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Geospatial-Based Analysis of Balance in Elementary Education

—Taking Elementary Schools in Changsha Five Core Districts as Examples

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Abstract

The balanced development of the elementary education sector has been a long goal pursued by the education departments of various places, and is also an outcome expected by the people. Based on a study of the equilibrium of the spatial distribution of the capacity saturation models of all the primary schools in Changsha's (China) five core districts, the results show that the overall geographical distribution of the primary schools in Changsha is relatively balanced, based on the natural characteristics of Changsha, such as human geography, and the moderate gradient between the central urban area and the primary schools in the suburbs and outer suburbs. Then the Theil index model was introduced, and the results of the model analysis show that the differences between elementary schools in Changsha urban area are relatively small, and the main differences originate from between districts rather than within districts, and subtle differences among regions mainly reflect in the teacher strength.

Keywords

Geospatial, Education, Balance Development, Primary School, Theil Index

1. Introduction

Education is the keystone of a hundred-year plan. It is the foundation of the country, as well as the foundation of social and national prosperity. In general, education can be broadly divided into elementary education, higher education and adult education. Among them, elementary education is the cornerstone of all educational processes and plays a fundamental and leading role in the national education system. Elementary education is the largest and most comprehensive stage in basic education (except for preschool). Different from higher education which emphasizes multi-category, multi-gradient and distinctive development, elementary education emphasizes full coverage and balanced development without difference.

In order to develop education and build a strong country, we must first strengthen elementary education, give priority to the development of education and promote the balanced development of elementary education with high quality. Since the founding of the People's Republic of China, especially since the reform and opening-up, our economy has developed rapidly. At the same time, our educational cause has also been pushed forward vigorously, and a series of world-famous achievements have been made, for example, the enrolment rate of children of primary school age went from less than 20 percent in 1949 to 94 percent in 1978 to 99.98 percent today. At present, the main contradiction of our country's elementary education has changed from "Being educated" to "Enjoying a good education" [1]. The main cause of the social phenomenon of people trying to get into good schools is the unbalanced development of our elementary education. Urban basic education is now better than rural ones, and the eastern region as a whole is better than the central and western regions. In order to solve the regional differences in educational resources, especially between urban and rural areas, the state and education departments at all levels have introduced a large number of policies and measures, for example, the Ministry of Education clearly stated in its 2019 report that "We should optimize the allocation of educational resources and gradually narrow the gap between regions, urban and rural areas, and basic education schools" [2]. The problem of educational equity is a social problem. To solve it, we must face up to and discover the regional differences in education first.

The term "Equilibrium" originated in physics and originally meant a state in which a body remains at rest or moves at a constant speed while the whole force is in equilibrium [3]. Later the concept of equilibrium was introduced into economics to describe supply and demand in a stable state, in which the market factors of production and consumer goods income are exactly the same. At present, different scholars have put forward different opinions or definitions of the balanced development of education from different angles. On the one hand, some scholars believe that the balanced development of human-made education is basically the equal distribution of educational resources, for example, Li and Tao [4] used a DEA-Tobit model to Quantitative analyze the efficiency of resource allocation in China's 31 provinces, cities and autonomous regions, the result shows that the main reason for the difference of regional education in China is the difference of resource allocation efficiency. Zhao [5] used principal component analysis and the DEA method to analyze the educational resource allocation of 1019 primary schools in a city in eastern China. The main reason for the difference between urban and rural education in this city lies in the significant difference in the investment of educational resources between urban and rural areas. A quantitative analysis of Puyang's educational development was conducted by Gong [6], and it revealed that the difference in resource allocation between urban and rural schools is an important reason for the unbalanced development of education. On the other hand, education funds management and school management system are also considered to affect the balanced development of education is another important reason. Wang's survey found that the main cause of China's compulsory education imbalance was the obvious regional differences in education spending [7]. Psacharopoulos [8] has conducted research on the balanced development of education through three aspects: the teaching staff, the conditions for running a school and the curriculum offering. It is pointed out that the imperfection of educational policy and school system is the primary cause of the unbalanced development of education.

