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Research on the Spatial Characteristics of Physical Education Teacher Allocation in Schools at the Basic Education Level

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Abstract: In the context of educational equity and balanced allocation of high-quality educational resources, the distribution of physical education (PE) teachers is a key factor in improving educational quality and reducing regional differences. This study examines the spatial allocation characteristics of school PE teachers at the basic education level in Xi'an, aiming to reveal overall spatial patterns and regional disparities. In this study, Xi'an City was selected as a case, and an evaluation index system was constructed using literature review and the entropy weight method. Furthermore, quantitative methods including the natural breaks classification method, Kriging interpolation, and spatial autocorrelation analysis were employed to examine the current status and spatial distribution characteristics of physical education teachers in primary and secondary schools in Xi'an. The results indicate a clear central–periphery gradient: resources are concentrated in central urban districts and become progressively scarce toward the suburbs. A positive global Moran's I (0.268, Z=5.079, p<0.01) confirms significant clustering: high-value areas form contiguous clusters in the central city, while low-value clusters dominate in remote counties, with scattered high-low "island" and low-high "depression" patterns at transitional zones. We also observed that student-to-teacher ratios are much higher in the core city (indicating heavier teacher workloads) whereas suburban schools face high vacancy rates and lower proportions of specialized and fully-trained PE teachers, emphasizing rural–urban inequity in teacher quality. Based on these findings, we recommend targeted resource placement: increasing quotas and incentives in underserved suburban areas, enhancing rural educational infrastructure, and strengthening teacher training and mobility programs to promote balanced, high-quality development of educational resources.
Keywords: Physical Education Teacher Allocation, Educational Equity, Spatial Analysis.

1. Introduction

The process of education modernization has made education equity one of the central challenges of education policy in many nations. The Chinese government seeks to develop a high-quality, balanced public education service system to reduce the inequality of regional education resources and achieve education equity (General Office of the CPC Central Committee & General Office of the State Council, 2023; Ministry of Education of the People's Republic of China, 2020). Historicization of Education Equity means that, in academic development, students can reasonably and fairly obtain an educational resource that they need for their development, and that a rational distribution of educational resources is the enormous way to achieve equity in education, and not only this, but is also a scientific, reasonable, policy orientation; as well, it is an important strategic guiding ideology (Zhai, 2006). Research has similarly noted that fair geographic distribution of educational resources leads to the diminishing of educational differences in terms of educational equity. There is significant research on this topic, from other

countries and countries, much of which was found in the US, and suggested ill-equitable geographic distribution of skilled teacher resources across schools/districts exacerbated the educational disadvantage of disadvantaged groups (Adamson & Darling-Hammond, 2012). In its report entitled Equity and Quality in Education the Organisation for Economic Cooperation and Development (OECD) stated that establishing equity within education entails establishing fairness and inclusion in the distribution of resources, and that students' access to education should not be impeded by their socioeconomic circumstances or by the areas in which they have been raised (OECD, 2012). Advancing recent scholarship, Tate proposed the idea of the "geography of opportunity," asserting that where a person is located defines the social, educational, and economic resources available to them. He showed that rapidly industrializing Centers are located in rapidly growing industrial centers with neighborhoods facing high poverty and low educational attainment; for example, neighborhoods adjacent to biotech and telecommunications clusters often had high-poverty, low-performing schools. This illustrates an "uneven geography of opportunity" in which spatially contagious economic and educational benefits coexist with invisibility, and were not present nearby (Tate, 2008). In accordance with this framework, the spatial inequities in educational resources identified in our analysis can be seen as different expressions of the same structural logic: areas with an abundance of schools, qualified teachers, and course offerings represent higher-opportunity areas whereas under-resourced areas represent the opposite of that higher opportunity landscape. By clearly framing our analysis within Tate's theoretical framework, we emphasize that educational resource distribution is not value-neutral, but rather, part of wider inequity patterns, ultimately highlighting the theoretical significance in where students live is an important determinant of their educational opportunities (Gulson & Symes, 2007).

Competing in school sports contributes a unique and important role in students' physical well-being, enhancing physical fitness, and developing group solidarity and quality (Bailey, 2006). With the proposed thorough advancement of education modernization and quality education, education authorities at all levels are beginning to pay more attention to the distribution of school sports resources as a means of supporting the comprehensive development of students and the formation of lifelong sport habits (Ministry of Education of the People's Republic of China, 2020).

In China, the distribution of teacher resources at the basic education level is really based on the establishment plan of the educational authorities, school size, student-teacher ratio standards, funding, etc. But in terms of the allocation of physical education (PE) teachers, the distribution faces challenges: first, significant urban-rural differences the urban-rural dichotomy caused by historical imbalanced economic levels, infrastructure, etc., result in a shortage of physical education teachers in schools in suburban and remote areas; Secondly, notable interschool differences there is a discernible gap between key schools and general schools when it comes to recruitment routes, treatment, and training opportunities (Adamson & Darling-Hammond, 2012); Finally, limited mobility of teachers; remote areas have difficulty attracting and retaining high-level PE teachers because of limited living and career development conditions (Liang & Ma, 2021). These unequal distribution of resources not only affects the level of quality of their classroom teaching, and limits students participation in PE, it may also negatively influence students' academic performance

and overall quality improvement (OECD, 2012).

Yet, as of now, there is a scarcity of empirical research in China examining the spatial lens of the imbalanced allocation of school physical education teachers. So, amidst the background above, there is great academic value and practical significance in examining the spatial distribution characteristics of school physical education teachers. One significant aspect is that spatial analysis reveals the geographic pattern and spatial concentration phenomenon of teacher allocation, and further enriches the theoretical viewpoint of balanced distribution of educational resources. At the same time, there are international studies using GIS technology for spatial analysis in education. For example, Singleton and Longley examined the geographic differences of educational development indicators across the UK using spatial modeling to provide an intuitive geographic viewpoint for research topics in educational equity. These international experiences show that the spatial analysis methodology used in this study has international applicability. In particular, spatial auto correlation analysis can assess if there is a clustering or random pattern of the distribution of teachers, which is important to help understand educational regional inequity. Meanwhile, from the policy practice perspective, knowing the "high country" and "low country" of teacher resources is critical in guiding the accurate implementation of policy. Through identifying high density and low vulnerability areas, education administrations was able to implement resource investments and adjust the distribution of teachers, to facilitate equality of opportunity and improve allocation of educational resources.

On this basis, this research uses Xi'an, Shaanxi Province, as a case study to systematically investigate the spatial characteristics of how physical education teachers are allocated to education-level basic education (primary and secondary) schools in a city. Xi'an is an important economic, cultural, and educational center in northwestern China, and typical in terms of urban-rural differences in educational resources. The decision to study this city as a case study is not only able to provide empirical research evidence for the study of spatial balanced allocation of educational resources, but also to some degree fills the research void of empirical research in the field of modeling spatial distribution of educational resources in China (Liang & Ma, 2021). The primary goals of the research and associated research questions were: (1) to highlight the overall spatial pattern of the allocation of school physical education teachers at the basic education level in Xi'an, and urban-rural differences; (2) to test whether the allocation of school physical education teacher evidenced a significant agglomeration, and distinguishing the details behind the distribution of districts of high-value, low-value, and heterogeneous districts.; (3) To interpret the diversity in the spatial distribution of the indicators; and (4) To examine those above spatial distribution characteristics in terms of implications for educational equity and the optimal allocation of educational resources.

Upon this study's epistemically guided foundation, this paper adopts the conceptual framework of sports geography (Shi, 2005, 2007) (an approach to spatial distribution of sports resources and phenomena), evaluates the weights of evaluation indexes using the entropy value method, and provides a systematic representation (with visualization) of the spatial characteristics and regional discrepancies of the sharing of physical education teachers by employing GIS spatial visualization and spatial auto-correlation analyses. The remainder of this paper is organized as follows:

section 1 outlines the data sources for the study; section 2 details the building of the evaluation index system and research design (methodology); section 3 reports the results from spatial analysis of physical education faculty distribution; and section 4 concludes with suggestions for future research, but also include study limitations.

1.1. Data Sources

This research locates and delimitates it's cases of study from the 13 districts and counties subsumed under Xi'an, Shaanxi Province, China, covering 1,504 primary and secondary educational institutions in Xi'an, with data provided for 2024. The study scope includes all types of schools at the basic education stage of schooling: elementary school, junior high schools, senior high schools, nine-year, twelve-year, complete middle schools, and secondary vocational schools.

The data used in this study comes from officially recognized publicly available statistics and is thus authoritative and reliable.

More specifically:

① **Data Collection and Calibration of Evaluation Indicators:** The data for each indicator for teachers mainly comes from official publications, such as the China Urban Statistical Yearbook, Shaanxi Provincial Statistical Yearbook, Xi'an Municipal Statistical Yearbook, etc., and is based on the annual reports on the work of school physical education published by Ministry of Education, which this research team obtains by comparing one by one.

② **School Geographic Location Data Acquisition:** Using the Google Maps API platform, the team accessed the reverse geocoding interface to get the geographic coordinates of each school by entering the address of each school. The coordinates obtained were then compared and verified with the educational resources distribution map uploaded on the official website of Xi'an Municipal Bureau of Education to confirm the accuracy of the school's location.

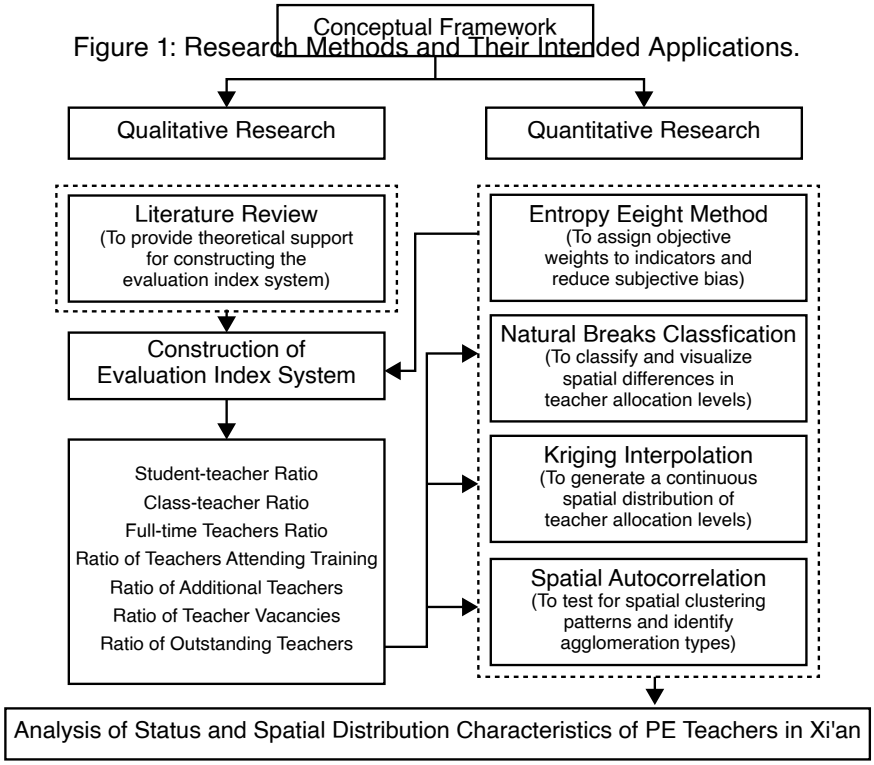
③ **Data Verification:** In order to guarantee accurate and consistent data, this study undertook a number of verification activities. This study randomly selected 100 schools in the city, and checked their statistical yearbook data one by one, and used time-series analysis and other verification techniques to verify the continuity and reliability of data for key indicators. After undertaking these verifications, a complete and consistent database was developed.

