objects between the gravitational field and electromagnetic field space and explains that different types of matter in natural space can be interconnected, influenced, and transformed and can interact with one another through these fields. In recent years, its theoretical connotation and thinking mode have gradually expanded and broken through the traditional application scope and are widely used by many scholars in other related fields, such as economics, sociology, and ecology, including the resource [72], residential [73], and park green space fields [74]. The resource space formed by the coupling of geographic space and resource demand space has the characteristics of a field. The scope of this resource can include energy, urban division of labor, and residential location, as well as various public resources within urban and rural areas [72]. Educational resources distributed within a certain spatial range can have a spatial distribution like fields in physics and possess resource potential. As an important component of educational resources, educational facilities provide cultural and educational functions for rural residents. The position, advantageous functions, and attractiveness of each educational facility generate the “field effect” of education, considering the multiple dimensional functions of various educational facilities within a certain spatial range. The non-equilibrium of the “field effect” in different villages leads to material migration and energy exchange, thereby promoting the uneven distribution of education [75]. When farmers are dissatisfied with the “educational field effect” of their existing residential location, they choose educational facilities with a higher “field effect”. Compared with existing methods, the field potential theory can comprehensively reflect the current spatial status of basic education facilities while pointing out the functional direction of optimizing the layout.

Based on this theory, Liji Township, Xinzhou District, Wuhan City, was selected as a case study area. A three-component index evaluation system was then established for basic education facility potential energy, district factors, and service thresholds. By using methods such as the minimum-resistance model and field potential model, a comprehensive evaluation of the multi-spatial resistance analysis of each component index and the “field potential effect” was conducted to explore the optimization of the rural basic education facility layout, with the aim of providing a scientific basis and decision-making reference for the allocation and layout optimization of basic education infrastructure in towns and townships.

3. Materials and Methods

3.1. Research Area

Located in the northeast part of Wuhan, Xinzhou District is one of the six new districts in Wuhan. Liji Township is located in the northwest part of the district, adjacent to

Zhucheng Street in the east and Wangji Street in the south, while facing the Daoshui River across Cangbu Street in the west, approximately 13 km away from the main urban area of Xinzhou District. A water system runs through the west side of the township from north to south, with the main terrain being plains and hills. The total area of the township is 85.72 square kilometers, with 2 communities and 43 administrative villages under its jurisdiction. As of the end of 2022, the total number of permanent residents was 73,100. There are 11 elementary schools with 214 teachers and 1944 students. Currently, there is a significant difference in scale among elementary schools. The larger-scale central schools and elementary schools are mainly concentrated at the east and west ends, presenting a pattern of distribution along the roads (Figure 1). In the hilly areas of the northern and central parts of the town, the number of elementary school students and the size of the buildings are relatively small. Due to urbanization and population outflow, Liji Township is experiencing a hollowing out of its village settlements and a continuous decrease in the number of students, leading to changes in the supply-and-demand structure of its elementary schools, which need further optimization and improvement.

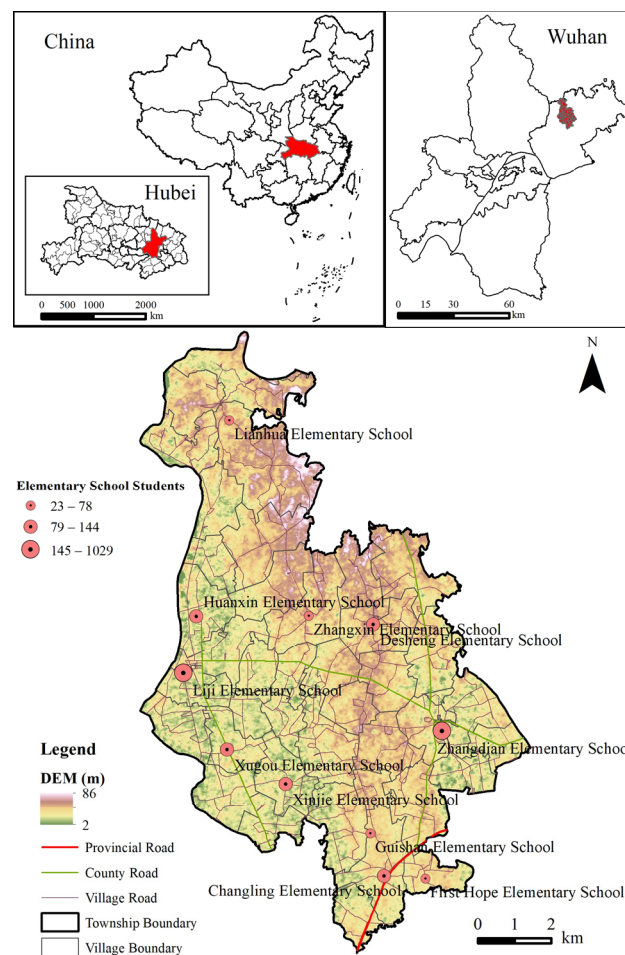


Figure 1. Location of the research area.

3.2. Data Source

The following data were used by the research institute: (1) Spatial data. The basic education point of interest (POI) facility data were sourced from the Amap Geographic Service Platform (<https://lbs.amap.com/>, accessed on 20 December 2022) and obtained through web crawling, filtering, and deduplication as of December 2022; these data included information such as name, address, latitude, and longitude, and category. The traffic data (provincial roads, county roads, township roads, and other roads) were downloaded

from the Open Street Map website and underwent topological checks to establish reasonable topological connectivity and to build a road network dataset. (2) Attribute data. The socioeconomic statistical data were obtained from the 2022 Wuhan Geographical National Conditions Census and Monitoring Data, the 2022 Wuhan and Xinzhou District Statistical Yearbook, and the Wuhan National Economic and Social Development Statistical Bulletin. (3) The research team consists of 30 professional teachers and doctoral students, and they conducted two field surveys in November 2020 and November 2021, which covered the current scale, spatial distribution, service scope, and socioeconomic development of primary schools in Liji Township. This survey collected relevant information and basic data through methods such as interviews, questionnaire surveys, and field visits. According to a survey, most of the school-age population in Liji Township's elementary schools commute by walking or riding electric bikes. To more accurately reflect the actual situation, search thresholds were set for these two modes of transportation. According to the Guiding Opinions of the General Office of the State Council on Strengthening the Construction of Small-Scale Rural Schools and Township Boarding Schools, small-scale rural schools are required to enroll students who live nearby, with travel times generally not exceeding 30 min. In accordance with the requirements of the Technical Guidelines for Community Life Circle Planning (TD/T1062-2021) [76], the comprehensive selection of students should ensure that the walking time to school does not exceed 30 min and that the driving time (including electric vehicles) does not exceed 15 min.