The most intuitive explanation of the balance of education space is that the distribution of schools and students is in a state of balance, that is, the demand for students and the supply of school capacity. As early as 2001, China promulgated "The tenth five-year plan" for education, in which the requirements for primary school students to enroll in a nearby school were clearly stated, in essence, it requires the region to balance its educational planning and educational demand. Spatial equilibrium is a kind of equilibrium matched by the distribution of schools and students, including four aspects: region, urban and rural areas, inter-school and community [9]. In his doctoral thesis, Lu [10] constructed a method to measure the equilibrium of educational resources allocation from a spatial perspective, and initially realized the equilibrium evaluation of compulsory education resources allocation. Taking the distribution of primary and secondary schools as the starting point, Du [11] analyzed the coverage of schools and the convenience of going to school from the perspective of equal educational opportunities, so as to evaluate the balance of the distribution space of schools. On the basis of previous studies, Yan [1] has established a framework for evaluating and influencing the spatial equilibrium of urban basic education, which has some guiding value for the spatial layout of urban primary and secondary schools.

The studies mentioned above have examined the balanced development of elementary schools in China from different perspectives and provided some valuable suggestions for school resource allocation and layout, but they all have been theoretically conceived and framed from a macroscopic point of view and have not involved the analysis of specific scientific data, and some of the findings have been difficult to comprehend and realize. In recent years, with the emergence of new concepts such as intelligence education, the role of big data in educational development and equilibrium monitoring has become more and more obvious. Various technologies, such as educational big data analysis and artificial intelligence, have been integrated into all aspects of education. It has a wide and profound influence on the distribution of educational resources, the monitoring of teaching quality, the growth of students, the supervision of teachers' teaching quality and educational decision-making. At the Big Data Conference, General Secretary XI also stressed that we should fully utilize and give full play to the role of big data and implement the national big data development strategy, taking into account the current actual situation, let big data serve all aspects of economic, social and educational development. Therefore, based on the analysis, this study will analyze the spatial distribution and student supply and demand saturation of 306 primary schools in the five districts of Changsha, on this basis, the Theil index model was used to study the differences in the distribution of schools and students in Changsha as a whole and among the districts, and then the results were presented in a data visualization way, finally, based on the research results of the balanced layout and development of school space to provide policy recommendations.

2. Data Sources and Analytical Models

2.1. Data Sources

The study used macro data on 2021 of 306 primary schools in Changsha's five core urban districts (Furong, Kaifu, Yuhua, Tianxin and Yuelu District), the longitude and latitude coordinates of each school can be obtained by locating each school using the map of Baidu, the data include the name of the school, the district, the longitude, the latitude, the number of students in the school, the number of staff and the area occupied. The descriptive statistical analysis is shown in **Table 1**.

As can be seen from **Table 1**, there are 354,301 students and 19,829 staff in 306 primary schools in the five districts of Changsha. The total area of the campus is 4,634,691 m^2. It can also be seen in the table that there is a huge difference between the size of a school run by a colonel and the size of a school run by a colonel. The smallest school has only 29 students and five staff members, and the smallest school has a total area of 1482 m^2, while the largest school has 5415 students, 294 staff and 57,060 m^2.

2.2. Analytical Models

First of all, whether the geographical distribution of the school is reasonable or not needs to be determined whether the supply of the school matches the demand

Table 1. Descriptive statistics of used data.

	Longitude	Latitude	Number of students (unit)	Number of staff (unit)	Floor space (m^2)
minimum	112.6	27.96	29	5	1482
median	113.0	28.13	865.5	48.5	13,065
mean	113.0	28.17	1157.8	64.8	15,146
maximum	113.2	28.37	5415	294	57,060
total	-	-	354,301	19,829	4,634,691

of the students, in order to verify the rationality of school distribution, the capacity saturation model can be introduced. Then the Theil index model is established to study the difference between school supply and student demand among the five districts in Changsha, and make full use of the sensitivity of Theil index to the intra-group and inter-group differences to analyze the sources of the differences in the spatial distribution of schools in each district.

1) Capacity saturation model

Whether the distribution of school space is balanced or not needs to take into account the distribution of schools and students, the essence of which is the balance between the supply of school degrees and the demand for students. The number of students on campus can be regarded as the demand for students, and the campus area (capacity) can reflect the actual degree supply (carrying capacity) of the school. In order to study whether the two are in equilibrium, we introduce the capacity saturation model:

$$C_i = \frac{N_i}{M_i}$$

where C_i denotes the capacity saturation level of school *i*, and the N_i, M_i, and S_i represent the number of students, available degrees, and campus area of the *i-th* school respectively.

