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GIS-Based Suitability Evaluation and Coupling Coordination Analysis of the Spatial Layout of Small-Scale Kindergartens in Rural Areas of Sichuan, China: A Case Study of ZJ County

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Abstract:

To optimize the spatial layout of small-scale kindergartens in rural Sichuan and promote the balanced allocation and co-construction/sharing of preschool education resources, this study takes small-scale kindergartens in the rural areas of ZJ County, Sichuan Province as a case. Based on POI data and employing analytical techniques including standard deviational ellipse, kernel density estimation, multi-factor weighted evaluation, and coupling coordination degree model, we examine their spatial distribution patterns and layout suitability, and further analyze the intrinsic coupling coordination relationships. The results indicate that the spatial distribution of kindergartens in the region exhibits a pattern of "single-core agglomeration with peripheral dispersion", with XC Town concentrating 44.4% of the county's kindergartens, showing pronounced spatial polarization. In addition, population density, road density, and terrain slope jointly shape a suitability gradient for rural small-scale kindergarten layout that is favorable in valley areas but poor in mountainous areas, and some high-suitability settlement patches on the periphery exhibit supply-demand gaps in preschool education resources. The spatial differentiation of coupling coordination degree is significant, with well-matched conditions in the core urban area but generally low levels in peripheral townships. Further discussion addresses aspects such as the spatial supply-demand layout of preschool education resources, regional disparities in polarization degree, constraints imposed by factors including population, roads, and terrain, and the spatial overlap between coupling coordination degree and suitability. Finally, differentiated recommendations are proposed, including improving quality and efficiency of small-scale kindergartens, supplementing construction in key townships, and flexibly supplying services in high-mountain areas.

Keywords:

rural small-scale kindergartens, spatial layout, suitability evaluation, coupling coordination, ZJ county, Sichuan

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1. Introduction

A hundred years of life begin with early education. High-quality preschool education bears on the healthy growth of hundreds of millions of children and on the nation's development and future. The high-quality development of rural preschool education is of great significance for revitalising rural education, building a strong education nation, and advancing Chinese path to modernisation. Since the 18th National Congress of the Communist Party of China, preschool education in China has achieved rapid progress, with the gross enrolment rate rising substantially and problems such as "difficulty in accessing kindergarten" and "high costs of kindergarten" being markedly alleviated. In 2024, the Preschool Education Law of the People's Republic of China was formally promulgated, which explicitly proposes "building a public-service system for preschool education that covers both urban and rural areas, has a rational layout, is public-welfare oriented, inclusive, safe and high-quality", and requires "prioritising support for the development of preschool education in rural areas, old revolutionary base areas, ethnic minority areas, border areas, and underdeveloped regions"[1]. However, against the backdrop of a sustained decline in the newborn population and rapid urbanisation, rural preschool education is confronted with a series of new challenges: many small-scale kindergartens (or preschool teaching sites) are experiencing shrinking enrolments, resource shortages, and worrying quality, and some are even at risk of closure. These issues may lead to longer travel distances and higher costs for rural school-age children to access kindergarten, thereby undermining the realisation of educational equity[2]. Particularly in rural areas, the interplay of natural and social conditions—such as complex terrain, inconvenient transportation, and scattered population—makes the spatial layout of kindergartens even more complicated[3].

At present, the province has achieved notable results in enabling rural children to "attend kindergarten nearby". Yet, incongruities have emerged between the layout of small-scale kindergartens (teaching sites) and the demand for student enrolment as well as the allocation of educational resources. Most analyses of these issues have been conducted from the perspectives of theoretical deduction, subjective surveys of stakeholders, or urban-based kindergarten governance approaches, and there remains a lack of evidence from interdisciplinary research fields such as systematic spatial analysis based on geographic location. Consequently, the practical effectiveness of specific measures to address these problems has been limited.