3.3. Research Methods

3.3.1. Evaluation Index and Research Framework

Due to their unique geographical features and trends of hollowing out and aging of the population, rural areas face challenges in achieving the equalization of basic education infrastructure, such as dispersed population and facility configuration decisions. Therefore, the optimization of the spatial layout faces the typical contradiction of “threshold-accessibility” [77]. Given the current socioeconomic development conditions in Liji Township, it is not realistic to achieve a completely uniform spatial layout of all rural basic education infrastructure. Instead, the configuration mode should be guided by population density, dispersion degree, and distribution characteristics to improve the efficiency of educational infrastructure. A multidimensional evaluation index system for basic education facility potential was constructed by combining the two core elements of “economies of scale” and “service radius” in the configuration of rural basic education infrastructure and including a potential energy index, a district index, and a threshold index [78] (Table 1). “Economies of scale” refers to the current development status of basic education infrastructure and the level of development of the villages where it is located; “Service radius” refers to the spatial coverage of basic education facilities. These two indicators are the core indicators that the Chinese government considers when making plans, ensuring that the layout of rural education balances efficiency and fairness. The potential energy index and threshold index reflect the scale benefits of education, while the regional index reflects the service radius of educational facilities. The indicator character represents the direction of the indicator, where pluses represent its positive effect on the objective layer, and minuses represent its negative effect. In addition, the entropy method was employed to comprehensively determine the weights and scores of each indicator.

- (1) Potential energy index: This index refers to the scale and effectiveness of basic education infrastructure and reflects the construction and service levels of rural basic education infrastructure [79]. Larger schools can accommodate more students and teachers, with better-equipped teaching infrastructure, a higher quality of teaching, and a wider range of influence [80]. Large schools can attract more students from

surrounding areas, and they have a larger scale and more benefits. This index is represented by the student population, number of teachers, land area, building area, and student capacity per one thousand people.

- (2) District index: This index refers to the service radius of basic education infrastructure and reflects the accessibility and convenience of the spatial layout of rural basic education infrastructure [81]. A denser network of the rural basic education infrastructure decreases the distance to rural settlements, town centers, and transportation arteries, increases accessibility, and improves the satisfaction of rural residents. This index is represented by the road density, traffic accessibility, distance to the town center, and maximum service radius. The accessibility of transportation and distance to the town center is based on the actual road network of Liji Township, calculated using the two-step floating catchment area method [82]. The maximum service radius of the school is calculated using the Huff model [83].
- (3) Service threshold index: This index refers to the development level of the rural settlements where basic education infrastructure is located and reflects the level of socio-economic development and population structure of the administrative village where rural basic education infrastructure is located [84]. More populous rural settlements have a larger source of students, and a higher level of socioeconomic development in a rural settlement can better guarantee the development of basic education in rural areas. The indicators of the permanent population size, population structure of settlements, area of residential buildings, area of cultivated land, proportion of construction land area, number of agricultural cooperative organizations, and total output value of the secondary industry were selected. This article is organized as follows (Figure 2).

Table 1. Indicators for the multidimensional field evaluation index of rural elementary school education infrastructure.

Objective Layer	Indicator Layer	Indicator Character	Weight	Indicators	Indicator Interpretation
Potential energy index	Number of students	+	0.073	Number of students on campus (person)	Educational strength
	Number of teachers	+	0.057	Number of faculty and staff (person)	Educational strength
	Land area	+	0.05	School land area (m ²)	School size
	Building area	+	0.057	The total building area of the school (m ²)	Capital Investment intensity
	Student capacity per one thousand people	+	0.06	Number of students per thousand (person/thousand persons)	
District index	Road density	+	0.072	Total mileage of administrative village road/area of administrative village (m/km ²)	Road network distribution
	Traffic accessibility	+	0.061	Actual road network analysis (Two-step floating catchment area method)	Travel efficiency
	Distance to town center	-	0.041	Actual road network analysis (Two-step floating catchment area method)	Convenience of livelihood
	Maximum service radius	+	0.035	Actual road network analysis (Huff model)	Radiation range
Service threshold index	Permanent population	+	0.032	The total number of permanent residents in the village where the school belongs (persons)	Population base of students
	Population structure of settlements	+	0.017	Population under the age of 18/total registered residence population (%)	The proportion of school-age population
	Area of residential buildings	+	0.024	Building area of each administrative village (m ²)	Living standard
	Area of cultivated land	+	0.025	Area of cultivated land/administrative village area (%)	Potential of agricultural development
	Proportion of construction land area	+	0.1	Construction land area/administrative village area (%)	Urbanization development level
	Number of agricultural cooperative organizations	+	0.026	Number of cooperative organizations within administrative villages (individual)	Agricultural specialization level
	Total output value of the secondary industry	+	0.27	Total registered capital of enterprises in administrative villages (ten thousand yuan)	Economic strength

“+” Representing a positive indicator, the larger the value, the better the evaluation. “-” Represents a negative indicator, the larger the value, the worse the evaluation.