The number of places to be provided is generally determined by the size of the school, *i.e.* the area of the school and the number of teachers (*i.e.* the teacher-student ratio). The state and local education departments have clearly stipulated that the area occupied by all primary school students should not be less than 9.4 m^2 per person. The Education Department of Changsha municipal government stipulated that the area of students in the city center should be 11.11 or more (the size of classes should be 30 or more). Taking into account the actual situation of local standards, we have chosen 11.11 m^2 per person as the minimum average campus area for a student-to-teacher ratio of not less than 1/19. Therefore, the number of degrees that a school can theoretically provide can be calculated by:

$$M_i = \sqrt{\frac{S_i}{A_S} \times \frac{T_i}{A_T}}$$

where S_i and T_i denote the actual area occupied and the number of staff of the *i-th* school, respectively, and A_s and A_T are the local minimum per-pupil floor space threshold and the teacher-student ratio threshold, respectively. Here $A_s = 11.11$ and $A_T = 1/19$ and then:

$$C_i = \frac{N_i}{M_i} = \frac{N_i}{\sqrt{\frac{S_i}{A_S} \times \frac{T_i}{A_T}}} = \sqrt{\frac{A_s A_T}{A_{ai} A_{Ti}}},$$

of which A_{ai} and A_{Ti} denote the actual per-pupil floor space and student-teacher ratio for the *i-th* school.

The above capacity saturation is a dimensionless value, and its supply-demand relationship with schools and students is shown in Table 2. When the C value of capacity saturation is between 0.8 and 1.2, we think that the spatial distribution of the school is basically balanced with the distribution of student demand; A value of C between 1.2 and 1.5 indicates that the school slightly does not meet the needs of the students in the area; a value of C above 1.5 indicates the number of degree of the school is insufficient. When the value of C is between 0.6 and 0.8, it shows that the scale of running a school in this area is slightly larger than the actual demand. If $C < 0.6$, it means that the scale of the school in this area is overplus.

Following the definition of single school capacity saturation, the capacity saturation of each district is the ratio of the actual number of all students in the district to the number of places that all schools can provide. Therefore, the model can be established as follows:

$$QC_j = \frac{QN_j}{QM_j} = \sqrt{\frac{A_s A_T}{A_{aj} A_{Tj}}}$$

among them QC_j, QN_j, QM_j, A_{aj}, A_{Tj} are the capacity saturation, the total number of students, the total number of degrees theoretically available, the average area of students and the teacher-student ratio of the *j-th* district, respectively.

2) Theil index model

The Theil index is a well-known measure of diversity, and its most notable feature is its sensitivity to subtle within-group and between-group differences. In general, the smaller the Theil index, the smaller the difference, and vice versa. If each district is grouped, the differences between schools in the same district can be considered intra-group differences, and the differences between schools in different districts can be considered inter-group differences. In order to further study the difference of school spatial distribution among the five districts in Changsha, we choose Theil index to evaluate. There are two types of the Theil index: T index and L index, which are modeled as:

$$T = \sum_{i=1}^{N} y_i \log \frac{y_i}{p_i},$$

together with

$$L = \sum_{i=1}^{N} p_i \log \frac{p_i}{y_i},$$

among them, N is the number of regions, and y_i is the proportion of indicators examined in region i to the total indicators, and p_i is the proportion of the number of students in region i to the overall number of students. In order to study the

Table 2. Capacity saturation and supply and demand in elementary school.

C value	$C < 0.6$	$0.6 < C < 0.8$	$0.8 < C < 1.2$	$1.2 < C < 1.5$	$C > 1.5$
supply-demand relationship	overplus	slight overplus	balance	tight	insufficient

differences in the spatial distribution of schools in the five districts within Changsha, we adopt T index, and investigate the index as capacity saturation.

The Theil index model of the overall difference of the spatial distribution of schools in the five districts in Changsha can be established as follows:

$$T_p = \sum_j \sum_i \frac{Y_{ji}}{Y_j} \log \frac{Y_{ji}/Y}{P_{ji}/P},$$

where Y_{ji} is the number of available places that can theoretically be provided by the *i-th* school in the *j-th* region, and Y_j is the number of theoretically available places for all schools in the *j-th* Region, Y is the number of theoretically available places in the five districts of Changsha, P_{ji} is the number of students enrolled in school i within the *j-th* region, and P_j is the total number of students enrolled in the school in the *j-th* region, and P is the total number of students enrolled within the five regions.