A review of domestic and international scholarship reveals that existing studies have mostly focused on the spatial layout of preschool education resources in urban areas, with considerably less attention paid to rural kindergartens, especially small-scale rural ones. The few studies that do exist tend to emphasise a single dimension—such as accessibility or suitability—and rarely associate the current distribution with construction-suitability conditions in an integrated manner[4][5][6]. This study focuses on rural kindergartens in ZJ County, Sichuan Province, with particular attention to the development of small-scale kindergartens and "One Village, One Kindergarten" teaching sites. By comprehensively employing spatial analysis and multi-factor evaluation methods, we map the spatial distribution pattern of these small-scale kindergartens (teaching sites), assess their layout suitability, and introduce a coupling coordination model to identify the degree of match between the two. Through this approach, we attempt to explore the current status of co-construction and sharing of preschool education resources among small-scale rural kindergartens (teaching sites) and their underlying mechanisms, so as to help improve the quality of these institutions and promote the safe, high-quality, univer-

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sal, and inclusive development of preschool education in rural areas.

2. Study Area and Data Sources

2.1 Overview of the Study Area

ZJ County is located in the southwestern part of Sichuan Province, between 27°45′–28°21′ N latitude and 102°22′–103°19′ E longitude. It covers an area of 2,564.75 km² and administers 20 townships (towns). The registered population is 351,917, while the permanent population is 257,000. The county features rugged terrain with interlocking river valleys and mountainous areas, and significant variations in traffic accessibility. It is a typical mountainous agricultural county.

2.2 Data Sources and Preprocessing

The research data include POI data of kindergartens (preschool teaching sites) in ZJ County, administrative boundary data, road network data, DEM data, and demographic statistics. The kindergarten (teaching site) data were obtained from the official website of ZJ County People's Government, with an update date of 30 April 2026. After screening, a total of 54 kindergartens (teaching sites) were identified. Through geocoding, the detailed addresses were converted into longitude and latitude coordinates, generating a spatial point dataset of kindergartens (teaching sites). Administrative boundary data were derived from the Resource and Environment Science Data Platform (https://www.resdc.cn/), using the national administrative village boundary dataset for 2024. Road vector data were obtained from the National Geographic Information Public Service Platform and BIGEMAP for kernel density analysis of roads. DEM elevation data were sourced from the Geospatial Data Cloud (https://www.gscloud.cn/) to extract slope gradients for evaluating construction constraints on kindergarten (teaching site) placement. Population data were obtained from the Bulletin of the Seventh National Population Census of ZJ County (No. 2), serving as the base data for population density interpolation.

3. Data Processing Methods and Techniques

3.1 Standard Deviational Ellipse

The standard deviational ellipse is a classical spatial statistical tool for point features. It determines the elliptical geometry by calculating the standard deviation of distances from each point to the ellipse centre, and can intuitively reflect the dispersion degree, dominant direction, and agglomeration centre of the spatial distribution of geographic elements[7]. Specifically, the centre point represents the mean centre of the spatial distribution; the long axis indicates the main extension direction; the short axis reflects the degree of dispersion; and the ellipse area characterises the overall clustering range. This method is used in this study to identify the overall spatial distribution direction and clustering extent of kindergartens (teaching sites) in ZJ County.

3.2 Kernel Density Estimation

Kernel density estimation is used to calculate the spatial density of point and line features within their sur-

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rounding neighbourhoods, converting discrete vector elements into continuous density raster surfaces[8]. In this study, kernel density estimation is applied separately to kindergarten (teaching site) points, population, and road networks to output continuous density surfaces, thereby visually representing the spatial agglomeration of kindergartens (teaching sites), the population clustering pattern, and the spatial distribution of road traffic.