2. Research Methods

To clarify the research objectives and the systematic application of methods and to enhance transparency in the research design, a conceptual framework was created (Figure 1). The conceptual framework clearly distinguishes between qualitative and quantitative research methods, alongside their respective purposes and functional roles in the research. The qualitative element based on literature provides the theoretical basis in constructing the evaluation index system. The quantitative element comprises the entropy weight method to weight the indices, and the use of spatial analytical strategies, which includes natural breaks classification method, Kriging interpolation, and spatial autocorrelation analysis, to describe the current status and spatial distribution characteristics of physical education teachers in primary and

secondary schools in Xi'an. The framework supports a systematic understanding of the development and monitoring path of evaluation index system.

Figure 1: Research Methods and Their Intended Applications.



2.1. Construction of the Indicator System

The notion of "school physical education teacher" is the object of this study. In the overall education system, physical education teachers are considered the primary force behind school physical education work. It means physical education teachers are not just responsible for teaching in the school classroom but are also to promote the health of students and be responsible for organizing and promoting physical activity for all students, in and out of the classroom. The definitions of physical education teacher resources from scholars in the domestic sector may vary by point of emphasis: - Zhang Dachao, in his view of physical education teacher resources, he means the manpower that has educational and teaching capacity, to be successful of completing everyday physical education teacher's teaching, training and after school services, which is the most important part of an educational resource. Li Yi considers the physical education teacher in the group of educational human resources with the understanding that, it is an important driver of the overall healthy growth of young people through the promotion of participation. 'In fact, regarding the thoughts of educational human resources, physical education teachers as part of the school education system, coaches members of the sports system, and social sport

professionals and technicians, are all together when addressing physical education teacher resources.' (Zhang & Meng, 2011; Liu et al. 2024). Furthermore, Wang Yafei noted that the human resources of physical education teachers are an important guarantee for the normal development of classroom physical education teaching and extracurricular physical activities, which is based mainly on having teachers with a professional understanding of physical education and health that can emerge as sports skills (Liu et al., 2024); Li Rong classified physical education teachers into classroom teachers, special coaches, and activity organizers according to functional role, into junior, intermediate, and senior according to professional level, into full time and part-time according to nature of position, and into full time and part-time teachers, and new, key and senior teachers according to development stage. The results from the study demonstrate that physical education teachers enact numerous roles in relation to students' physical and mental health and developing lifelong exercise habits, and that teachers' professional identities are now more closely aligned with public health priorities.

To conduct an assessment of school physical education teachers' development level, it should be measured from the dimensions of "quantity-structure-quality-professionalization (Hardman & Marshall, 2014). The "quantity" dimension mainly reflects the scale of supply of teachers in light of demand, or more simply, supply, such as the actual number of physical education teachers, students per teacher, classes per teacher, and other indicators (Hardman & Marshall, 2014). The "structure" dimension addresses the makeup of the teaching force, e.g., teachers' academic title, subject areas, ages and gender mix, proportion of full-time teachers, etc. Li & Hang, (2001); an organized teacher structure can enable diversified teaching skills and be a continuous supply of teachers. the "quality" dimension focuses on professionalism and effectiveness of the teaching workforce, such as teachers' professional qualifications, teaching ability, and teaching effectiveness. In recent years, scholars have developed a competency model for physical education teachers to describe the combination of knowledge, skills and attitudes that high-quality teachers should possess, which relates to the four main competency/multi-competence elements of teachers' professional knowledge, teaching skill, classroom management and interpersonal interactions with students which are arguably the main elements impacting the effectiveness of teaching and learning (Baumgartner, 2022; Kyrgiridis et al., 2014). Simultaneously, the dimension of "professionalization" indicates the extent to which there is further professional development and ability for continuous improvement, such as how frequently PE teachers receive training and continuing education, the degree of participation in teaching and research, and the mechanism for training new teachers (Latino, Romano & Tafuri, 2024). For example, the participation rates of teachers in courses of training and the number of times they have professional training is typically used as key indicators of teachers' commitment to professional learning, and teachers who have a great deal of specialization develop a greater understanding of the structure and intent of the curriculum standards which leads to the overall development of their students (Fu & Xi, 2023). Global surveys have also found that policy adherence in physical education programs, in many countries and areas, is less than complete, and incomplete teacher training affects the quality of teaching and learning. As such,

we can only develop a high-level school physical education teaching force by optimizing teacher structures while maintaining an appropriate number of teachers, engaging in continued quality improvement of their teaching, and increasing their professional development.

In the above study, we view "school physical education teachers" as a team of teachers in schools.. These teachers work in schools to reach the goals of physical education and promote students' physical health and movement skill development. These teams are the main force of physical education and activities in schools and take on the role of teaching, health, education, organization, and management, etc. The connotation of this dimension also includes the number and scale of teachers, structural composition, quality level, and degree of specialization. With the concept of this dimension, and under consideration of the theoretical attributes of an educational evaluation index system and relevant policies, this study constructed a scientific rational evaluation index of the balanced development of school physical education teachers focusing on the quantity supply and quality upgrade of teachers, and core indicators such as number of students per teacher (Fan, 2019).

Table 1: Evaluation Index System of Physical Education Teacher Allocation in Schools.

Target Layer (Overall goal)	Index Layer (Indicator)	Measurement method	Relationship (±)	Weight (%)
Level of PE teacher allocation in schools	Student-teacher ratio	Total number of students/Total number of teachers	- (negative)	10.64
	Class-teacher ratio	Total number of classes/Total number of teachers	- (negative)	3.83
	Full-time teachers ratio	Number of full-time teachers/Total teachers	+ (positive)	11.63
	Ratio of teachers attending training	Number of teachers participating in training activities/Total number of teachers	+ (positive)	10.62
	Ratio of additional teachers	Number of new teachers/Total teachers	+ (positive)	27.07
	Ratio of teacher vacancies	(Number of teachers to be assigned - number of teachers actually in service)/ Number of teachers to be assigned	- (negative)	12.69
	Ratio of outstanding teachers	Number of teachers honored at county level or above/Total number of teachers.	+ (positive)	23.52

Number of classes per teacher (Xue, 2020), ratio of full-time teachers (Zhang, Hu & Liu, 2016), ratio of teachers participating in training (Zhao, Deng & Hu, 2024), ratio of additional teachers (Li, 2022), ratio of vacant teachers (Wang et al., 2024), and ratio of excellent teachers (Hu & Yang, 2014), so as to show the overall picture of the quantity supply of school physical education teachers, to provide a basis and reference to relevant educational authorities to evaluate the balanced allocation level of physical education teachers in the basic education stage. It provides a framework and benchmark for the education departments to evaluate the equitable distribution of PE teacher allocation at the primary school level. The definitions and indicators of the aforementioned indicators are outlined in Table 1 and were selected based on literature or policy (the student-teacher ratio and class-teacher ratio uses the national department of education standards, the full-time teachers and the participation rate use the documents put forth by the Ministry of Education,

the rate of teacher additions and the rate of teacher deficiencies use an educational statistics methodology, the rate excellent teachers is based on the standards for the evaluation and designation of excellence, etc).

In this work, we calculated the weights of the above indicators with the information entropy assignment method (entropy value method), allowing us to reflect, as objectively and fairly possible, the relative importance of each indicator to the overall level of teacher allocation, and avoid subjective assignment (Jiang, Chen & Liu, 2023; Pu, 2017; Wang & Guo, 2024). As can be seen in Table 1, it is the weight score (%) for each indicator using the entropy value method. On this basis, we calculated the comprehensive index of physical education teacher allocation of each school, which allows us to characterize the overall strength of the schools' allocation levels of school PE teachers.

2.2. Methods of Spatial Analysis

2.2.1. Literature Review Method

The literature research method was used in order to inform the rationality of the research and to guide the decision making of the indicators. Using search terms such as "school physical education resources", "spatial allocation", and "teacher resources", relevant literature was searched in databases such as CNKI, Web of Science and JSTOR. After acquiring the literature, studies that were the most relevant to this research were determined by scanning titles, reading abstracts then reading full text. The literature review aided in analysing the hotspots of research and developmental trajectory of the work which provided theoretical support for the development of the index system and decision on models.

2.2.2. Natural Breakpoint Method (Jenks)

Upon receiving complete rank of the evaluation indicators for each school, spatial visualization and analysis were performed using GIS tools. The teacher allocation index was classified and shown using the Jenks natural breaks classification method. Jenks classification takes into account the distribution patterns of the data itself, and allows for automatic classification thresholds. The Jenks method was chosen since this classification prime to maximize the differences between classes while allowing visualization of the spatial distribution pattern of teacher levels (Wu & Li, 2013). The teacher composite index of the city's 1504 schools was then organized into five levels in order to illustrate the varied levels of resource inequality among schools. The schools with the highest composite index are termed "high value schools" to signify that their PE teachers' resources are almost entirely optimal; the schools with the lowest composite index are termed "low value schools" to signify that their PE teachers' resources are extremely limited; The schools in between are defined as "medium-high value schools" and "medium value schools" respectively. The lowest bracket of schools is classified as "low value schools" meaning they have almost no ability to resource teachers; then there are "medium-high value schools", "medium value schools", and "medium-low value schools" as the declines begin. These classifications are determined from the quantitative teacher index which is

an indication of the relative level of teacher resources for a school, and not from subjective consideration such as administrative divisions.

2.2.3. Kriging Interpolation

To specify a continuous spatial distribution of teacher levels, we develop a continuous spatial distribution of the teacher resource allocation index from the discrete school point data via ordinary Kriging interpolation; Kriging provides a continuous spatial distribution map that illustrates the gradient and trend of resource levels with spatial location and to help capture potential patterns of spatial heterogeneity (Liu, Huang & Ding, 2019).

2.2.4. Spatial Auto-correlation

In order to quantitively explore the spatial agglomeration of teacher allocation, we actually used spatial auto-correlation analysis so that the global Moran's I index was computed to assess whether the overall distribution had significant spatial agglomeration or a stochastic distribution, and then we could identify specific various agglomeration, and their specific locations based on Local Moran's I (LISA). The Global Moran's I could test whether the overall allocation of PE teachers in schools in Xi'an is generally spatially auto-correlated or with spatial stochasticity (ie, resource rich and resource poor schools cluster apart) while the local LISA could then identify heterogeneous correlations, e.g. high-high clusters (H-H), low-low clusters (L-L), high-low clusters (H-L) or low-low clusters (L-H) and clarify which areas can be classified as resource "cluster". In order to be clear which areas can be classifed as resource "highlands" or "depressions" (Liu et al., 2019). Then methods of spatial auto-correlation analysis provided a check for both whether or not these areas were spatially agglomerated and subsequently pursued other rationales for the development of the spatial distributions. Hence, using the above methods together can answer the questions raised by the research: from the overall pattern down to the local hotspots, the use of the qualitative description combined with quantitative testing gives credibility and scientific legitimacy to the analytic conclusions.

3. Results and Analysis

3.1. Regional Overview

Xi'an (34°15' - 34°45'N, 108°27' - 109°23'E) is an important cultural and educational city in northwest China. The city and its 13 districts/counties have a total of 1,504 schools and 1,554,977 students. There are significant contrasts regarding the quantity and quality of PE teachers, notably across regions (i.e., urban versus rural). In 2024, Xi'an needed a total of 968 (10.98%) primary/secondary PE teachers, and newly trained teachers only satisfied 9.39% of the total need. This large gap between demand and supply is caused by the large number of students in the urban core and the level of investment in public education. Specifically, rural areas are not very attractive for teachers leading to recruitment and retention issues in more remote suburbs (e.g., Lantian and Zhouzhi).