The difference between schools in the *jth* district is:

$$T_{pj} = \sum_i \left(\frac{Y_{ji}}{Y_j} \log \frac{Y_{ji}/Y_j}{P_{ji}/P_j} \right).$$

Thus the overall difference in the spatial distribution of schools, denoted as T_P, can be decomposed into:

$$T_p = \sum_j \frac{Y_j}{Y} T_{pj} + \sum_j \frac{Y_j}{Y} \log \frac{Y_j/Y}{P_j/P} = T_W + T_B.$$

In the formula T_P can be split into two parts, the intra-regional (intra-group) differences, denoted as T_W, and inter-regional (inter-group) differences, denoted as T_B.

3. Analysis on the Sources of Spatial Distribution Differences of Primary Schools in Five Districts of Changsha City

Firstly, the distribution of primary schools in Changsha's five core urban areas is visualized by R software. **Figure 1** shows the distribution of primary schools in Changsha's five core urban areas, and **Figure 2** shows the distribution of primary schools' nuclear density. Combined with the visualizations in **Figure 1** and **Figure 2**, the distribution of Changsha primary schools shows a radiative pattern with the center of Furong District spreading out layer by layer. Peripheral areas such as northern Kaifu District, southern Yuhua District and Western Yuelu District have relatively few schools. The population and functional zoning of Changsha can be found, the distribution of schools in Changsha accords with the law of population, topography and functional area. Furong District, Yuhua District, Kaifu District and Tianxin District, the junction of the four districts has always been the main urban area of Changsha, the region is densely populated, with demand for schools, and therefore more schools. Among the sparsely populated areas with schools, the northern part of Kaifu District is undeveloped, with a relatively small population of mainly agricultural and mountainous land,

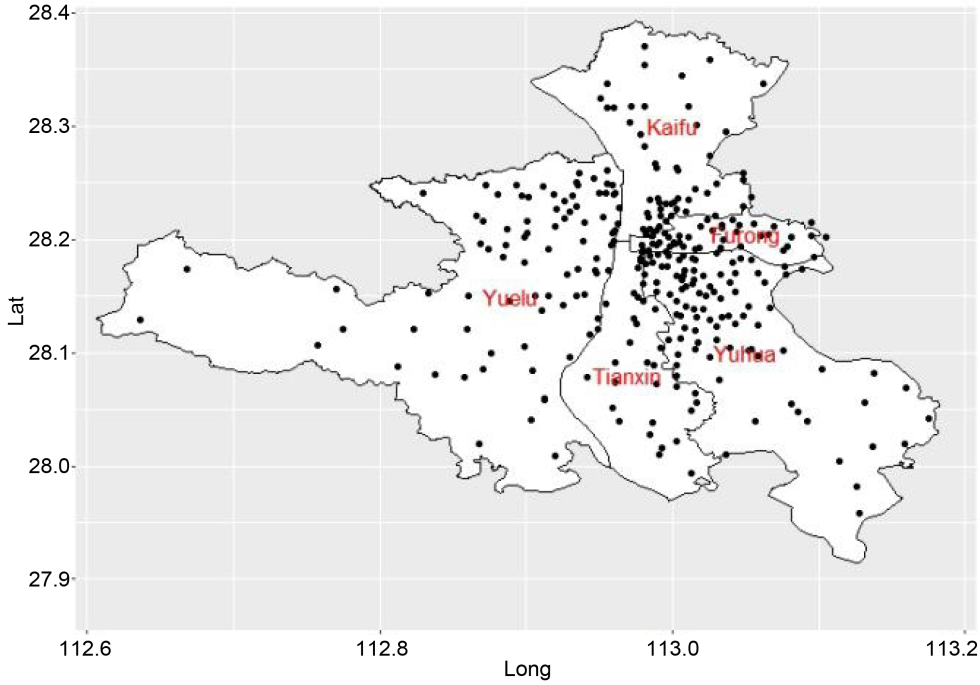

Figure 1. Primary school distribution.