3.3 Suitability Evaluation for Kindergarten Layout

A GIS-based multi-factor weighted overlay evaluation method[8] is adopted. Population density, road density, and terrain slope raster factors are selected to construct a suitability evaluation system for the layout of kindergartens (teaching sites) in ZJ County. Each factor is classified into five levels using the natural breaks method and assigned scores from 1 to 5, with higher scores indicating more favourable conditions for kindergarten (teaching site) layout under that individual criterion. Following the principles of demand priority, traffic adaptability, and terrain constraints, the weights are determined as: population density 0.5, road density 0.3, and slope 0.2. Through pixel-by-pixel raster calculation, a continuous suitability raster for kindergarten (teaching site) layout across the entire county is obtained, with scores ranging from 0 to 5. The resulting scores are again classified into five grades using the natural breaks method.

3.4 Coupling Coordination Degree Analysis

The coupling coordination model can measure the degree of mutual matching and coordinated development between two systems[9]. In this study, the spatial distribution density of kindergartens (teaching sites) is taken as subsystem 1, and the layout suitability of kindergartens (teaching sites) as subsystem 2. The coupling coordination degree is calculated for each spatial unit to identify whether the current distribution of kindergartens (teaching sites) matches the regional suitability conditions for layout. The coupling coordination degree ranges from 0 to 1, with higher values indicating a stronger degree of matching and coordination between the existing distribution and the layout suitability.

4. Results and Analysis

4.1 Analysis of the Spatial Pattern of Kindergartens

Statistics on the number of kindergartens (teaching sites) in the 20 townships of ZJ County are presented in Table 1. Among the 20 townships, XC Town has 24 kindergartens (teaching sites), accounting for 44.4% of the county's total; CB Town has 5, SK Town has 3, and five townships including BE Town and DM Town each have 2, while the remaining 12 townships have only 1 each.

Table 1. Number of kindergartens (teaching sites) by township in ZJ County

Township	Number of kindergartens (teaching sites)	Township	Number of kindergartens (teaching sites)
XC Town	24	EE Town	1
CB Town	5	GL Town	1
SK Town	3	GQ Town	1

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BE Town	2	HG Township	1
DM Town	2	JFG Town	1
QH Township	2	JQ Township	1
SCH Town	2	MG Township	1
ZH Town	2	RH Township	1
BL Township	1	TBL Township	1
BY Township	1	ZP Township	1

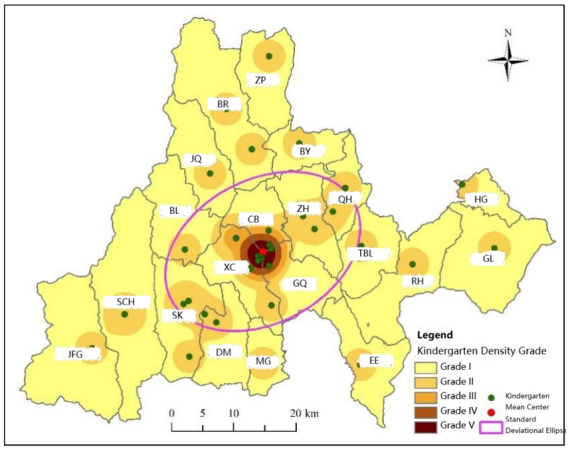


Figure 1. Spatial distribution pattern of kindergartens (teaching sites) in ZJ County

The overall spatial distribution of kindergartens (teaching sites) in ZJ County exhibits a pattern of "single-core agglomeration with peripheral dispersion". The centre of the standard deviational ellipse is located in XC Town, which is the core of kindergarten distribution; the long axis runs in a northeast-southwest direction, indicating that the overall distribution extends along that orientation. The ellipse covers the county seat and its neighbouring townships, while only scattered kindergartens (teaching sites) appear in the vast peripheral townships outside the ellipse, with low kernel density levels and an absence of secondary agglomeration centres. This indicates a marked spatial polarisation of kindergarten (teaching site) distribution (see Figure 1.).