3.2. Spatial Pattern of Teacher Allocation

Figure 2: Geographic Location Map of Primary and Secondary Schools in Xi'an.

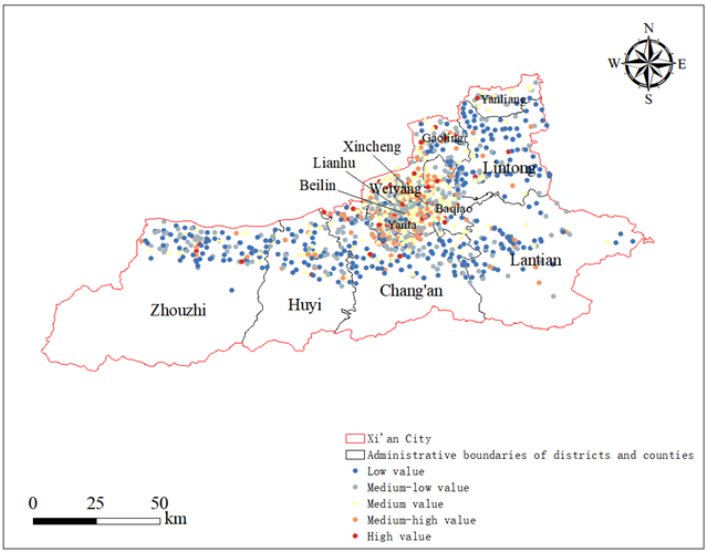


Figure 3: Kriging Interpolation of Physical Education Teacher Allocation in Schools in Xi'an.

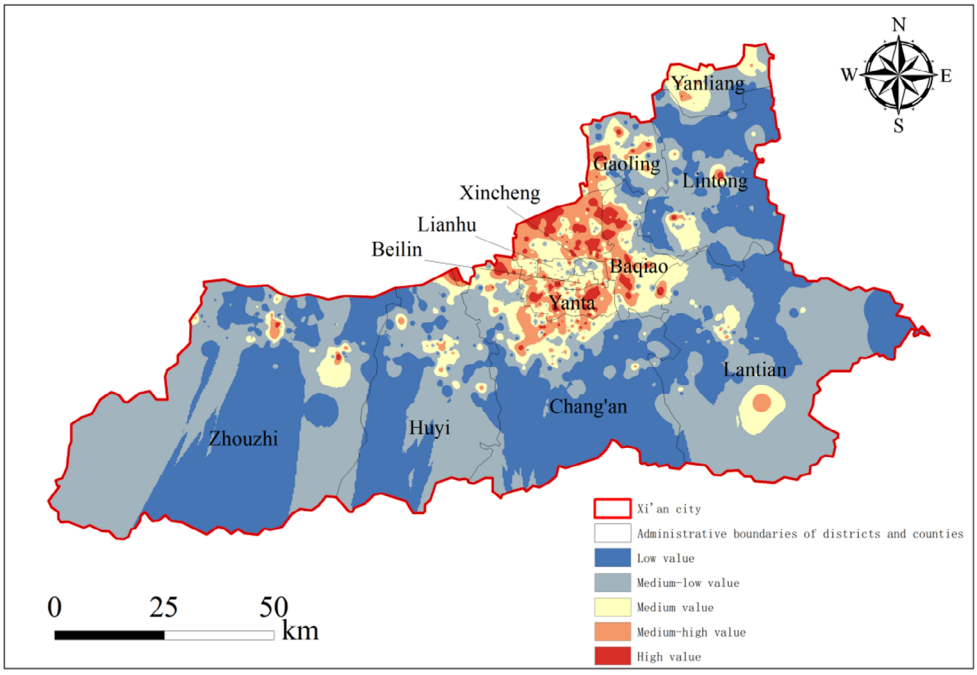


Figure 2 illustrates all schools, while Figure 3 depicts the Kriging interpolation of the composite teacher allocation index. Results reveal a pronounced center–periphery

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gradient: teacher resources are densest in the central districts and their thin out toward the suburbs. Over 40% of schools (627 out of 1,504) have an allocation index greater than the city average, and they are found mainly in the six core urban districts (Yanta, Weiyang, Baqiao, Beilin, Xincheng, Lianhu). The majority of schools (839, 55.8%) being allocated medium-low or low levels of resources. Under-resourced schools are located in remote counties (e.g., Lantian, Zhouzhi, Huyi) with a serious resource shortfall as result. Some fringe schools in or on the edge of a central district demonstrate very low allocations, perhaps more so because they exist as peripheral schools within the urban context. In summary, the impact of the city as a center of resource flows has been distinguished, while the peripheral areas of the city remains resource deficient.

There is a clear urban–rural gradient when examining schools by region. The central urban districts consist mainly of high- and medium-high allocation schools due to strong economic and political support for education and an ecosystem of many high- or medium-high allocation schools. Extended urban areas (e.g., Gaoling, Lintong) consist almost entirely of medium-low allocation or low allocation schools and have overall worse teacher levels. The distant suburbs (Chang'an, Zhouzhi, Lantian, Huyi) have a predominantly low-level allocation: for example, Chang'an has 11 schools at the high and medium-high allocation levels versus 77 at the low allocation level, meaning investing in education is strongly polarized. Zhouzhi, Lantian, Huyi are nearly all medium-low allocation to low allocation schools and they work with severe teacher shortages. Overall, the further from the center you go, the higher the proportion of under-resourced schools.

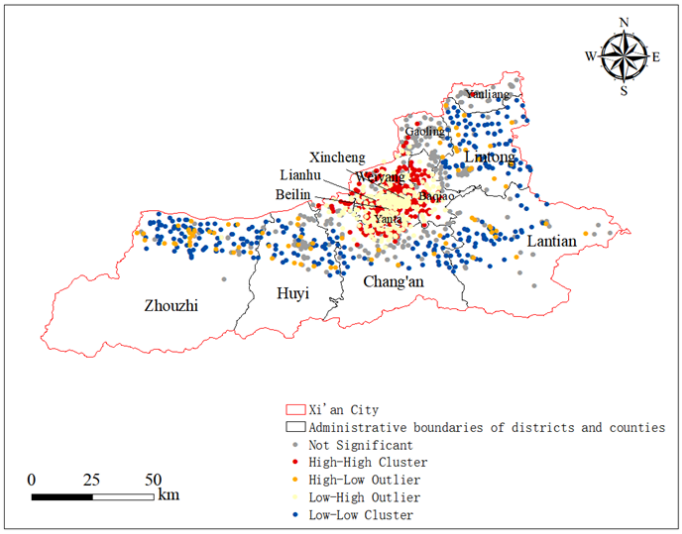
The Kriging interpolation (Figure 3) highlights this gradient: teacher allocation values demonstrate a continuous decrease as one moves away from the core. The decrease is most steep to the northwest and north, and most shallow to the southeast. There are also a few localized "hotspots" of more relatively high allocation in the suburbs (mostly around central schools, or schools with more resources). These spots would suggest that while the downtown core experiences the highest values of allocation, there are some sub-centers outside the core that are less concentrated.

3.3. Spatial Autocorrelation

Global Moran's I = 0.268 ($Z = 5.079$, $p < 0.01$) indicates significant positive spatial autocorrelation; meaning that schools, similar in levels of teacher allocation, spatially cluster. Local indicators of spatial association (LISA) (Figure 4) determines 321 schools fall within high–high (H-H) clusters and 302 fall within low–low (L-L) clusters, with 76 high–low (H-L) outliers and 250 low–high (L-H) outlier (the remaining 555 schools do not have significant clustering).

H-H Clusters: These are generally concentrated in the central city and its immediate suburban districts with strong economic and educational investment and positioning themselves with the highest quality teachers to form a corridor of high resource levels, extending along the axes of most development from the urban core. Gaoling and Baqiao, both adjacent areas also exhibit H-H characteristics reflecting anticipated resource savings through policy -driven resource spreading extending from the urban core.

Figure 4: Spatial LISA map of physical education teacher allocation in schools in Xi'an, China.



L-L Clusters: They are fairly prevalent in remote counties (Zhouzhi, Huyi, Lantian) which are located far away from cities, have lower levels of development and no qualified teachers. This shows "backward agglomeration" of low-quality schools together.

H-L Outliers: The 76 schools function as "islands of quality"; high allocation schools that are islands in a sea of lower-allocation neighbors. Most of them are situated in urban-rural transition zones, and we believe they have retained high quality because targeted support has compensated for weak surrounding schools.

L-H Outliers: These 250 schools are best thought of as a "depression" in terms of resources; they are low-allocation schools within high-resourced neighborhoods. They exist mostly within the main urban area, indicating that even in overall wealth, some schools in these areas are poor, probably for historical reasons or teacher mobility.

To sum up, Xi'an's distribution of PE teachers confirms a bipolar aggregation and village-level heterogeneity: high-quality PE teacher resources cluster in the central city and specific sub-centers in the suburbs, while poorly resourced schools cluster in more outlying areas. A few pockets of isolation and hollow are at the urban - rural fringe.

3.4. Indicator Level Analysis

In order to further disclose the particular differences in teacher allocation, the study analyzed the spatial distribution of the sub-indicators in the evaluation system, in which Kriging interpolation was used to obtain the spatial distribution maps of each teacher allocation indicator in Xi'an (Figures 5a - f), and the natural breakpoint method was used to classify the grades to analyze the patterns of spatial gradient, the characteristics of aggregation and the degree of difference of different indicators. The spatial characteristics of each of the principal indicators are discussed below separately:

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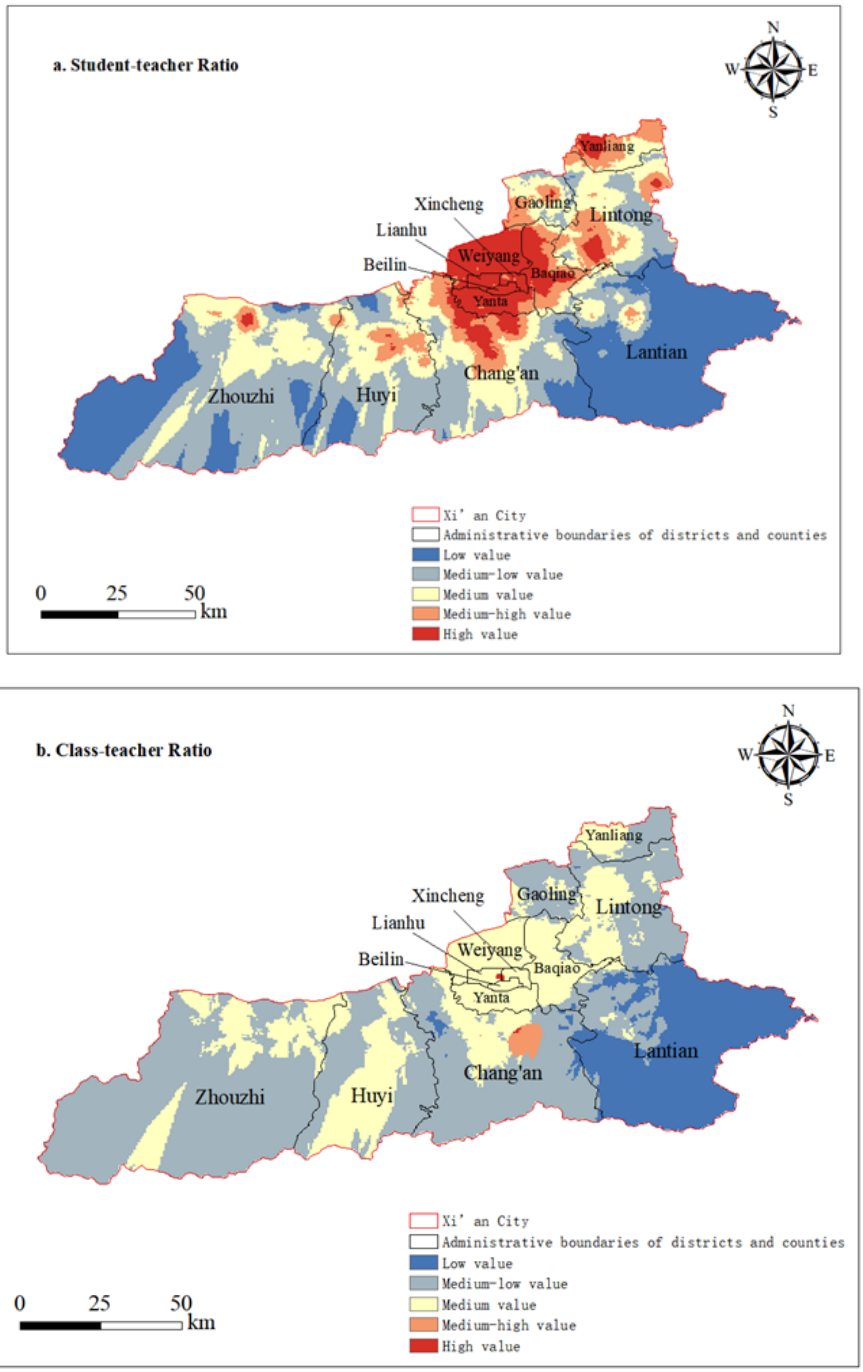
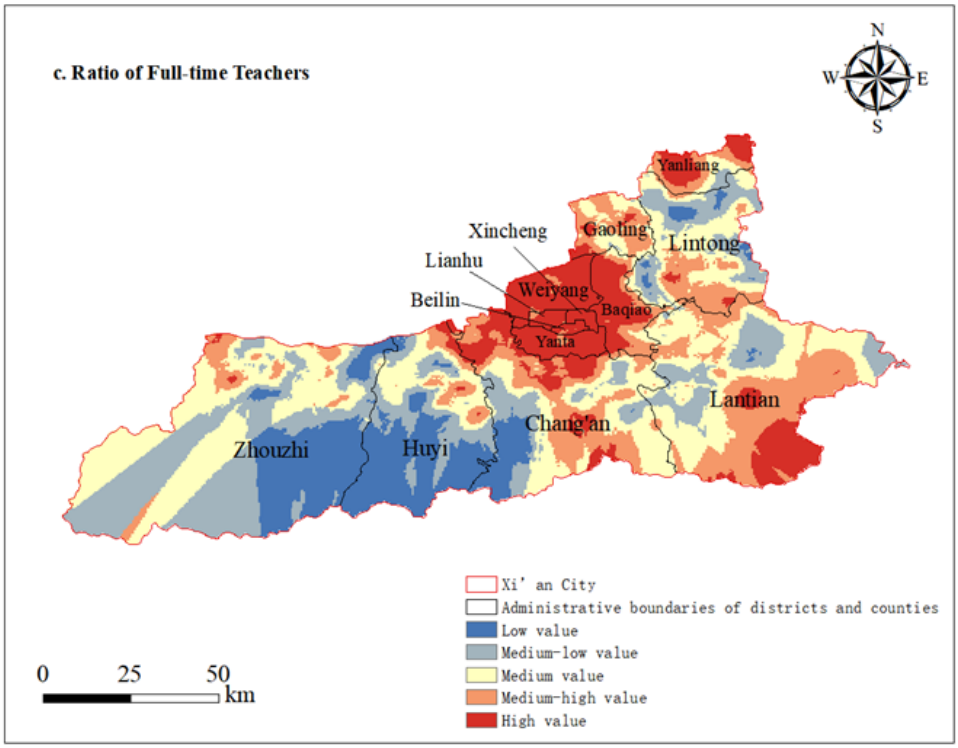
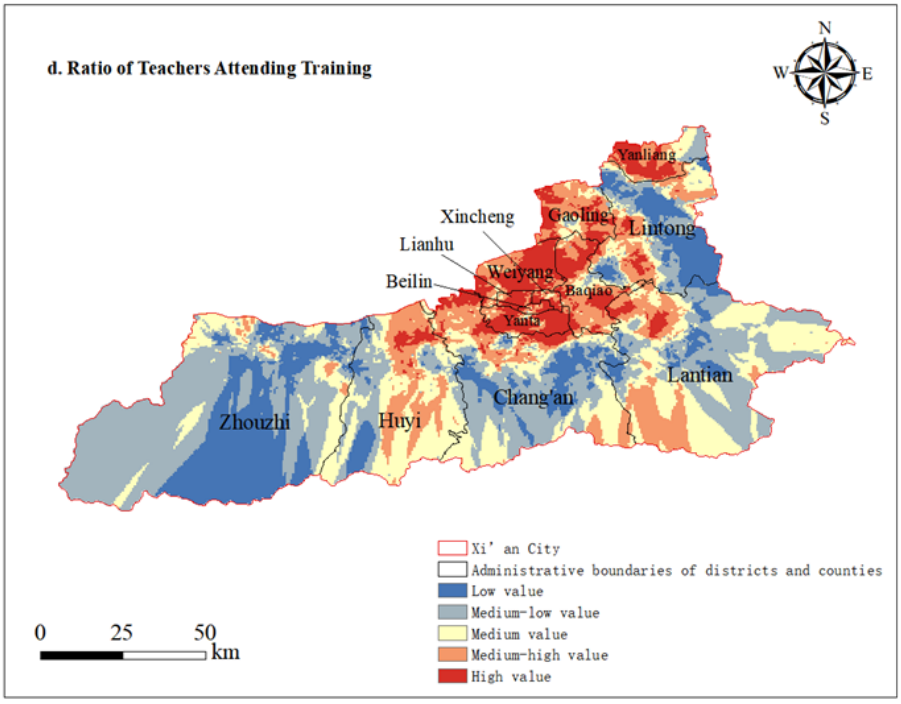
Figure 5: Kriging Interpolation of Physical Education Teacher Allocation in Schools in Xi'an.







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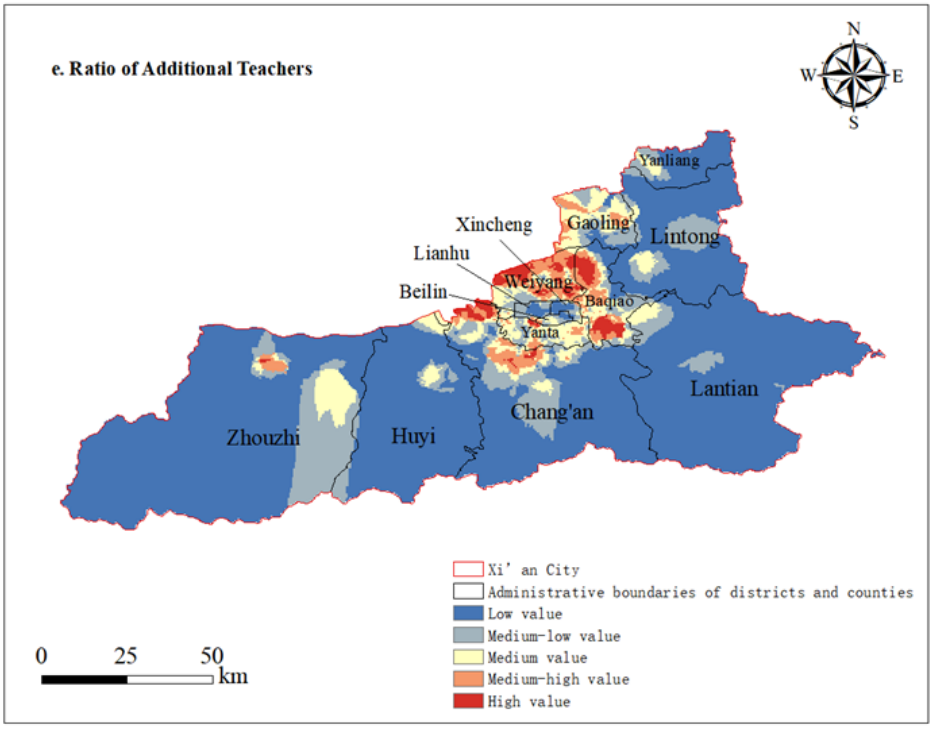
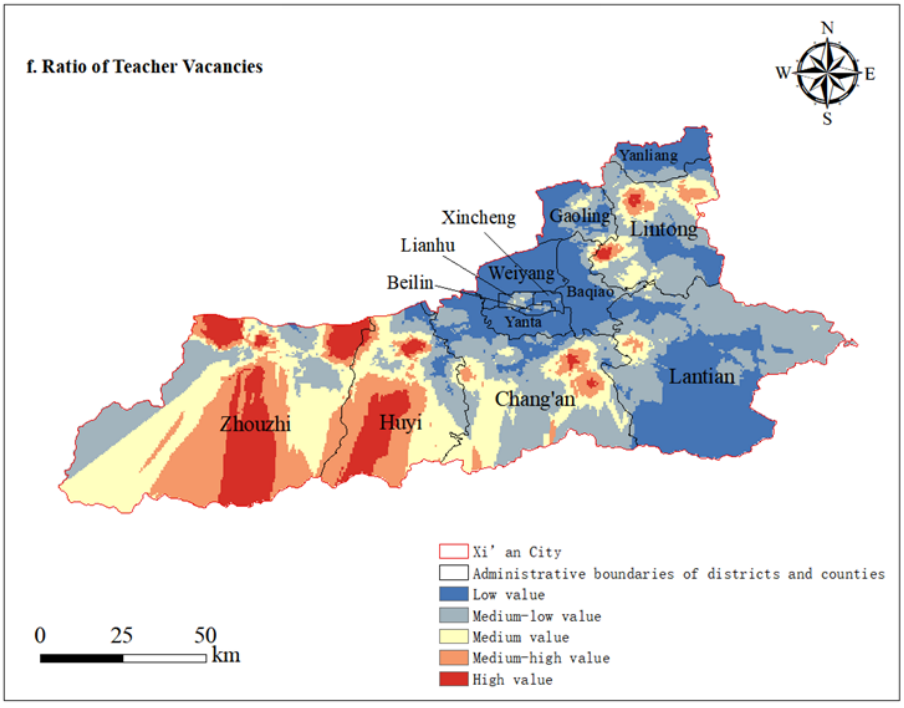
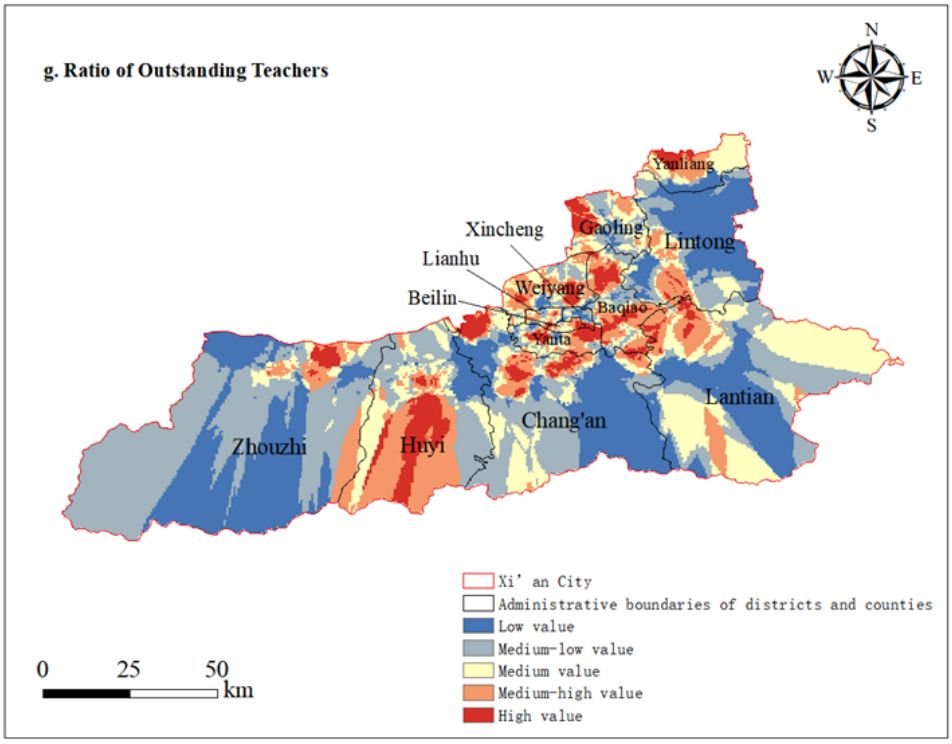