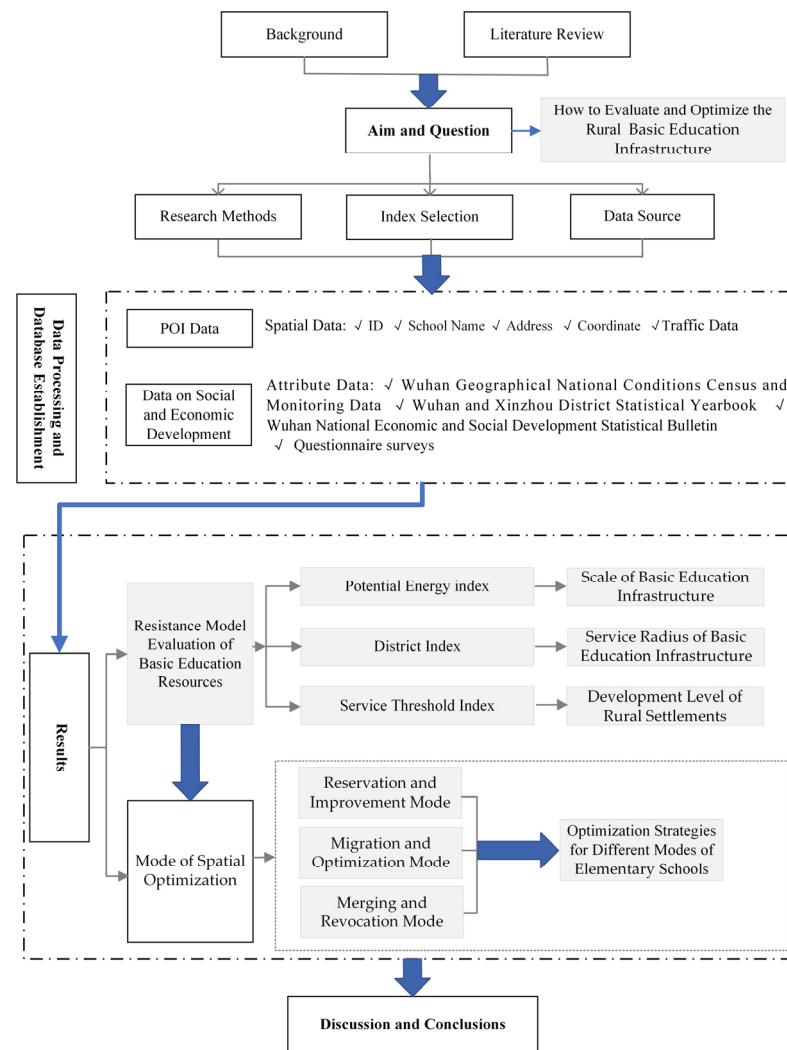


Figure 2. Research framework and steps.

3.3.2. Minimum Cumulative Resistance Model

The minimum cumulative resistance (MCR) model in the article refers to the model of the resistance cost borne by educational facility points during the coverage process towards peripheral destinations. The core process is the competitive diffusion of the source to surrounding spatial units within the resistance surface system [85]. The optimization of the layout of rural basic education infrastructure can be understood as the process of controlling and covering educational resources in rural spaces, which requires overcoming layout resistance, and the extent of the resistance directly affects the trend of the spatial distribution optimization of educational resources. The spatial layout of rural basic education infrastructure is often influenced by factors such as rural socioeconomic development, location, transportation factors, and development conditions. This spatial layout is applicable to the MCR model and can reflect the trend of rural basic education facility development by establishing resistance surfaces. The calculation method is as follows:

$$MCR = f_{\min} \sum_{j=n}^{i=m} (D_{ij} \times R_i) \quad (1)$$

MC is the MCR value, and D_{ij} represents the spatial distance from the source site j to the ground landscape unit i ; in this article, it refers to the distance from primary school facilities to residential areas. R_i represents the resistance coefficient of the ground landscape unit i , and f represents the positive correlation between the MCR and ecological processes. The source location in this study is 11 rural schools.

3.3.3. Field Potential Model

“Field” refers to the spatial form to which the activity subject is attached, and “potential” is the measurement of the field. The existence of a “field potential” is determined through the non-equilibrium of the environmental system, which leads to the migration of matter, exchange of energy, and transmission of information [86]. The main service providers of rural basic education infrastructure objectively measure and compare various dimensional indices of each educational facility within their service scope, which reflects the index ranking, functional advantages, and regional attractiveness of each educational facility within a certain regional scope. The size of rural basic education infrastructure varies under different natural, social, and economic conditions in different rural areas [45]. Rural basic education infrastructure comprises multidimensional spatial units formed by the interaction of the construction level and the external environmental system [87]. The size of the comprehensive educational field of a rural basic education facility can be represented by the sum of the index values of various field components of the evaluation unit, and the calculation method is as follows:

$$N_i = \sum_{i=1}^n \sum_{j=1}^m (X_{ij} \times W_j) \quad (2)$$

In the formula, X_{ij} is the normalized value of the i -th rural education facility indicator j according to the maximum value standard, W_j is the weight of indicator j , m is the total number of indicators, $\sum_{j=1}^m (X_{ij} \times W_j)$ is the potential component value of educational facility i , and n is the selected number of potential components of the educational facility. N_i refers to the comprehensive situation of rural basic education. A larger value indicates a higher overall educational level of rural basic education infrastructure and a more concentrated scale, which leads to greater attraction and cohesion for residents within the service range.

3.3.4. Spatial Distribution Optimization of Basic Education Infrastructure

The optimization of the basic education infrastructure layout should not simply emphasize the economies of scale of schools but should follow the strategy of “tailoring measures to local conditions, gradual implementation, step-by-step approach, and differentiated treatment”. The targeted construction of spatial distribution optimization types for rural basic education infrastructure was carried out based on the analysis of multi-space resistance and a comprehensive evaluation of field potential in rural basic education.