4.2 Results and Analysis of Population, Transport, and Terrain Factors

Population density, road density, and terrain slope are the three core factors constraining the layout of kindergartens (teaching sites) in mountainous county areas. Among them, population density reflects the level of student source agglomeration: higher density implies a larger number of school-age children and a more urgent demand for services. Road density reflects traffic accessibility: areas with high road density have lower travel costs and better locational conditions. Slope is a rigid natural constraint: steep slopes pose construction difficulties and higher geological risks, making them unsuitable for kindergarten establishment. In this study, kernel density estimation was applied to population data and road vectors respectively, and slope analysis was conducted on the DEM. Each factor was then classified into five grades using the natural breaks method and assigned scores from 1 to 5, with higher scores indicating more favourable conditions for kindergarten (teaching site) layout under that specific criterion.

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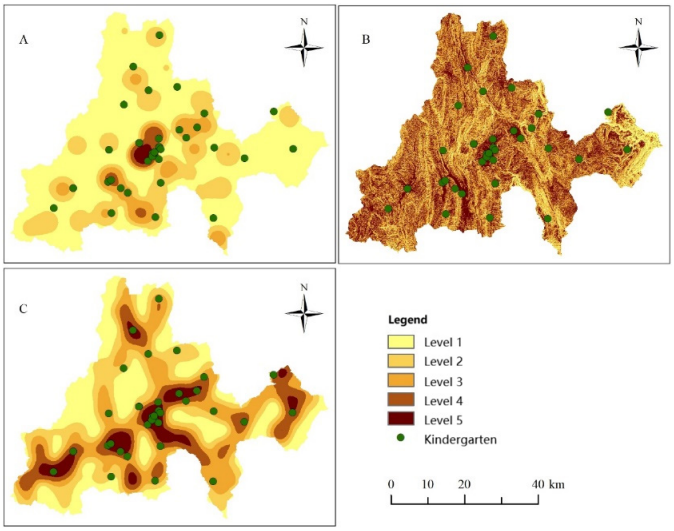


Figure 2. Spatial distribution of single-factor suitability grades in ZJ County (Note: A, population suitability grade; B, slope suitability grade; C, road suitability grade)

From the single-factor evaluation results (see Figure 2), the high-value core of population density is concentrated in the urban area of XC Town, with secondary agglomeration patches in CB, SK, and ZH Townships, while remote townships in the northern, eastern, and southern parts of the county have sparse population and scattered student sources. High-value road density zones extend along the main county roads, forming local high-value points at township seats, whereas road networks in marginal mountainous areas are of lower grade. Slope-suitable areas are confined to the county's river valleys and some flat lands in townships, while steep slopes are widespread across the vast mountainous regions. Overlaying the existing kindergarten (teaching site) points onto each factor layer reveals that most kindergartens (teaching sites) are located in township seats and valley areas with medium-to-high population density, medium-to-high road grades, and relatively gentle slopes, indicating generally reasonable site selection. However, two problems are also identified: first, some peripheral population agglomeration patches lack kindergarten (teaching site) coverage, creating gaps between demand and supply; second, some mountainous kindergartens (teaching sites) are surrounded by low-density road networks with insufficient accessibility, and the limited flat land available for new construction is further constrained by steep terrain.

4.3 Comprehensive Suitability Evaluation Results and Analysis

By performing a weighted raster overlay of the three factors—population density, road density, and slope—according to their assigned weights, we obtained the spatial distribution of comprehensive suitability for kindergarten (teaching site) layout in ZJ County (see Figure 3). From the comprehensive suitability results, high-suitability areas (grades "excellent" and "good") are concentrated in the central-western valley corridor of the county, covering XC Town, CB Town, SK Town, ZH Town, northern SCH Town, and the riverside areas of GQ Town. This belt features gentle terrain, dense road networks, and clustered population, making it the core zone most suitable for concentrated kindergarten construction across the county. Medium-suitability areas are scattered in patches across the gentle slopes of valleys in transitional townships such as BE Town, DM Town, JFG Town, TBL Township, and QH Township, where local conditions allow for kindergarten es-

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tablishment but existing coverage is insufficient. Low-suitability areas are widely distributed in the eastern, northern, and southern high-mountain townships, where steep terrain, sparse road networks, and scattered population impose triple constraints, leaving only sporadic suitable patches at township seats and rendering overall construction conditions extremely limited. In general, the spatial differentiation of suitability is rigidly controlled by valley landforms and mountain ranges, exhibiting a response pattern of "beads along the river" and "agglomeration around towns".