e. Ratio of Additional Teachers
N
W
E
S
Yanliang
Xincheng
Gaoling
Lintong
Lianhu
Weiyang
Beilin
Baqiao
Yanta
Lantian
Chang'an
Zhouzhi
Huyi
Xi' an City
Administrative boundaries of districts and counties
Low value
Medium-low value
Medium value
Medium-high value
High value
0
25
50
km


f. Ratio of Teacher Vacancies
N
W
E
S
Yanliang
Xincheng
Gaoling
Lintong
Lianhu
Weiyang
Beilin
Baqiao
Yanta
Lantian
Chang'an
Zhouzhi
Huyi
Xi' an City
Administrative boundaries of districts and counties
Low value
Medium-low value
Medium value
Medium-high value
High value
0
25
50
km



3.4.1. Student-teacher Ratio

The student-teacher ratio represents the number of students for each teacher. The higher the ratio the more students per teacher (increased demands of resources), lower ratios indicate a relatively more adequate amount of teachers (resources are more abundant). In Figure 5a we see an overall decrease in the student-teacher ratio within Xi'an by region, with a clear gradient. Within the central city and inner suburban regions, due to the high student population and relatively lagged teacher supplementation, we see a notably higher student-teacher ratio, which suggests a large burden on teachers. The farther away from the city centre that we move, the student density decreased and the teacher population was relatively abundant, therefore the student-teacher ratio decreased and in some remote schools it seemed that there were idle teacher resources. This pattern demonstrates that urbanization and the arrangement of economic development has made a major impact on the allocation of educational resources: central urban locations are effectively supporting large student populations whilst facing a shortage of teachers, and remote rural schools are faced with essentially supporting an adequate number of teachers with a little student demand, resulting in underutilized teaching resources.

3.4.2. Class Teacher Ratio

The class-teacher ratio is the average number of classes allowed to each teacher, to a higher extent indicated higher values show that each teacher has a set number

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of permitted classes but has higher amounts of pressure to teach more classes and lower values show they have adequate number of staff and fewer classes being taught coterminously.

As illustrated in Figure 5b, the spatial distribution trends between class-to-teacher ratios and student-to-teacher ratios in Xi'an are similar: both are most abundant in public school in the center of the city (urban), gradually decreasing in the peripheral areas, there are class-to-teacher ratios in most of the areas of Xi'an at a reasonable and balanced level, students per classroom teacher. Furthermore, there are several outer suburban districts where classroom teacher ratios are very low (in relation to number of classes), denoting that there are sufficient teachers, and an advantage to the distribution of teachers to the number of classrooms. Overall, there is reasonable balance and distribution of classroom to teachers ratios, however there are isolated areas where the classroom to teacher ratio is significant . For example, in particular central educational facilities between districts of Xincheng, Lianhu, Beilin) and at points in Chang'an, classroom teacher ratios are far higher than locations nearby. It is possible that these facilities have dramatically changed in relation to their student populations, with an insufficiency of classroom teacher replacements and growth demands to expand into classrooms. Note that while areas surveyed in Xi'an have a some fixed base support of teachers, there were clearly periods of pressure in relation to classroom teacher supply, at times of increasing student populations that keeps the ratios in the same balanced but generally higher reserved level for classroom teacher ratios.

3.4.3. Full-time Teachers Ratio

The full-time teachers ratio indicates the proportion of full-time physical education teachers among physical education teachers. A larger proportion indicates more full-time teachers in the physical education teaching force in the area, which points to the teaching work being relatively stable and more professional in nature; a smaller proportion means that part-time teachers account for a large proportion of the teaching force and this may jeopardize the predictability and continuity of ratios encumbered by other type educators tablets within or outside one's community.

As noted in Figure 5c, the overall prevalence of full-time physical education teachers in Xi'an schools is good, although some variation between areas is evident. The schools in the six districts of the main urban area and the eastern suburban districts near to the central city (e.g., Chang'an, Lintong, Gaoling, Yanliang, etc.) have a generally higher full-time teachers ratio, meaning these areas can attract and retain a higher number of full-time physical education teachers. Conversely, the full-time teachers ratio for marginal suburb districts and counties in the western and southwestern regions of Xi'an (e.g., Zhouzhi county, Huyi district), was significantly lower, and many schools had a disparity in full-time to part-time teachers, echoing the lack of alluring characteristics of marginal areas for physical education teachers and their retention. For we know it is very rare for teacher resources to flow from central urban areas to remote areas, the professionalization of the teaching staff in these peripheral schools has relatively slowly improved.

3.4.4. Ratio of Teachers Attending Training

The ratio of trainers attending training is expressed in the proportion of physical education teachers attending training and subsequent education. The expression of a high ratio of teachers attending training means that the teachers are participating in training which by virtue can result in possibly favorable outcomes of professional development and enhancement of teaching ability; conversely, low ratios of teachers attending training can represent relative weaknesses of teacher training in an area that may likely have problems with outdated teaching methods, or stagnancy in teaching quality.

Figure 5d shows that the overall proportion of all teachers participating in training activities in all districts and counties of Xi'an is relatively high, and that there is a clear trend towards spatial extension. Taking downtown Xi'an as the geospatial center, we see an area of high participation rates extending, especially in the northeast and eastern directions; a high-value training circle is formed with the following rates in decreasing gradient: areas with the highest amount of good training opportunities and the highest amount of teachers participating in training include from Beilin, Yanta, Weiyang, and in central urban areas that have a lot of the training opportunities have a great advantage for proportion in participating in teacher training; areas that are outside of downtown Xi'an, in peri-urban areas, such as Gaoling, Lintong, Yanliang are where the training resources from all urban areas are able to radiate in this next high-value belt area. In opposition to this, districts and counties somewhat, notably limiting the opportunities for participating in training are located to the southwest and west areas of Zhouzhi, Huyi and Lantian are authorities that can be classified as 'on the periphery' of the centric training resources; this level should be concerning for these authorities who are experiencing constrained professional development opportunities due to lack of training offerings and attendance by teachers. The south and southeastern regions are transitional areas exhibiting moderate degrees of teacher training attendance and, therefore, comparable opportunities in training; all have the potential to improve further.

3.4.5. Ratio of Additional Teachers

The ratio of new teachers indicates the ratio of new physical education teachers to the number of teachers in the year. To have a higher adding rate implies there was a relatively large number of new teachers. This can help relieve the amount of shortages for teachers and the teacher-student ratio, or similar. Having a low adding rate means you had a very small supply or amount of new teachers which could be an indirect effect of adding even more shortages for teachers and further distressing the teaching loads of teachers. As illustrated by Figure 5e, ratio of new teachers across Xi'an's urban structure has a distribution that is highly spatially unequal, resulting in a differentiated pattern: low in the core of the city, high in the periphery of the city, and inadequate in the far suburbs (for instance, in the center of the city (Beilin, Xincheng, Lianhu, and other main urban areas), new teacher ratios were fairly low, meaning there are only a limited number of new teachers in mature urban areas and that the teacher pool seems saturated; meanwhile, in the periphery bordering the core (Weiyang, Baqiao, Yanta, Gaoling, etc.), ratios were significantly higher: new teacher ratios were significantly higher, creating a high value ring across the urban core with plenty of new teacher additions) showing that the spatial distribution of new teacher resources does not

monotonically decrease in the radial direction, rather inputs were strongly concentrated on the periphery of the center. However, the reason for the circular line distribution is that: 1) the education resources in the central city are sufficiently well-developed to not create enough demand for new teachers; and 2) current policy support may skew toward newly developed areas in the suburbs; or 3) even though remote areas are in demand for additional teachers, it is not attractive enough for new teachers to go there and claim those jobs. This irregular distribution of growth is evidence of structural issues in the flow and distribution of resources for teachers that need further attention.

3.4.6. Ratio of Teacher Vacancies

The vacancy rate of teachers indicates the ratio between actual number of teachers in post, to the number of teachers that should be in post. A high teacher vacancy rate indicates that the school is short on teachers which may lead to challenges such as too many students being assigned to teachers, teachers become overburdened, teachers become burnt out; having a low vacancy rate means that teachers are generally fully staffed and educational resources are relatively available, which can help ensure quality teaching and equity in education, but we also need to be aware of potential downsides of too many resources, redundancy, and not having rotational positions.

The teacher vacancies in Xi'an (as seen in Figure 5f) reflect a structure that is highly uneven and complex. There are a multi-center and multi-corridor distribution of vacancies. The overall shortages in the central city and suburb areas is low and there are plenty of teacher resources; however, in certain directions away from the core there are many corridors with high teacher shortages. For example, the western direction of Zhouzhi, had a large belt of high vacancies that persists for dozens of kilometers. In Zhouzhi's case, the southeast direction (around Lantian) had a low vacancy rate, indicating it had fewer vacant teacher positions. Additionally, in the southern suburbs of the city (e.g. around Chang'an and Lintong), there were also some isolated "hotspots" of high shortages, distributed point-like, indicating periods or structural difficulties in refilling teachers to certain places. Overall, the distribution of ratio of teacher vacancies in Xi'an present a complex pattern of multiple cores, axes, and levels, mirroring the uneven distribution of teachers resources: teacher shortages being severely concentrated and contiguous in some urban-rural arrangements and remote areas, identifying sites key for political intervention.

3.4.7. Ratio of Outstanding Teachers

The ratio of outstanding teachers indicates the ratio of outstanding physical education teachers to the total count of physical education teachers who are recognized or acknowledged at a county-leveled basis or higher. A high ratio indicates that a region has more recognized outstanding teachers which typically indicates positive aspects of recognized outstanding teachers: the professional competency of outstanding teachers, the considerable teaching quality and educational accomplishments of outstanding teachers, and school reputation from having recognized outstanding teachers; whereas a low ratio means that there are low levels of outstanding teachers, which may indicate insufficient teacher incentives, halting progress in teaching quality, imbalance in educational resource allocation, which in the end reduced teacher surge,

overall teacher development, competitiveness of regional education.