- (1) Based on the above evaluation index system, the spatial resistance of Liji Township’s basic education infrastructure was superimposed, and the resistance surface was divided into five categories, namely, the maximum-resistance zone, high-resistance zone, moderate-resistance zone, low-resistance zone, and minimum-resistance zone, by using the natural breakpoint method. Moreover, the values of the field components were evaluated, and frequency histogram statistics were calculated. Then, the equal interval method was employed to divide the potential energy, district, and threshold field component indices into the three value intervals of high, medium, and low.
- (2) Education infrastructure with low potential energy index resistance has high-potential energy component values, indicating that the current school development foundation

is good, the school construction and the scale of teachers and students are large-scale, the investment cost is high, and the region is highly attractive to the surrounding residents. When the district index resistance is low and the district component value is correspondingly high, this indicates that the current school is in a good location with good accessibility and a wide service influence range. When the threshold index resistance is low and the threshold component value is high, this suggests that the school's village has a large population, a high degree of aggregation, good industrial development, and a high potential for future education enrolment.

- (3) The model types for optimizing the spatial layout of rural basic education infrastructure were determined based on the division of the above components into appropriate levels and the evaluation calculation results (Table 2) [78]. Low-threshold component values indicate that the scale of educational infrastructure in the village is small and that socioeconomic development is relatively underdeveloped, making it unsuitable for village living and production. It may gradually decline and be merged in the future, so low-threshold component values are defined as the Type III optimization category. High-potential component values indicate that the current educational infrastructure has advantages such as a good educational scale and a solid foundation for construction. When high-potential component values are selected as alternative types, the remaining types, after excluding Type III, form the Type I category. Similarly, when high district component values are selected as alternative types, the remaining types, after excluding Types I and III classifications, are Type II optimization types.

Table 2. Decision-making rules of field potential classification and optimization mode of rural basic education infrastructure.

Classification Type	Potential Energy Component	District Component	Threshold Component	Combination Type
I	High suitability	High/moderate/low suitability	High/moderate suitability	Reservation and improvement mode
II	Moderate/low suitability	High suitability	High/moderate suitability	Migration and optimization mode
III	High/moderate/low suitability	High/moderate/low suitability	Low suitability	Merging and revocation mode

4. Results

4.1. Resistance Model Evaluation Analysis

The component index and overall resistance value formed by the resistance factor and weight values, according to Table 1, were calculated and visualized using ArcGIS (Figure 3), with the results showing that there are significant spatial differences in the resistance surface of the basic education infrastructure in Liji Town Elementary School. The areas with the least resistance and relatively less resistance were concentrated on the east and west sides of the township, while the areas with the greatest resistance and relatively greater resistance were mainly distributed in the southern and northeastern regions. In terms of the quantity index, except for the potential energy index, all other indices showed a spatial pattern with less resistance in the surrounding areas centered on Liji Elementary School and Zhangdian Elementary School and greater resistance in the north–south region.

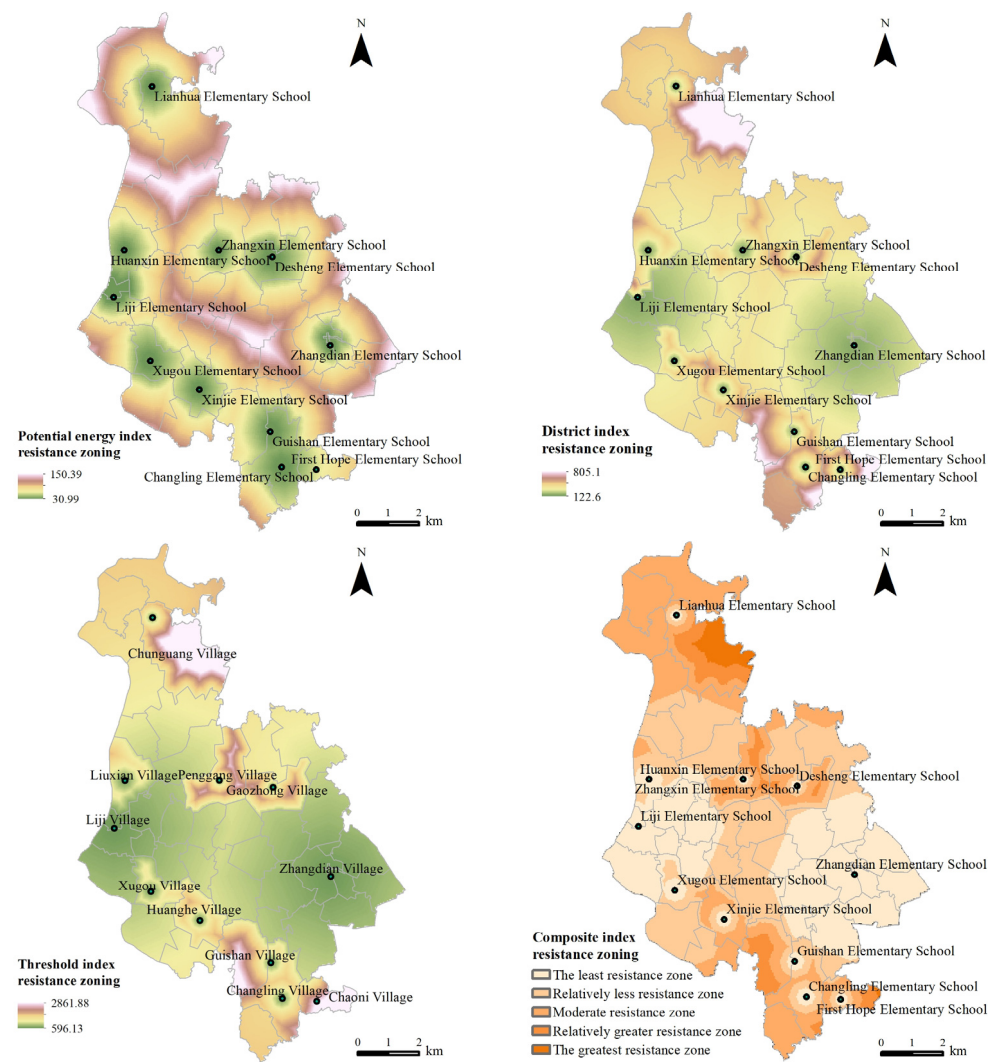


Figure 3. Minimum resistance surface of rural elementary school education infrastructure.