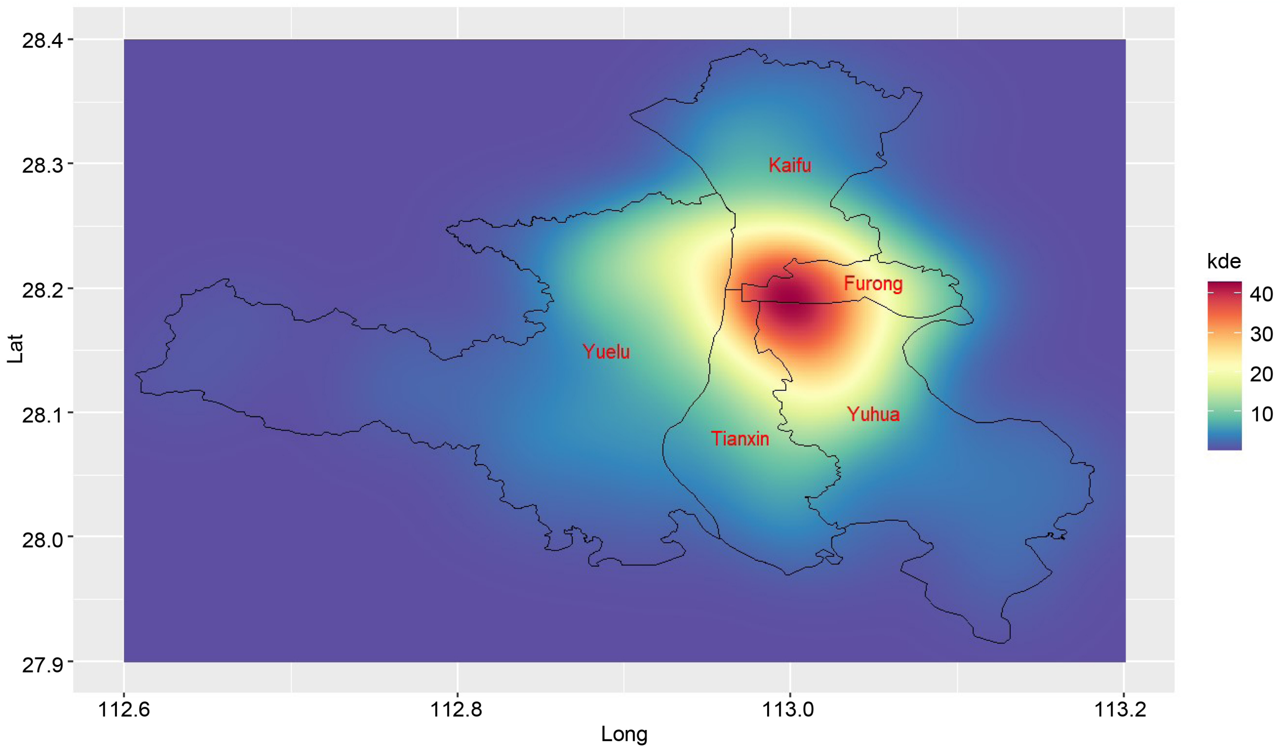

Figure 2. Kernel density map of elementary school distribution.

while the western part of Yuelu District is an industrial park and mountainous area with relatively few commercial and residential buildings, most of which are villages, while the southern part of Yuhua District is a mountainous area. Forest parks and villages for recreation are the main natural and cultural distribution. The population is relatively small, and schools are scattered in villages. Therefore, from the perspective of human geography, the spatial distribution of primary schools in Changsha's five core areas is basically reasonable, in line with natural laws such as population distribution.

3.1. Capacity Saturation Analysis

In order to analyze the rationality of the spatial distribution of primary schools in the five districts of Changsha, the capacity saturation of all primary schools in the five districts was analyzed. The capacity saturation diagram for all schools can be derived separately from the capacity saturation model in 2.2 (see **Figure 3**).