As indicated in Figure 5g, the spatial distribution of the proportion of top-ranking teachers in Xi'an shows a complex agglomeration pattern with numerous cores and axes, which deviates from the simple center-periphery gradient pattern. Additionally to the main urban centre there are also considerable high-value areas dispersed, there are evidential signs of multipolarisation and leapfrog diffusion. The high-value areas that were identified in this analysis had a discontinuous and multi-dimensional spatial distribution: there were high-value points located in the transitional zone on the boundary of the core urban area, and high-value clusters further along the periphery of the city (e.g. around the Gaoling and Lintong areas), which reflects the impact of targeted support from education authorities on (certain) key schools, special programs or qualified teachers. Because of this, the spatial distribution of excellent teacher resources has obvious traces of non-uniform policy radiation across space, rather than just decaying by distance. Furthermore, the high-value areas cluster mostly in the east and northeast, but there are also lower secondary clusters 2 in the northwest and south (as in Chang'an), indicating that the growing and attracting of excellent teachers is impacted by multiple forces (including policy support, cluster effects of high-quality schools, and regional educational traditions, etc.). Instead, the low-value districts typically demonstrate the "depressions" surrounding or separating highly-valued districts: as in low-large districts with a low proportion of excellent teachers surrounded or separated by scattered high-value districts, which is usually simply due to geographical remoteness from districts, weak educational resources and no policies of support that cause difficulties to attract and try to growing excellent teachers. In general, the spatial distribution of the outstanding teachers' ratio shows the overall characteristic of multipolar, multi-zone, jump and coexist, at the same time, the low value area is not completely adjacent to the concept of marginal disadvantaged areas, it presents a certain type of spatial "depression", ex-disequilibrium, characterized by the extrusion of high value areas.

To further distinguish the allocation of physical education teachers from urban areas versus remoter areas, Table 2 summarizes differences in selected indicators between the central urban districts and remote suburban counties in Xi'an.

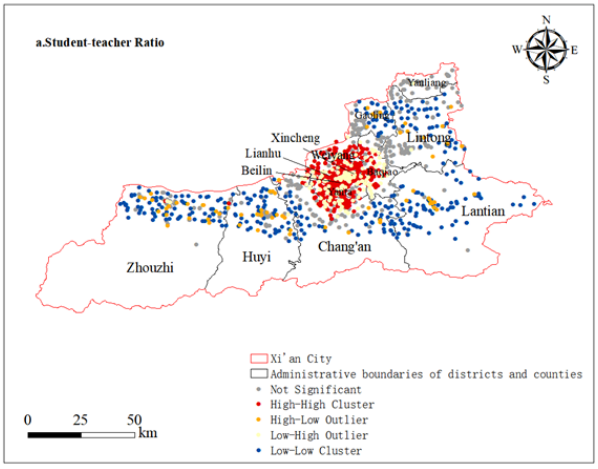
Table 2: Comparison of Key Indicators of Physical Education Teacher Allocation between Central Urban Districts and Remote Suburban Counties in Xi'an.

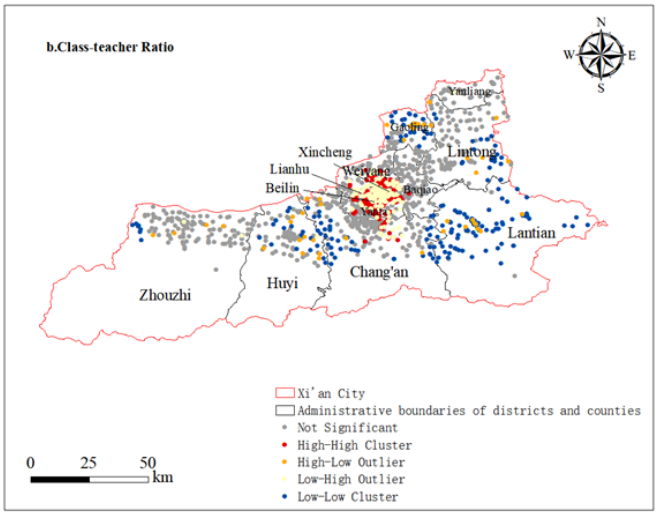
Indicator	Central Urban Districts (Main City)	Remote Suburban Counties (Far Periphery)
Student-teacher ratio	High – many students per teacher	Low – fewer students per teacher
Class-teacher ratio	High – teachers handle more classes on average	Low – teachers handle fewer classes on average
Full-time teachers ratio	High – majority of PE teachers are full-time	Low – many PE teachers are part-time
Ratio of teachers attending training	High – frequent teacher training participation	Low – infrequent teacher training participation
Ratio of additional teachers	Low – limited need for new teachers (staff saturated)	Low – insufficient new teacher supply (recruitment issues)
Ratio of teacher vacancies	Low – minimal teacher shortages	High – significant teacher shortages
Ratio of outstanding teachers	High – more award-winning teachers	Low – few award-winning teachers

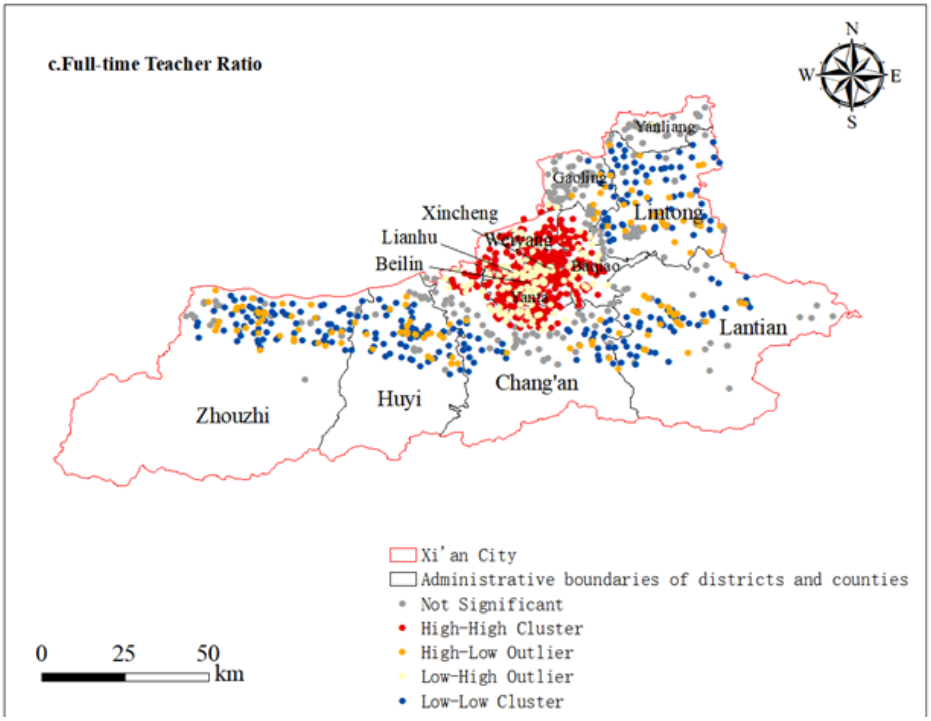
3.5. Spatial Aggregation Characteristics of Indicators

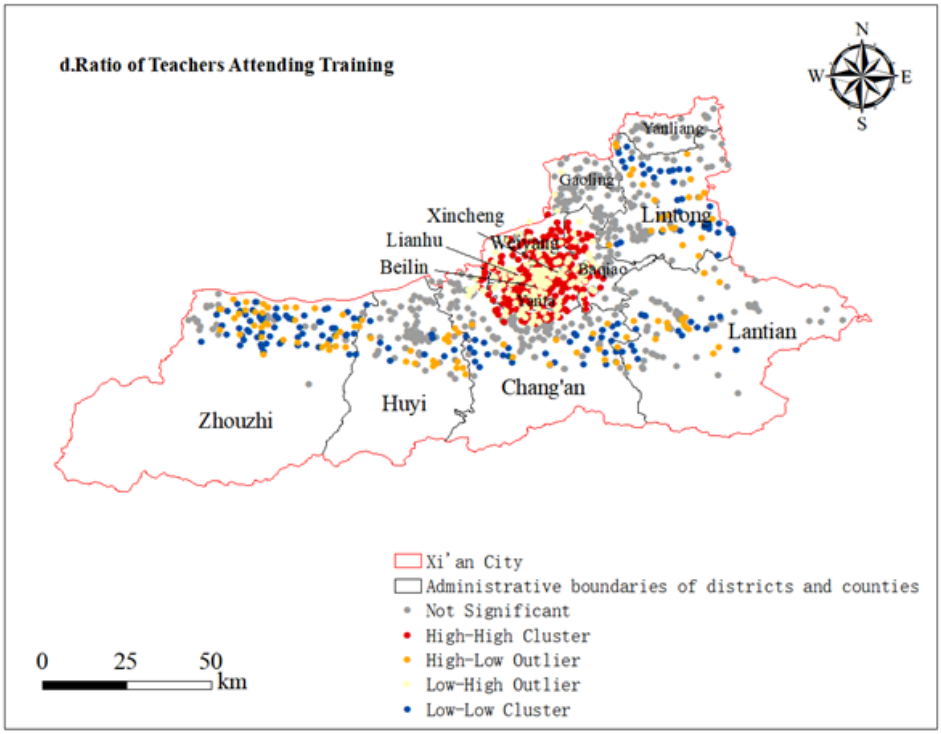
The spatial aggregation analysis using the Localized Moran Index for each of the above indicators (Table 3) provides complementary information about the spatial agglomeration/disaggregation characteristics of each teacher staffing indicator in Xi'an (Figures 6a - g). The results show that there was a large proportion of non-significant areas (e.g., class-teacher ratio, excellent teacher ratio), indicating that the spatial auto-correlation of most schools in Xi'an is weak, and that the spatial aggregation of overall teacher allocation is not significant. However, for key indicators such as student-teacher ratio, full-times teacher ratio, and ratio of teachers attending training, there were a high number of significant regions, which indicates the instance of resource polarization, and spatial heterogeneity in local regions. The specific analyses as follows:

Figure 6: Spatial LISA Map of Physical Education Teacher Allocation in Schools Indicator in Xi'an.