4.2. Field Potential Evaluation

The results for the basic education field in Liji Town Elementary School were calculated according to the model of educational field measurement (Table 3). Zhangdian Elementary School and Liji Elementary School have significant differences in terms of their school scale and service scope compared to the schools in nearby and distant villages, with the potential energy component showing the most obvious difference in the form of a gradual decrease from the central village to the surrounding nearby and distant villages. The territorial component and threshold component of rural education infrastructure in nearby villages are significantly greater than those in distant villages because the socioeconomic development and spatial accessibility of the schools in nearby rural settlements are significantly greater. The spatial distributions of the potential energy component and threshold component of basic education infrastructure in the central villages are essentially consistent, indicating that the degree of hollowing out in the central villages is relatively low, and the level of socioeconomic development is consistent with the construction of basic education infrastructure. The potential energy and threshold components of basic education infrastructure in the distant villages are generally low, which reflects the weak socioeconomic development of the corresponding rural settlements, small school scale, and significant influence from the topography, resulting in inconvenient transportation.

Table 3. Evaluation results of rural elementary school education infrastructure.

School Name	Potential Energy Index		District Index		Service Threshold Index		Comprehensive Index of Educational Field	
	Numerical Value	Rank	Numerical Value	Rank	Numerical Value	Rank	Numerical Value	Rank
Huanxin Elementary School	0.0896	10	0.2789	8	0.1985	3	0.2379	7
Changling Elementary School	0.2850	3	0.3060	5	0.1905	4	0.3085	3
Xinjie Elementary School	0.1759	7	0.3072	4	0.1315	7	0.2392	6
Xugou Elementary School	0.2234	6	0.3441	3	0.1617	5	0.2878	4
Zhangdian Elementary School	0.6381	2	0.7018	2	0.3370	2	0.6965	2
Liji Elementary School	0.9845	1	0.7244	1	0.9187	1	0.8606	1
Desheng Elementary School	0.2639	5	0.2203	10	0.1058	10	0.2290	8
Lianhua Elementary School	0.1572	8	0.2832	7	0.1217	8	0.2183	9
Guishan Elementary School	0.1098	9	0.2214	9	0.1478	6	0.2011	10
First Hope Elementary School	0.2690	4	0.3058	6	0.0980	11	0.2562	5
Zhangxin Elementary School	0.0380	11	0.1558	11	0.1199	9	0.1248	11

4.3. Optimization of the Layout of Basic Education Infrastructure

In the different stages of development, from “universal basic education” to the “balanced allocation of resources”, the adjustment of the educational resource layout is an important means to achieve goals. The division results of the field potential component levels, optimization types, and optimization modes of the basic education infrastructure in each village (Table 4) and the spatial distribution optimization layout map (Figure 4) were obtained based on the analyses of the spatial resistance and field potential evaluation results of the rural basic education infrastructure in Liji Township combined with the spatial optimization model of rural basic education infrastructure.

- (1) Reservation and improvement category. This type of school is in the central village, with good socioeconomic development and a high quality of education, making it a key educational facility for future development. The schools in this category are Liji Elementary School, Zhangdian Elementary School, and Changling Elementary School. The individual component values of Liji Elementary School and Zhangdian Elementary School are relatively high. The villages where the two schools are located have flat terrain and good socioeconomic development conditions, and one of the schools is close to the town center. The school is large in terms of its land area, building infrastructure, and enrolment numbers, and it is located at the intersection of two county roads, making it not only easily accessible for transportation but also highly appealing for students. Due to its large service area, further improvements in educational resources and the expansion of teaching infrastructure are needed. The threshold and district weight of Changling Elementary School are relatively high. It is close to the provincial and county roads, and the school has a large land area. The surrounding rural settlements have a high density and population size and thus provide a good source of students. Therefore, it is necessary to further comprehensively improve the campus environment, integrate and gather scattered educational resources, improve the scale of the land space and facility construction, further invest in the teaching staff and promote enrolment, and accordingly enhance the comprehensive strength of basic education.
- (2) Migration and optimization category. This type of school has an average scale, a relatively small service radius, and a low level of economic development in the village where it is located. This category is oriented towards integrated education functionality and fairness and involves the rational replacement and relocation of the current elementary school spatial layout, optimization of the allocation of basic education resources, improvement of the quality of rural basic education infrastructure,

and conversion of vacated educational land into rural public activity spaces. The migration-optimized schools include Xinjie Elementary School, Xugou Elementary School, Desheng Elementary School, and Lianhua Elementary School. Xinjie Elementary School is in the center of Huanghe Village, but it is far from the county and village roads, and the current enrolment scale is insufficient. It can be merged with Xugou Elementary School and appropriately relocated southeast along the county road to further integrate educational resources and more effectively extend to and serve the southeast rural settlements. The threshold index of Desheng Primary School is relatively high, with good student potential, but it is far from county and village roads, resulting in poor service balance and centrality. The migration of this school to the eastern county roads is recommended to serve rural settlements in the central and eastern regions and promote the rational and optimized allocation of primary education resources in the central and eastern regions of Liji Street. The scale of Lianhua Elementary School is average, but the surrounding rural settlements have high density and great potential for students. It is recommended to relocate this school to the southern part of Chunguang Village. On the one hand, the area has dense rural roads and convenient transportation, and on the other hand, it extends to the southern countryside.