As can be seen in **Figure 3**, the vast majority of primary schools in Changsha belong to the balanced school in terms of geographical spatial distribution, which further validates the theory of natural human geography in **Figure 1** and **Figure 2**. A total of four "insufficient" schools are located in Yuhua District (two), Kaifu District and Yuelu District (one each), respectively. The "tight" schools are mainly located in the old urban areas at the junction of Furong District and Tianxin districts. These places have a larger number of primary

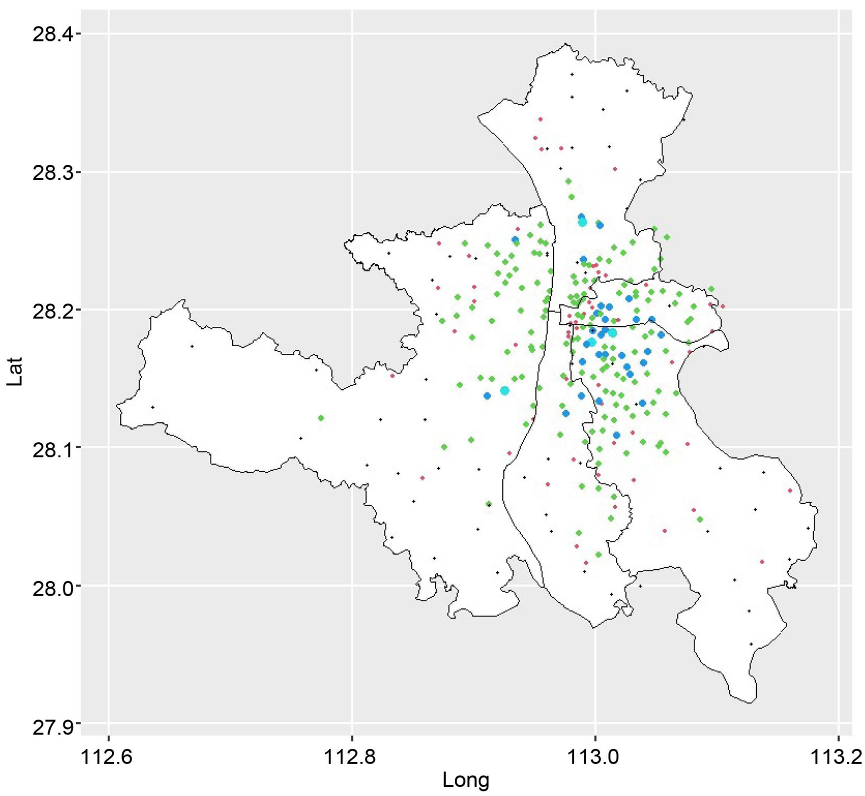

Figure 3. Capacity saturation of elementary school. (The green dot means "Balance"; the red dot is "slight overplus"; the black dot means "overplus"; the dark blue dot means "tight"; the light blue dot is "insufficient"; and the size of the dot represents the saturation level.)

schools, but the venues are smaller because of the large number of students, therefore, the actual demand for degrees is slightly larger than the theoretical supply, but the overall situation is still relatively balanced. "slight overplus" schools are mainly located in the suburbs of four urban areas, namely Kaifu, Tianxin, Yuelu and Yuhua District. These areas have relatively large schools but relatively small numbers of students, so theoretically, there is still a certain amount of degree supply space, and as the urban area expands, the capacity saturation of these schools will be further enhanced. "overplus" schools are mainly located in the outer suburbs of the four urban areas, which are either in remote mountainous areas or in agricultural villages and industrial zones, therefore, it belongs to the university with low capacity saturation.

To further analyze the overall saturation of the five urban areas, according toformula (4), the overall capacity saturation of Furong, Kaifu, Tianxin, Yuhua and Yuelu regions can be obtained as follows: 0.67, 0.78, 0.76, 0.66 and 0.78 respectively. This shows that the capacity saturation of primary schools in the core area of Changsha is in the category of "slight surplus", and the geographical spatial distribution of the four districts of Kaifu, Tianxin and Yuelu is very close to equilibrium.

3.2. Analysis of the Sources of Spatial Difference

According to formulas (7)-(9) and with the help of R software, it is possible to establish the evaluation model of the Theil index. The results of the Theil index analysis are obtained by comparing the area of the school and the number of teaching staff (see Table 3).