Overlaying the existing kindergarten (teaching site) points onto the comprehensive suitability layer shows that the vast majority of kindergartens in the county seat fall into the "excellent" and "good" suitability zones, indicating generally favourable site selection conditions. Most kindergartens (teaching sites) in peripheral townships are distributed in locally higher-suitability patches at township seats. However, it is also found that some peripheral areas with "good" comprehensive suitability lack kindergarten (teaching site) points, representing potential resource gap zones. A small number of kindergarten (teaching site) points are located in areas of medium or lower suitability, where site selection is relatively constrained by local land conditions.

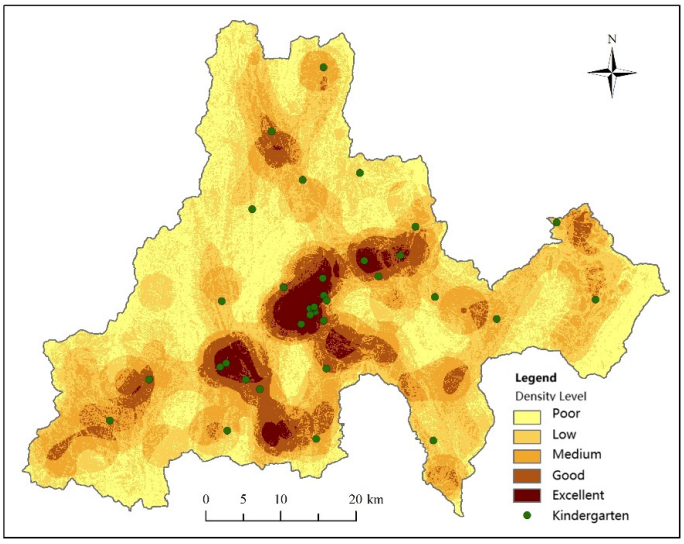


Figure 3. Spatial distribution of comprehensive suitability grades for kindergarten (teaching site) layout in ZJ County

4.4 Coupling Coordination Results and Analysis

By calculating the coupling coordination between the distribution density of kindergartens (teaching sites) and their layout suitability, we obtained the spatial distribution map of the coupling coordination degree across the entire county (see Figure 4). The spatial results show that high-coupling coordination areas (0.6–1.0) are concentrated in the core area of XC Town, where the distribution density and suitability conditions are highly matched. Medium-coordination areas (0.4–0.6) are found in central townships such as Chengbei and Sikai, achieving a basic level of match. Low-coordination areas (0–0.4) are widely distributed along the county's margins; among these, some are constrained by natural conditions (high-mountain areas), while others have acceptable suitability but insufficient supply (valley settlement patches)—the latter being the primary targets for optimisation. Overall, the pattern shows a differentiation of "high in the centre, low in the periph-

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ery; high in valleys, low in mountainous areas". The matching degree within the county seat is high, while the coupling coordination levels in the vast peripheral townships urgently need improvement.