- (3) Merging and revocation category. This type of school has a small scale and service radius, severe population outflow from villages, a low level of socioeconomic development, and faces the dilemma of decline. The schools in the merging and revocation category mainly include Huanxin Elementary School, First Hope Elementary School, Guishan Elementary School, and Zhangxin Elementary School. These types of elementary schools have low potential and threshold values, and the villages to which they belong are far from the center of the region. These schools have a small area and building scale, the educational infrastructure is dilapidated, and the teaching staff are weak. Huanxin Elementary School has a low potential energy index and district index, and its infrastructure and accessibility are insufficient. However, it is adjacent to Liji Elementary School, and its threshold index is high. It is recommended that this school merge with Liji Elementary School to enhance its service scope. First, Hope Elementary School and Guishan Elementary School are located near the county road with convenient transportation, but are adjacent to Changling Elementary School. Due to the catchment areas of the aforementioned central schools, their service scope is limited to Chaoni Village and Guishan Village. The current situation of student loss is serious, and the quality of education is poor. It is suggested that these schools merge with the Changling Elementary School nearby. In addition, Zhangxin Elementary School is in a rural area with complex topography and landforms. The output value of secondary industry and the number of agricultural cooperative organizations are relatively small. The socioeconomic conditions are relatively poor, and a stable population of students is not guaranteed. There is competition and duplication of construction with Desheng Elementary School in the east. The balance of serving the surrounding villages is poor. Merging with Desheng Elementary School is recommended to further improve the efficiency of school operations and the quality of service.

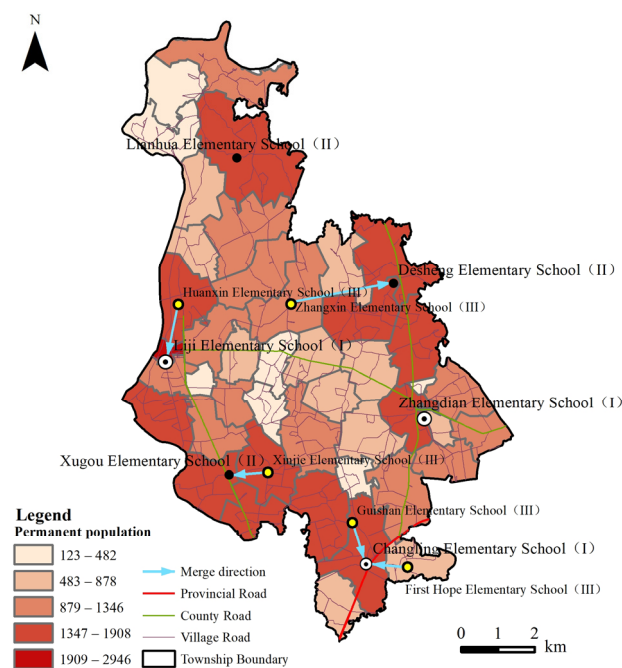


Figure 4. Spatial distribution optimization of rural elementary school education infrastructure.

Table 4. Spatial distribution optimization classification and pattern design results of rural elementary school education infrastructure.

School Name	Component Combination of Potential Energy–District–Service Threshold	Optimization Type	Optimization Strategy
Huanxin Elementary School	Low–low–high	Merging and revocation (III)	Merge to Liji Elementary School
Changling Elementary School	High–moderate–high	Reservation and improvement (I)	Strengthen and improve educational resources, enhance school-supporting infrastructure
Xinjie Elementary School	Low–moderate–low	Merging and revocation (III)	Merge to Xugou Elementary School
Xugou Elementary School	Moderate–high–moderate	Migration and optimization (II)	Migration to the southeast, near the county road
Zhangdian Elementary School	High–moderate–moderate	Reservation and improvement (I)	Strengthen and improve educational resources and increase the scale of schools
Liji Elementary School	High–moderate–high	Reservation and improvement (I)	Strengthen and improve educational resources and increase the scale of schools
Desheng Elementary School	Moderate–low–moderate	Migration and optimization (II)	Migration to the northeast, near the county road
Lianhua Elementary School	Low–moderate–moderate	Migration and optimization (II)	Migration to the south, near the village road
Guishan Elementary School	Low–moderate–low	Migration and optimization (III)	Merge to Changling Elementary School
First Hope Elementary School	Moderate–moderate–low	Merging and revocation (III)	Merge to Changling Elementary School
Zhangxin Elementary School	Low–moderate–low	Merging and revocation (III)	Merge to Desheng Elementary School

5. Discussion

5.1. Analysis of Rural Education Resource Merger and Stratum Competition

5.1.1. The Advantages and Disadvantages of School Consolidation

School consolidation—the closure and merger of small schools to form larger schools—is a common strategy to economize and create an environment for staff and students with better resources in the context of demographic changes. An extremely rapid fertility decline and urbanization have accelerated pressures for system consolidation in China. The State Council announced the Rural Primary School Consolidation Program (RPSCP) in 2001, which essentially involved shutting down remote village schools and merging students into centralized town or country schools. School consolidation was implemented rapidly in China. The official data indicate that nearly 312,400 primary schools were closed due to the consolidation program between 2001 and 2011, an extreme decrease of 56.42% [88].

It should be pointed out that the merger of schools will inevitably lead to an increase in students’ distance to school. However, school consolidation can help maintain standardized school sizes and maintain educational standards in the context of the continuous decline in the rural population size. Most empirical studies have shown that the resource effect of the policy of school mergers and acquisitions in China is significant, and the destructive effect

is not obvious, especially for areas with small student populations in rural schools [89,90]. In the rural survey of Liji Town, 74.88% of students had a transportation time to school of less than 25 min, and 73.41% of students chose non-walking methods. Rural residents can afford to pay more transportation costs to receive better education. In addition, the optimization plan proposed in this article can be utilized to convert the merged schools into public activity spaces or landscape green spaces or transfer the land and use the transfer proceeds to purchase school buses for students who live farther away from school. Finally, the 14th Five-Year Plan proposes to strengthen the construction of rural boarding schools to solve the problem of students attending schools far away. Boarding can offset some of the negative effects caused by the increase in commuting distance.