The Theil index shows that the main differences among the five districts in Changsha in terms of both the per capita floor space and the teacher-student ratios of individual schools come from the differences between districts, *i.e.*, the average floor area per student and the ratio of teachers to students per student

Table 3. Theil index and its decomposition of the spatial distribution of schools in Changsha's five core districts.

groups			Furong	Kaifu	Tianxin	Yuhua	Yuelu
Average floor area per student	Interval difference	Theil value	0.0972	0.2359	0.1139	0.1932	0.2440
		contribution	98.83%	99.82%	99.70%	97.57%	95.63%
	Within difference	Theil value	0.0011	0.0004	0.0003	0.0048	0.0111
		contribution	1.17%	0.18%	0.30%	2.43%	4.57%
	Total Theil value		0.0983	0.2363	0.1142	0.1980	0.2551
Teacher-student ratio	Interval difference	Theil value	0.0014	0.0080	0.0081	0.0068	0.0071
		contribution	96.85%	79.11%	93.80%	79.36%	71.61%
	Within difference	Theil value	4.43e−05	2.11e−03	5.34e−04	1.77e−03	2.83e-03
		contribution	3.15%	20.89%	6.20%	20.64%	28.39%
	Total Theil value		0.0014	0.0101	0.0086	00086	0.0099

are larger than the differences among the schools in the five regions: Furong, Kaifu, Tianxin, Yuhua and Yuelu District. In terms of per capita floor space, Yuelu District has the greatest variation, both within and between districts. This is because the Yuelu District is one of the areas that have been relatively developed in the last decade. It has built Meixi Lake, Yanghu Lake and other new towns, leading the schools in other areas in terms of educational resources. Furong district has the smallest difference in the area covered by students. This is also in line with the fact that Furong District is an old city with a fixed size and number of schools. Generally speaking, the difference of primary schools in the five core districts of Changsha mainly comes from the district and the contribution of Theil index is above 95%. In terms of the teacher-student ratio, the overall difference still came from district to district. The difference contribution between the Furong District and Tianxin Districts was 90%, the other three districts, although relatively low compared with the first two districts, all contributed more than 70% of the interval difference, and the difference in the teacher-student ratio in Yuelu District was still the largest among the five districts. On the whole, Theil indices in the area of teacher-student ratio are all in the range of 0.001 to 0.01, the difference is very small, which shows that the teacher allocation in Changsha primary schools is reasonable.

4. Conclusions and Policy Recommendations

Changsha has long been regarded as a model for the basic education of the country, sending a large number of high-quality talents to the country every year, based on the analysis of the primary schools' capacity saturation and Theil index in the five core districts of Changsha, the following conclusions can be drawn: The distribution of primary schools in the five main urban districts of Changsha is relatively balanced as a whole, basically can meet the needs of students in all regions. The distribution of primary schools in Changsha gradually spreads to the surrounding areas with the central city as the core, which is basically in line with the city's human and geographical distribution. The development differences among the primary schools in Changsha are basically balanced; the differences among the five central districts in Changsha are slightly different, which are mainly reflected in the area occupied by schools, and the differences are even smaller in the ratio of teachers to students; the construction and development of Changsha primary school are moderately advanced. According to the result of saturation capacity analysis, the overloaded schools in Changsha are mainly concentrated in the old city, and the expansion of the schools in the old city is limited, thus causing the shortage of teaching land. The Suburban and exurb schools show the characteristics of low-surplus schools and high-surplus schools. Considering the continuous development and expansion of the city, these schools will gradually become balanced. Based on the above four conclusions, the article gives the following three suggestions:

Reasonable adjustment and optimization of primary school service area layout.

Although the spatial distribution of the primary schools in the five core districts of Changsha is relatively balanced, there are still some schools that are short of teaching space and teaching staff, resulting in "Low-shortage schools" that in theory cannot match the number of students enrolled, many of these "tight schools" are surrounded by "balanced schools" or even "slight overplus schools", so the division and adjustment of primary school service areas can be further optimized, to balance the teaching resources among schools.

Balance teaching resources and build up national confidence in the nearby primary schools. Changsha has a total of four "insufficient schools", further research found that these four primary schools are the citizens of the "Famous school" which, to a certain extent, reflects the good schools to attend a large number of students, difficult to obtain a degree phenomenon, in order to solve this problem, we can adapt the system of teachers and teaching resources flow in the region, and build up citizens' confidence in the school near their home by helping the school.

In order to promote the experience of the layout and development of elementary school in Changsha to other areas, as a basic education province, Hunan has a strong reputation in the basic education field. However, the basic education development of Changsha is not balanced, with the restrictions on non-local schools in the city. The loss of quality local resources has been mitigated to some extent, but the development of local basic education schools is more important than restricting the flow of students, in turn, the basic education development of the whole province will move towards equilibrium.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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