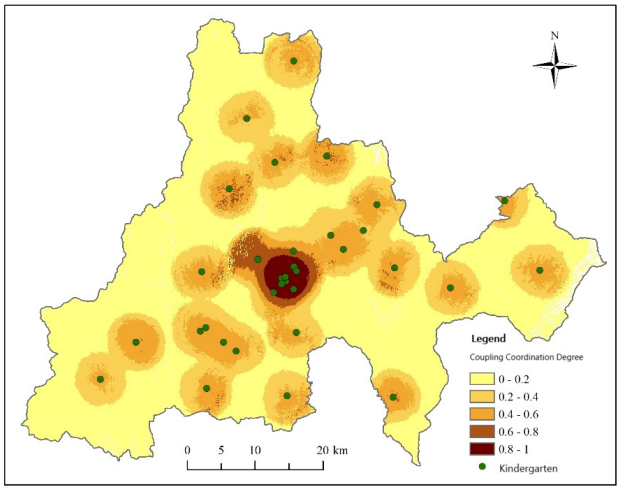


Figure 4. Spatial characteristics of the coupling coordination degree between distribution density and layout suitability of kindergartens (teaching sites) in ZJ County

5. Discussion and Recommendations

5.1 Discussion

Based on the results of the suitability evaluation and coupling coordination analysis of the spatial layout of small-scale kindergartens (preschool teaching sites) in rural ZJ County, this study discusses the following aspects: the spatial supply-demand layout of preschool education resources, regional differences in polarisation degree, the constraints imposed by factors such as population, roads, and terrain, and the spatial overlap between coupling coordination degree and suitability.

First, the coupling coordination degree analysis provides a supply-demand perspective framework for understanding the spatial layout of preschool education resources in rural county areas. In ZJ County, the coupling coordination degree between the distribution density and layout suitability of small-scale rural kindergartens (teaching sites) exhibits characteristics of being high in the centre, low in the periphery; high in valleys, and low in mountainous areas. Among these, high-coupling coordination areas are concentrated in the XC Town area, where distribution density and suitability conditions are highly matched; medium-coordination areas are found in central townships such as CB and SK; and low-coordination areas are distributed in the peripheral townships, further classified into two types: naturally constrained and undersupplied. Fan Lihui (2015) evaluated the supply-demand relationship of educational and medical facilities in Beijing using a coordinated development degree model, and concluded that facilities of different spatial distribution types exhibit differentiated spatial layout characteristics[10]—a finding that is corroborated in this study. In addition, this study further applies the coupling coordination degree model to the analysis of the layout of small-scale kindergartens (teaching sites) in rural areas, and explores in depth the intrinsic differences between the two low-coordination spatial distribution types.

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Second, the spatial distribution of kindergartens (teaching sites) in ZJ County exhibits a pattern of single-core agglomeration with peripheral dispersion, and the degree of polarisation exceeds that reported in studies of urban areas, reflecting the particularities of preschool education resource allocation in mountainous rural regions with complex terrain. The standard deviational ellipse analysis shows that XC Town concentrates 44.4% of the county's total kindergarten enrolments, while each of the other townships has only one kindergarten (teaching site), with few and scattered enrolled children. The polarisation degree is far greater than that found in Cheng Shunqi's (2019) study of Fuzhou's urban area (excess in the centre, shortage on the periphery)[11] and Yuan Yaru's (2017) study of Chaoyang District, Changchun (concentration in the old city, gaps in new districts)[12]. Moreover, in contrast to the findings of Li Jing and Huang Daquan (2019) on Xicheng District, Beijing—where the concentration is of high-quality resources—the present case reflects a concentration of basic provision[13]. The underlying reason lies in the profound constraints that complex terrain imposes on population agglomeration and infrastructure development, which gives rise to the particularity of the spatial layout of basic public service facilities, including rural kindergartens.