5.1.2. Stratum Competition in the Process of High-Speed Urbanization

In the process of high-speed urbanization, stratum competition is gradually becoming an important factor affecting the transformation of rural education. Existing research on the interaction between education and social classes has been most widely influenced by the classic “status acquisition model” proposed by Blau Duncan, which mainly focuses on class differences in educational opportunities and resources and the micro impact of educational processes on class reproduction [91]. Specifically, with the comprehensive penetration of the market economy, economic differentiation in rural areas has emerged, and various forms of class competition have also appeared between different social classes. In cities, living a dignified life in urban communities has become an example of success to villages and has become the most prominent symbol of capital in class competition. The development goal of rural household universalism is to achieve the social mobility of families in village communities or to settle them in surrounding counties and cities. In the context of class competition, the combination of educational urbanization and rural household urbanization goals has increased daily the social importance of children’s education. Once children’s education is regarded as the main or only opportunity to achieve upward mobility in the family, continuous cohesion and the accumulation of resources within the family occur, and the possibility of achieving goals is enhanced through children’s education as they enter the city while alleviating the social pressure of class competition. Class competition in the process of high-speed urbanization is therefore becoming an important driving force for the transformation of rural education urbanization. However, this transformation deviates from the existing foundation of rural social development in terms of its speed and scale, leading to the defunding of rural education to a certain extent.

In this rural survey, 70.44% of residents believe that the quantity of public education is average or insufficient and that there is a lack of high-quality educational facilities. In the evaluation of the current teaching situation in the village by residents, 51.23% were generally satisfied, 37.44% were somewhat satisfied, and only 3.45% were very satisfied. The number and density of primary schools in new urban districts are much higher than those of middle schools. In addition, the agglomeration effect of each district center is obvious and attracts a larger population to the main urban area or district center, resulting in primary and secondary schools also clustering in the district center, making the service area of rural primary schools closer to the district center larger. Therefore, an increasing number of students are choosing to enter townships or city centers to obtain better educational resources.

5.2. The Application Prospects of This Method in the Layout of Educational Facilities

The development demand for new urban districts is high, and the supply of educational facilities is insufficient. The original education design based on townships cannot easily meet the needs of population growth. The education facilities at all levels in the new

urban district have problems such as a small service scale, small quantity, and large service radius. The development of the new area requires a reasonable layout of infrastructure, such as education and public services. Optimizing the location and scale of facilities helps to balance residents' supply–demand relationship. The field intensity effect model was used in this study to analyze the optimization of the spatial allocation of educational resources and prove that it has, to some extent, improved the uneven distribution of basic education resources in Liji Town. The research results can provide a reference for the rational layout and planning of primary education resources as well as the formulation of segmented enrollment policies. The method presented in this article can be applied to evaluate the public service space of compulsory education in other rural regions. In the public service system, there are scenarios such as dynamic demand, facility changes (increase or decrease or relocation), and changes in transportation conditions. When there is a change in the service system, the method described in this article can be used to re-evaluate its accessibility and differentiation and determine whether the level of public services has been improved and whether adjustments are necessary.

5.3. Suggestions for Rural Educational Development in the New Urban Districts of Metropolitan Areas

First, it is necessary to optimize the allocation of educational resources between urban and rural areas. The government should coordinate financial investments in urban and rural education to ensure the educational needs of rural students and provide sufficient educational resources for the urban school-age population to achieve unity of efficiency and equity. Second, diverse entities led by the government, such as social organizations, should be introduced to participate in rural basic education. Targeted and operational education services should also be provided in response to the current situation and development foundation of rural education in different regions in terms of education supply due to government failure.

Finally, the government needs to formulate optimization strategies for different types of schools. To preserve and improve the optimization type, the basic education infrastructure in this area should have a low cost and high efficiency, and residents should have a short travel time to school and high accessibility to education. In addition to fairness, the configuration efficiency of basic education infrastructure must be improved to save costs. The spatial allocation of basic education infrastructure should be gradually improved and enhanced while maintaining the current situation to achieve optimal efficiency in facility allocation and convenience for residents attending school. Regarding the migration-optimized optimization type, rural schools need to be appropriately equipped with basic education infrastructure or relocated and merged based on the specific population distribution of village settlements to ensure maximum facility efficiency, improve the convenience of residents' education, and achieve a good spatial configuration of basic education infrastructure. Regarding optimization withdrawal and cancellation, the scale of basic education infrastructure should be reduced, the utilization of educational resources should be improved, and a balance between the efficiency and fairness of educational facility allocation should be achieved based on the specific number of people served by basic education infrastructure in the settlement while maintaining educational equity among residents as much as possible. Additionally, the dismantling and merging of redundant basic education infrastructure should be addressed to improve facility configuration efficiency.

5.4. Limitations and Future Research Directions

Through an in-depth analysis of the “educational field situation” of rural basic education infrastructure, it is believed that the differences in the educational field situation are the objective basis and main driving force for optimizing the spatial layout of rural basic ed-

ucation infrastructure. However, the spatial distribution of rural basic education resources is the result of the accumulation and superposition of multiple factors during different development periods. Optimizing the layout of rural education infrastructure through field theory is aimed at addressing the current situation of rural socioeconomic development and a relatively stable population. Under the constraints of specific rural natural and location conditions, it is necessary to take the development time and sequence as the main objective, closely combine dynamic development factors such as rural consolidation, population migration, socioeconomic development, and local education policy guidance, and scientifically and reasonably guide the formation and optimization of the spatial patterns of rural basic education resources. Therefore, further exploration of these dynamic factors that affect the optimization of the spatial distribution of rural basic education infrastructure is still needed. It is necessary to continue conducting in-depth research on the matching and spatial distribution optimization potential, optimization benefit evaluation, and feedback mechanism of rural basic education infrastructure based on the theory of field potential.