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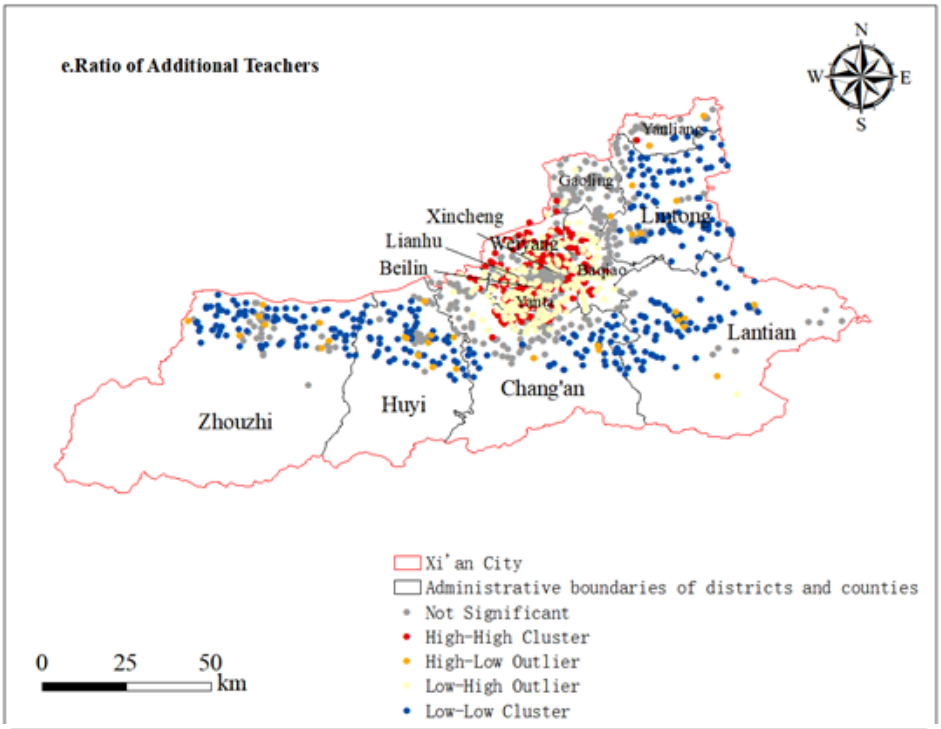
e.Ratio of Additional Teachers
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Lantian
Zhouzhi
Huyi
Chang'an
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Administrative boundaries of districts and counties
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High-High Cluster
High-Low Outlier
Low-High Outlier
Low-Low Cluster
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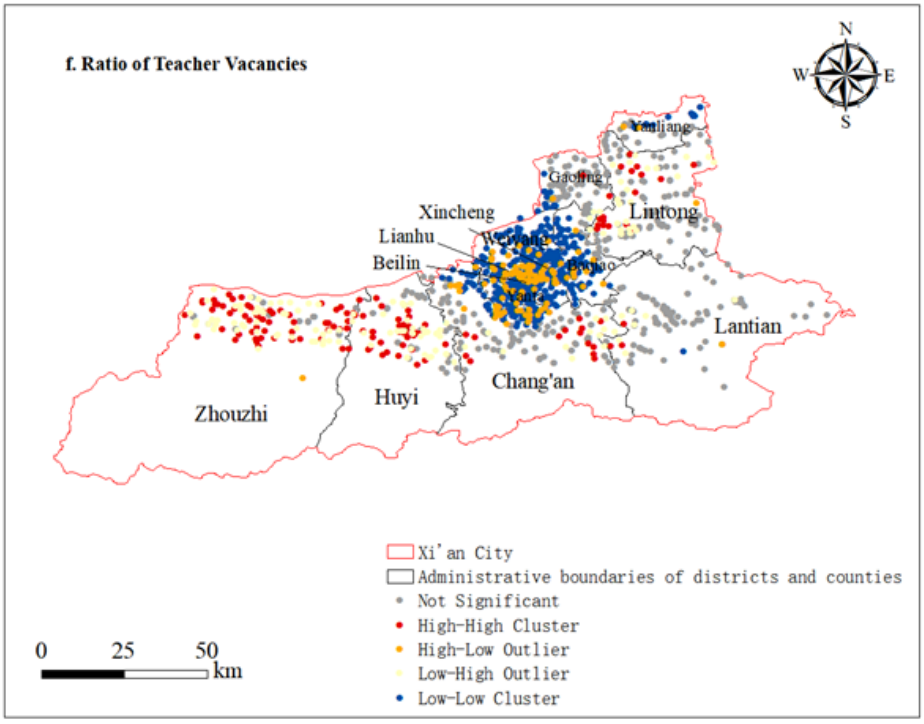
f. Ratio of Teacher Vacancies
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Huyi
Chang'an
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Administrative boundaries of districts and counties
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High-High Cluster
High-Low Outlier
Low-High Outlier
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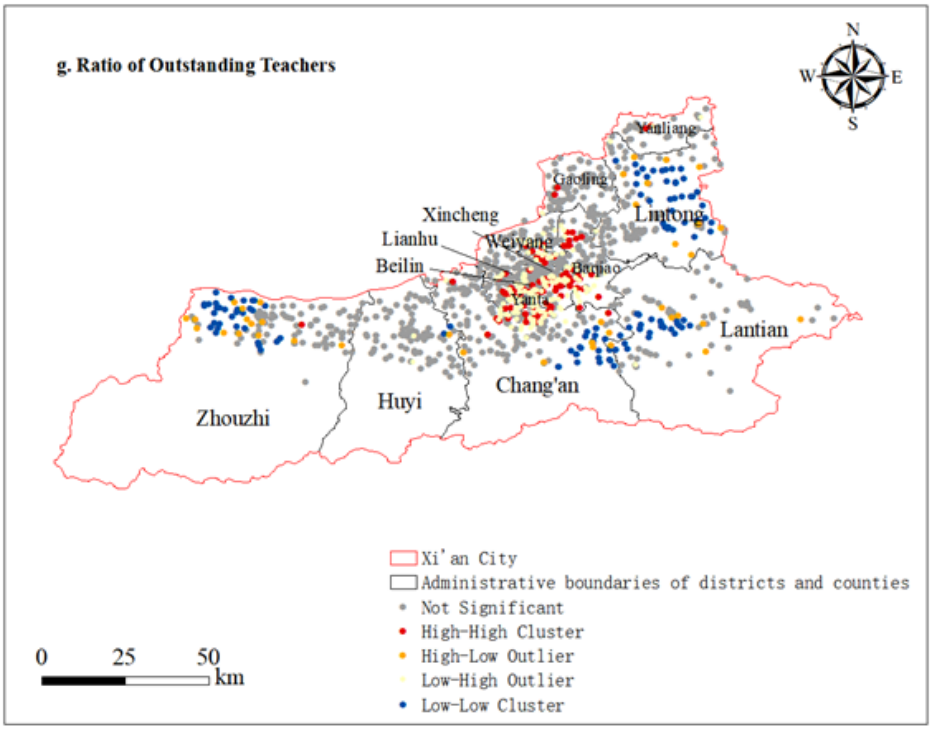

Table 3: Local Moran Analysis of Physical Education Teacher Allocation in Schools in Xi'an.

Aggregation		Indicators (number)						
		Student-teacher Ratio	Class-teacher Ratio	Full-time Teachers Ratio	Ratio of Teachers Attending Training	Ratio of Additional Teachers	Ratio of Teacher Vacancies	Ratio of Outstanding Teachers
Significant	H-H	454	201	538	448	207	139	111
	H-L	69	42	128	102	33	116	38
	L-H	125	126	127	143	203	128	146
	L-L	334	203	273	163	402	598	125
Not significant		522	932	438	648	659	523	1084

3.5.1. Student-teacher Ratio

As evidenced in Figure 6a, nearly 80% of the areas of H-H and L-L agglomeration exist in the city; this shows the polarized pattern of high and low student-teacher ratio areas, and shows that there are both "tight zones" of high concentration and "loose zones" of low density in teacher allocation. This indicates that Xi'an has both "tight zones" of high concentration and relatively widely extended "loose zones" in teacher allocation terms; H-H agglomeration areas are clearly concentrated in the core of Xi'an main city and Xi'an educational expansion axes, including Yanta, Weiyang and Beilin districts, as well as Gaoling and Baqiao districts which have close functional ties to the center. Beyond high concentration but still functionally concentrated and densely populated, along with an abundant student population is a severe shortage

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of teachers or comparatively, lack of expansion has not kept pace with the expansion of the student population; it may be said that student population has continued to become more and more dense, resulting in increasingly intense pressure to teach and learn. The clustering of H-H agglomeration areas in core sites not only indicates the "bottleneck" of internal education resources growth, but also indicates the trend of education investment growth in expanding areas like Gaoling and Baqiao needs to keep pace with urban expansion, as high student-teacher ratios would be less able to be eliminated. The mixed distribution of L-H and H-H agglomeration areas indicates the structural heterogeneity in a still resource-rich core area. The L-H agglomeration schools exist in a high-resource environmental condition, as contrasted with the surrounding schools in the same area that have high pupil-teacher ratios, illustrating the localized level imbalances. There remains basic education conditions to be further enhanced in the L-L agglomeration areas for improving the quality and desirability of teaching and learning, in order to hopefully encourage more rational resource usage and to prevent "sleepy zones" in education being created.

3.5.2. Class-teacher Ratio

As indicated in Figure 6b, it is clear that most schools do not display significant spatial clustering characteristics. The H-H and L-H agglomeration areas in the main urban area are mixed - the L-H agglomeration areas outnumber the H-H agglomeration areas, and H-H agglomeration areas do not exhibit significant tightly-clustered thermal zones. This indicates that there are still unequal educational resource allocations and spatial inequities in terms of space/resources even within the main urban areas. Particularly there is a marked disparity between the high concentration of high-quality resources and a surplus of educational resources in ordinary schools, therefore making H-H and L-H agglomeration area as mixed, but difficult to coalesce. Apart from Lantian County, the L-L agglomeration areas lie in the 'fringe' areas of Lintong, Chang'an, and Gaoling. The L-L agglomeration areas have teacher surpluses, but student shortages, indicating a "loose, but not used" resource situation. The L-L agglomeration areas are individually dispersed and dissociated from the main city by considerable amounts of districts with differences; this reflects the inequitable distribution of educational resources between city and country in space and highlights the problematic issue of spatial separation.

3.5.3. Full-time Teacher Ratio & Teacher Attending Training Ratio

As can be seen in Figure 6c and Figure 6d, the distribution of full-time teacher ratio and teacher training participation population and changing, the pattern of oblique and clustering is very similar - a high value aggregation in the urban center where the L-L agglomeration areas still represent the periphery (Lintong, Lantian, Chang'an, Huyi, Zhouzhi) high value compared to the overall pattern of strengths and advantages but the L-L agglomeration areas are not necessarily a large area of concentration - the presence of H-L, L-H scatter points suggest that there are micro differences in the overall patterns of strengths and weaknesses, and that required specifically targeted and precision measures adjusted to local circumstances.

3.5.4. Ratio of Additional Teachers in Physical Education

The counts of areas of H-H agglomeration or clustering shown in Figure 6e, are scarce and do not exactly describe when and where we expect to find the highest values (Main core). The whole situation was comprised of mostly insignificant points, and L-L (lower Lower) agglomeration - which suggested the resource investments of "new" beginner teachers did not create high levels of agglomeration, while the pattern showed more low-value school sites (L-L) in the periphery which had lower levels of adding new teachers, and the high-incremental "pattern" in the core was non-counted. The areas of L-H agglomeration is much higher in counts; there is evidence of "depressions" in parts of some districts meant to take advantage of incremental growth; age and gender also discount H-L types of schools where counts what very sparse describing a reflection of "top" (or "top-notch") geographic phenomenon.

3.5.5. Ratio of Teacher Vacancies

As shown in Figure 6f, the L-L agglomeration areas (598 schools) are the largest of the significant groupings and are clustered together largely in the central urban areas. This indicates that, for the most part, districts typically have low and similar physical education teacher shortages to one another, meaning that there isn't a major shortage of teachers in a significant number of districts. As you begin to move farther from the city, specifically in the direction of Zhouzhi and Huyi in the west, most of the schools in H-H agglomeration areas seem to show comparatively larger teacher shortages. The number of H-H districts (139) isn't massive and suggests that the regional clustering of very high shortages isn't very strong, but indicates that there isn't, overall, a large and severe city-wide "core zone" of teacher shortages.

3.5.6. Ratio of Outstanding Teachers

As depicted in Figure 6g, more than 70% of the schools have no distinguishable spatial clustering of high or low values, and exhibit the same "neutral dominance" pattern as the class-teacher ratio. That is, the distribution of excellent PE teachers in Xi'an is relatively evenly distributed with no significant core circle of high quality teachers on a large scale, and no significant large street disadvantaged districts with serious shortages. The areas of H-H and L-L agglomeration poles appear relatively weak and not in large scale contiguous manners, with areas of high quality teachers almost completely concentrated in the main urban area, while L-L agglomeration areas are concentrated in Lintong, Zhouzhi, Lantian, and portions of Chang'an.