Third, the combined constraining mechanism of population density, road density, and terrain slope on kindergarten layout is validated; the interplay among demand, transport, and terrain provides a reference for suitability evaluation in mountainous county areas. Single-factor analysis shows that the high-value core of population density is concentrated in the urban area of XC Town, while remote townships have sparse population and scattered student sources; high-value zones of road density extend along the main county roads, with marginal mountain areas having low-grade road networks; slope-suitable areas are confined to the county's river valleys and some flat lands in townships. Overlaying the kindergarten (teaching site) points onto each factor layer reveals that most kindergartens are generally reasonably sited, but mismatches also exist. On the one hand, some peripheral population agglomeration patches lack kindergarten coverage, consistent with the conclusion of Liu Xinyi (2019) regarding insufficient supply in Shuinan Town, Zhanggong District, Ganzhou[14]. On the other hand, some mountainous kindergartens are surrounded by low-density road networks with insufficient accessibility and are further constrained by steep terrain and other geographical factors, vividly illustrating the "public-oriented" analytical framework proposed by Hu Pan and Zhang Jianzhao (2013)[15].

Fourth, the spatial overlap analysis between the coupling coordination degree and the comprehensive suitability evaluation results indicates that the "valley corridor" constitutes the most suitable and most coordinated central area for concentrated kindergarten construction in ZJ County, offering insights for differentiated policy design for small-scale kindergartens in mountainous counties. The high-suitability and high-coordination areas overlap strongly in space, both being concentrated in the central-western "valley corridor" zone of the county, covering multiple riverside townships, which is the core area most suitable for concentrated kindergarten construction in ZJ County. Medium-suitability and medium-coordination areas are scattered in patches across the gentle valley slopes of transitional townships, where conditions allow for local kindergarten establishment but current coverage is insufficient. Low-suitability and low-coordination areas are widely distributed in the eastern, northern, and southern high-mountain townships, shaped by the combined effects of steep terrain, sparse road networks, and scattered population. This finding is similar to that of Han Zenglin, Du Peng, and Wang Li (2014) on primary school allocation in Ganjingzi District, Dalian[16]; however, the situation in ZJ County is even more pronounced, making it practically and theoretically difficult to construct

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large-scale standardised kindergartens in this region, and necessitating the exploration of a universal supply model for educational resources that differs from that of plain areas.

5.2 Recommendations

Based on the spatial distribution characteristics of kindergartens in ZJ County, the comprehensive suitability evaluation results, and the spatial differences in coupling coordination, this study proposes optimisation strategies for the spatial layout of small-scale kindergartens in rural areas, focusing on three differentiated aspects: improving quality and efficiency of small-scale kindergartens, supplementing construction in key townships, and flexibly supplying services in high-mountain areas.

First, control the increment in the core urban area and shift towards quality improvement. XC Town has a relatively high number of kindergartens and a high coupling coordination degree, indicating a good match between supply and suitability conditions. In the future, large-scale new kindergarten construction in the county seat should not be continued; instead, the focus should shift to optimising the existing stock, improving physical facilities, expanding teaching staff, enhancing the quality of care and education, and optimising service radii to avoid excessive resource concentration.

Second, supplement preschool facilities in peripheral high-suitability gap areas. For valley settlement patches that have reached a “good” or “medium” comprehensive suitability level but show low coupling coordination and insufficient existing supply, the central kindergartens in townships with a certain population size, such as SK Town and ZH Town, should be moderately expanded or renovated. For scattered village settlements, flexible rural preschool teaching sites may be established to fill service gaps and reduce long-distance commuting for young children. New construction or renovation projects should preferentially select plots with higher comprehensive suitability and avoid high-slope geological risk zones.

Third, implement flexible supply models in remote high-mountain areas. In the county’s high-mountain regions, where terrain is steep and the population is highly dispersed, the overall suitability is low, and large-scale standardised kindergarten construction is not feasible. Efforts should be made to strengthen the educational capacity of existing township central kindergartens and enhance their radiating effect. Meanwhile, models such as mobile preschool teaching sites and itinerant preschool education services should be promoted to reduce construction costs and ensure that young children in remote mountainous areas have basic access to preschool education. In parallel, rural road improvements in mountainous areas should be advanced to enhance the accessibility of existing kindergartens.

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