The problem of the spatial layout of rural basic education facilities cannot be solved solely by means of spatial adjustment. More often than not, spatial layout issues are the externalization of factors such as imbalanced supply-and-demand structures, imperfect supply methods, and deficiencies in institutional design at the spatial level. This also requires that when studying the spatial layout of basic education facilities, in addition to seeking the layout structure that maximizes resource utilization from the perspective of spatial geometry, attention should be paid to combining factors outside of space, including rural governance reform, financial and tax system guarantees, and public participation measures, in order to enhance the practical significance and implementation effectiveness of the optimization results. In addition, with the development of new urbanization, the spatial agglomeration and migration of populations, the implementation of rural revitalization policies, and the reform of the registered residence system, the existing rural basic education service facilities in the new urban area may face problems of disuse or insufficient capacity. It is necessary to obtain dynamic spatiotemporal data to predict and simulate the future development of rural basic education services.

6. Conclusions

A comprehensive field potential index evaluation system was established in this study on rural basic education infrastructure, guided by utilizing field potential theory by defining the connotations and measurement of educational field potential based on the elementary education and survey data of Liji Town in 2022. The potential energy, the district, and threshold component indices, and the comprehensive field potential index of rural basic education infrastructure in the research area were evaluated to determine the high, moderate, and low types of suitable educational infrastructure in the research area. The main conclusions of the above analysis are as follows:

- (1) There are significant spatial differences in the resistance surface of the basic education infrastructure in Liji Town Elementary School. The areas with the least resistance and relatively less resistance are concentrated on the east and west sides of the township, while the areas with the greatest resistance and relatively greater resistance are mainly distributed in the southern and northeastern regions.
- (2) There are spatial differences in the three components of the basic education field in Liji Town. The potential energy component and threshold component show a pattern of gradually decreasing from the central village to the periphery. However, the components of both the district and service thresholds showed higher values for the suburban villages and lower values for the peripheral villages.

- (3) A method for identifying the spatial distribution optimization types of rural basic education infrastructure was constructed, and three types of spatial distribution optimization models were designed, namely, retention and improvement, transfer and optimization, and consolidation and cancellation, which essentially conform to the actual situation of rural socioeconomic development in Liji Township.

Research shows that the current status of rural basic education infrastructure and the regional characteristics and functional orientation of the corresponding rural settlements can be fully reflected through the evaluation of rural basic education infrastructure and the design of spatial distribution optimization models. By evaluating and optimizing the use of inefficient, unreasonable, or underutilized rural basic education infrastructure in terms of its spatial layout, not only can the compatibility of subjective and objective factors such as rural education resources, natural resources, and social and economic development resources be achieved, but the suitability and science of optimizing rural infrastructure education space can also be analyzed from multiple dimensions and perspectives. This method can also be used to identify the sources of benefits from optimizing rural basic education facility space from multiple dimensions by providing new theoretical support and methodological innovation for the matching and optimization of rural basic education infrastructure, and it has certain reference significance for the matching and spatial distribution optimization practices of other related infrastructure, such as rural health care and cultural, sports, and commercial infrastructure.

In contrast to the traditional optimization methods that only consider spatial accessibility factors in basic education infrastructure [92,93] (such as potential models and the two-step floating catchment area method), the field potential effect describes the “educational field potential” of the village from multiple dimensions, which is beneficial for the accuracy of conceptual analysis. The field model optimization method considers both the accessibility of educational facilities and the natural and social development characteristics of rural areas. This model does not involve parameter selection, and its calculation results have clear practical guidance significance. It can be flexibly used to calculate educational facility service indicators (such as the school size, transportation accessibility, rural area where the school is located, and service coverage within a specific radius) and to create various thematic maps. Furthermore, effectively measuring the status of the construction of educational facilities and the regional characteristics and functional orientation of the rural settlements they belong to and identifying areas with poor spatial educational facilities and declining rural settlements can make up for the shortcomings of existing evaluation methods. Therefore, by reconfiguring and allocating rural basic education infrastructure resources, the layout and operational location of schools can be effectively changed. By integrating the spatial layout of educational resources, we can further leverage the synergistic driving effect of the rural spatial education scale.

Optimizing the spatial layout of rural basic education facilities can alleviate the spatial layout problem caused by the threshold-accessibility contradiction to a certain extent, but it is not the optimal solution. Rural areas need to closely link educational facilities with the economic development level, industrial structure, population structure changes, and other aspects. On the basis of inherent spatial characteristics, targeted, dynamic optimization should be carried out based on population changes. Therefore, scientific and objective research and evaluation are needed for the application of the above plan, and adjustments should be made according to local conditions. In addition, educational facilities are different from general economic goods or services, and efficiency cannot be blindly pursued at the expense of fairness. This also means that the spatial adjustment of educational facilities cannot be carried out simply due to scale reasons. We should coordinate on a larger scale and provide flexible support according to the differences in population structure and

demand in different regions. The facility scales are divided into three levels: “central town-central village-general village”. The reservation and improvement schools are located in the center of towns, and high-quality material and teaching resources should be concentrated in this area to develop education, thereby promoting the intensive use of facilities while playing a demonstrative role and guiding some students to gradually flow back to the central village. On the one hand, this can alleviate the pressure on the township center, and on the other hand, it can help develop the potential of educational facilities in the central village. The migration and optimization schools are located in the central villages, and this strengthens the construction of transportation and other infrastructure, improves the accessibility and service radius of existing facilities, reduces the overlap of service radii, and improves resource utilization efficiency. The merging and revocation schools are located in general villages. Due to the continuous loss of students, educational resources have not been fully utilized, resulting in the inefficient use of educational resources. Considering a small-scale, fully equipped, and high-quality development teaching model, an efficient communication platform between the central town schools and peripheral village schools is being constructed.

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