4. Conclusions and Recommendations

4.1. Main Findings

This research highlight the tremendous spatial disparity in PE teacher distribution at the basic education level in Xi'an. It addresses two key questions:

First, Overall Pattern and Urban–rural Differences? The distribution of PE teachers in Xi'an education system is uneven and follows a contrary "center strong – periphery weak" spatial pattern with stark urban-rural differences. The central urban

areas (e.g., Yanta, Weiyang, Beilin) have attracted many good quality PE teachers due to local overall economic development and basic education policies; thus, it is an agglomeration of high-value core-periphery. However, the distant suburban counties (e.g., Lantian, Zhouzhi, Huyi) chronic shortages of PE teacher, indicating that almost all their schools are in the low tier and the inertia of resource polarization.

Second, Spatial Clustering Characteristics? There is evident clustering: high-allocation postsecondary schools form H-H clusters in the urban core and along development corridors, and large L-L clusters are apparent in remote suburbs. There are also H-L "islands" in between urban and rural, where a few well-supported schools are prominent in their less affluent surroundings. In contrast, there are L-H "depressions" within the city where some schools are lagging in comparison to their wealthier environment. Overall, central and peripheral zones show opposite agglomerations leading to a bipolar spatial distribution exhibiting sharp regional contrasts.

Third, Indicator-level Disparities? We analyzed individual indicators to explain these patterns:

① **Student-teacher Ratio:** In central urban areas - the highest level of concentration (teachers are assigned heavy workloads) and remote areas; the lowest level of concentration (for students per teachers - teacher-market oversupply compared to student demand). This shows that urbanization transforms and concentrates students to the city and growth in teachers lags behind growth of other community-based social infrastructure.

② **Class Teacher Ratio:** Citywide generally balanced but some hotspots (e.g., junctions of Xincheng/Lianhu/Beilin and parts of Chang'an) demonstrate disproportionately high ratios from rapid growth of the student population and lack of adequate teachers being replaced.

③ **Full-time Teacher Ratio:** This points to an opportunity for growth. Reasons for this are likely unprecedented in Chinese cities, including successful recruitment of full-time professionals in core urban and nearest suburban districts (for example, Chang'an and Lintong) vs. much lower levels of structure and full-time professional periodicity in western/southwestern outlying districts (Zhouzhi and Huyi), whereby retaining full-time staff in marginal areas is difficult.

④ **Ratio of Teachers Attending Training:** Highest in urban districts, lowest in remote areas–urban-rural gaps in professional development are evident.

⑤ **Ratio of additional teachers:** Low in core city but increased in near suburbs, then dropped to very low in far suburbs - indicating a ring-shaped imbalance of staffing.

⑦ **Ratio of Outstanding Teachers:** Multipolar-high in city center and some suburbs, with vast remote regions having a low value "depression."

The causes of these patterns are fundamentally different - urban districts exist in strong economies and have robust support programs, so they have more capacity to attract and retain great PE teachers, while remote areas face an employment disadvantage and challenging conditions, making teacher recruitment and retention difficult.

4.2. Revelations and Recommendations

This study's results are significant contributions to national and international discussions about educational equity, especially in relation to spatial justice regarding

resource allocation. Building on the OECD's claim that equitable education includes equal opportunity regardless of location, our findings support the conclusion that students' access to qualified teachers is strongly influenced by geographic location in Xi'an specifically. This finding aligns with Tate's "geography of opportunity" framework, supporting the notion that spatial context may structure opportunities for educational attainment. Similar trends were seen in other parts of the globe. In Istanbul, Turkey, there are many private education opportunities in the city center but very few in outer districts. In Greece, as in cities like Athens and Thessaloniki, education is densely populated in urban settings, creating an accumulation of quality schools, facilities, and teachers in urban areas. The examples above present core-periphery mismatches in Xi'an, but there is an argument to be made that this is not merely an issue of Xi'an but an identifier of rural/urban divides in education globally.

Further evidence from around the world also supports this claim. In England, rural schools have consistent retention issues despite being highlighted in national policy around teacher equity (Brooks & Perryman, 2024); in Saudi Arabia, girls' schools are disproportionately placed in urban areas, stretching claims about equality and equity of geography; in Australia, despite redistribution strategies, staffing in remote areas has increased and gaps in urban and rural student outcomes remain; in North Sumatra Province, Indonesia, spatial analysis (Moran's I and LISA) demonstrate extreme rural-urban inequity in terms of infrastructure and student participation. Together, these examples show that spatial inequality in education is a global issue, not just a local problem. Significantly, the approach used in this study - combining GIS spatial analysis with a local equity evaluation index – is not only scalable but adaptable to other contexts. Policymakers and researchers in other locations, whether in China or other developing nations, can undertake the same general strategy when they want to better diagnose spatial disparities. These stakeholders can modify the indicator system for their local contexts and then target those areas that are relatively underserved. It may also support the development of evidence-led policies and bolster equity and more balanced and inclusive development overall. Thus, this inquiry is not only applicable for policy interventions for Xi'an, but also serves as an applicable framework to address education spatial inequity in different worldwide contexts. Drawing from these suggestions, we offer the following policy recommendations.

Firstly, in the Short Term, Priority Should be Given to Alleviating Teacher Shortages: For cases like Lantian, Zhouzhi, and Huyi where teacher shortages are most severe in remote suburban areas for example, the government should ramp up targeted resource input and the assignment of new PE teachers. For example, it should increase the establishment quotas and institute special recruitment to capitalize on excellent physical education teachers to the weak areas; at the same time, it should provide additional incentives such as post allowances or even guarantees on housing in order to make the remote schools attractive to teachers and ameliorate the shortage of teachers in the short term. If there is a rapid filling of the shortfall and it eases the burden on those teachers already working then the plight of teaching can be improved rapidly.

Secondly, in the Medium Term, Efforts Should Focus on Improving the Professionalization and Stability of the Teaching force in Disadvantaged Areas: In order to replenish teachers, a flexible training support system (e.g., use of mobile training platforms and improved distance training) should be used to

ensure that teachers in remote areas have opportunities to participate in training, and to develop their teaching capabilities as well as career development. Optimizing teacher recruitment and mobility methods, as well as policies promoting the mobility of excellent teachers from urban areas to suburban schools (e.g., using programs like “Urban Teachers to Rural Areas Service Program” or inter-school twinning) can allow quality teachers to function as radiating functionality. By improving the rate of participation in training and professionalism of teachers in remote suburban counties, we can integrate and narrow urban and rural teacher capabilities, while building and allocating secondary high-value areas (i.e., Baqiao and Weiyang) to develop and be growth engines for their neighbouring regions.

Finally, in the Long Term, Sustainable Balance in Educational Resource Allocation must be Achieved Through Institutional Mechanisms: We suggest that the reform of the interconnection of urban and rural education be accelerated, that geographical barriers gradually be lifted, and that with establishment management, title evaluation and remuneration, a uniform system for urban and rural areas is developed, so that a teachers’ resource was able to flow according to real demand. With well-established international learning, a long-term mechanism for supplementary and training teachers for rural and impoverished areas is possible, such as forming a “Rural Teacher Induction and Training Scheme” to recruit a pool of local teachers, and establishing a “rotation and exchange scheme”, which enables teachers to regularly teach in different regions, for the approximation of equal teaching experience and resources distribution. To approximate equal teaching experience and resources distribution. At the same time, it is necessary to improve the dynamic monitoring and pre-warning system of teacher deployment, and use GIS and big data technology to understand the changes in the teacher workforce by location, and scientifically predict teacher demand based on the trajectory of student population movement, to get the best possible deployment. By only integrating short-term replenishment, medium-term enhancement, and long-term mechanisms can we eventually realize a more balanced distribution of urban and rural educational resources and protect the simultaneous improvements in educational equity and quality.

4.3. Research Limitations and Future Directions

We recognize several limitations in this study to be considered in interpreting the findings:

① **Geographic Scope:** The analysis relates specifically to the city of Xi’an; future work should establish whether the same spatial patterns hold for different cities or even larger contexts.

② **Temporal Scope:** Due to the provision of data, this study only provides a cross-sectionary representation of teacher allocation; we cannot pick up on dynamic change and trends over time without time-series data.

③ **Data and Methodological Limitations:** The study utilizes official education statistics and spatial datasets that offer standardized and structured data suitable for large-scale spatial analysis. However, the validity of our results depends on the quality and consistency of the data. Reporting inaccuracy, missing data, or inconsistencies in classifications etc., may create biases in the spatial trends we identified. In addition, whilst we applied rigorous spatial techniques (Kriging interpolation, Morris' I), they are based on assumptions and values (those relating to spatial weight matrices) that can impact results. Qualitative validation

(e.g., interviews with educators, school-level documents) is absent from this study, taking away potential interpretational context. Thus, while the study offers replicable evidence, caution should be exercised and our findings should be understood within the limitations of the data environment and methodology.

④ **Reproducibility:** We have made replication possible through the use of publicly available data, and accepted analytical procedures. However, while we can reproduce our analysis, full reproducibility assumes data of the same level of detail was available in other contexts. The ability to replicate our analysis relies on data being available in other contexts, so the clear documentation of our sources, and methods would be key to enabling another researcher to use this framework in a different context.

Future research can build on this study and address the above limitations in various ways:

① **Time-series Analysis:** Having longitudinal data on teacher allocation would permit the examination of temporal trends and the development of spatial patterns, which would add to the current approach of examining the issue of allocation in a cross-sectional sense.

② **Expanded Indicators:** Adding additional dimensions to the evaluation framework may provide a fuller picture of balance in the distribution of resources. Indices connected to teacher effectiveness or student wellbeing may augment the analysis and point to factors other than counts alone.

③ **Comparative Studies:** Conducting comparisons across a diversity of cities, regions, or even countries would investigate the generalizability of the spatial patterns observed in Xi'an. This kind of comparative work would allow for a broader lens in terms of analyzing young teacher allocation issues and uncovering shared patterns or specific local characteristics.

④ **Qualitative Methods:** Using qualitative research (e.g. interviews with teachers and case studies of schools) mixed with quantitative GIS analysis, may help us to better understand some of the contextual factors that underlie the spatial patterns. Qualitative research would shed light upon the lived experiences of educators and the ways in which they may confront practical challenges that contribute to unequal allocation practices.

⑤ **Collaboration with Practitioners:** We must work with local education authorities and educators to ground-truth our findings. Working with the education bureau together, we can confirm and enhance the results of the GIS with on-the-ground experiences that allow us to indicate if the spatial patterns are practical realities and if not, we would have local knowledge on how these spatial patterns came to be. This would ultimately allow for improved context-appropriate policy responses.

We suggest that by recognizing these limitations and working in the above direction, future studies may extend and improve the framework we proposed, and lead to more equitable and effective allocation of teacher resources.

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Contributions

Chengwei Xu is the sole author of this work. Chengwei Xu conceived and designed the study, obtained ethics approval, acquired and curated the data, performed the analyses, interpreted the results, prepared the figures and tables, drafted and revised the manuscript, approved the submitted version, and agrees to be accountable for all aspects of the work..

Ethics Declarations

The study has not used or involved human or animal participants, thus has no requirement for ethics committee approval.

Data were taken either from publicly available government resources or collected from field surveys conducted by our academic research team, who were authorized and followed institutional protocols.

All basemaps (Figures 2 - 4, 5a - g, and 6a - g) in this study came from the Standard Map Service Platform of the Ministry of Natural Resources of the People's Republic of China (http://bzdt.ch.mnr.gov.cn/) province based on the standard map (GS (2024)0650). The maps can be used for academic and non-commercial purposes without changes to national boundaries or basemaps and were approached in accordance with national policy on open map usage and attribution, and the original source remains publicly available.

Competing Interests

The authors declare no competing interests.

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