scientific reports

OPEN

A study on the spatiotemporal evolutionary pattern and influencing factors of sports venues in Xi'an

Yang Liu[1], Shulin Zhang[2]✉, Yirong Zhao[3] & Dong Yi[4]

Based on multi-source data, the spatio-temporal distribution characteristics, evolution trends, and driving factors of sports venues in Xi'an City were systematically explored in this work. Utilizing the Kernel Density Estimation (KDE) method, the distribution density of sports venues in 2010, 2015, and 2020 was scientifically calculated. Furthermore, the Multi-Scale Geographically Weighted Regression (MGWR) model was employed to analyse the factors influencing regional sports venues. Our analysis demonstrated that the number of sports venues in Xi'an has progressively increased, exhibiting a trend of gradually diffusing outwards from the centers of Xincheng District, Beilin District, and Lianhu District. Their spatial distribution is affected to varying degrees by commerce, industry, population, transportation, ecology, topography, and landforms, with the impact of commerce, industry, and population beginning to diminish. The transportation and environmental quality are gradually becoming core factors, and the influence of slope on sports venues shows spatial consistency. Moreover, the study also probes into the complexity of various influencing factors and provides a reference for the rational layout of sports venues in other cities. The importance of constructing and arranging sports venues judiciously in positively correlated areas is underscored to optimize their role in urban development.

Keywords Sports venues, Spatio-temporal evolution, Influencing factors, MGWR, Xi'an

Over the last decades, China's economy has continued to develop, and residents' living standards have significantly improved, accompanied by an increasingly strong desire for a better life. China's sports industry has entered a new stage of development. The issuance of the "Healthy China 2030" Planning Outline has elevated the improvement of people's health to an unprecedented level. Especially in the "post-pandemic era", the health awareness of the people has notably increased, stimulating enthusiasm for physical exercise among the general public and achieving new breakthroughs in nationwide fitness. Sports venues, as the foundation for the development of the sports industry, are playing a crucial role in the supply-side structural reform in sports[1]. For this reason, they have attracted considerable government attention[2]. In recent years, local governments at all levels in China have constantly increased investments to actively promote the construction of multifunctional sports venues in order to meet the growing fitness needs of urban residents. As a result, the strategic position of sports venues in the urban development landscape has continuously elevated. Therefore, a deep understanding of the spatio-temporal evolution and influencing factors of the spatial distribution of sports venues is considered of great significance to fully leverage their comparative advantages.

With the vigorous development of sports and the acceleration of urbanization, sports venues, as vital public service resources in cities, have increasingly become the focus of the academic community. Since 2008, investigation on sports venues has gradually emerged as one of the research hotspots in sports science and its interdisciplinary fields. The research perspectives have been continuously expanded, and the research methods have become increasingly diverse, forming a relatively rich system of research outcomes. According to the existing works in the literature, academia has mainly conducted in-depth discussions around three core issues: spatial distribution, impact effects, and smart transformation[3–5]. In terms of spatial distribution research, systematic explorations from the perspectives of geography, urban planning, and other disciplines have been

[1]College of Physical Education and Health Sciences, Chongqing Normal University, Chongqing, China. [2]Physical Education College of Xinjiang Normal University, Urumqi, China. [3]Chinese International College of Dhurakij Pundit University, Bangkok, Thailand. [4]Department of Physical Education, Xinjiang University of Finance and Economics, Urumqi, China. ✉email: zsl1716@163.com

conducted. Various works in the literature including Yan Hua's and Tian Yunxi's studies have systematically refined and summarized the issues related to sports space in China[6,7], providing important theoretical references for subsequent research. Zhang used spatial analysis methods to deeply explore the spatial heterogeneity characteristics between the spatial distribution of sports venues and the urban population[8]. Zeng further pointed out that the spatial distribution of sports venues exhibits layout features that are oriented by economic conditions, urban morphology, road networks, and population distribution[9]. This discovery provides an important basis for an in-depth understanding of the underlying reason for the site selection of sports venues. In the field of impact effect research, the socio-economic effects of sports venues from multiple dimensions have been revealed. Through empirical research, it has been reported by various studies, such as Rahman and Grace's work that sports venues play multiple positive roles in urban development, including promoting urban renewal[10], regulating urban migration[11], and enhancing residents' life satisfaction[12]. However, it has been also pointed out that sports venues may bring negative effects, such as traffic congestion when hosting large-scale events[13], which raises important concerns for the planning and management of sports venues. It is noteworthy that Tabassum has focused on the impact of competition venues on athletes' competitive states[14]. From the perspective of urban economics, Ahlfeldt demonstrated the significant value of new sports venues as urban business cards[15] and confirmed their notable positive spillover effects on surrounding real estate prices[16]. These studies provide a multidimensional analytical framework for assessing the comprehensive benefits of sports venues. In terms of research on smart transformation, with the rapid development of new-generation information technology, the intelligent upgrading of sports venues has emerged as a new research trend. Currently, digital twin technology[17], green and low-carbon concepts[18], and artificial intelligence applications[19] constitute the three main directions of smart transformation for sports venues. The integrated application of these technological approaches is not only anticipated to enhance the operational efficiency of sports venues but also provide audiences with a higher-quality spectating experience, promoting the development of sports venues in the direction of intelligence and sustainability. Overall, the existing works in the literature highlight the characteristics of multidisciplinary integration, particularly achieving significant progress in the interdisciplinary field of spatial distribution and impact effects[20–22]. More attention has been paid to the interaction between sports science and disciplines, such as economics, geography, and sociology, which drive the innovations in research methods and induce the refinement of theoretical systems.

However, there are obvious limitations, in terms of spatio-temporal dimensions and methodological systems. First, the majority of the reported works employ static cross-sectional data[23], lacking tracking of the dynamic evolution of spatial patterns. Second, although preliminary attention has been given to the spatial heterogeneity of sports venues[24], most studies still rely on the utilization of traditional regression models[21]. Third, the existing literature has not yet effectively integrated big data on human activities[25], such as POI (Points of Interest), OSM (OpenStreetMap), and WorldPop. In the current coexistence of cyberspace and geospatial realms, big data has emerged as one of the most effective sources for quantitative measurements, providing a new breakthrough for research on the spatial heterogeneity of sports venues. It is thus apparent that further exploration and experimentation on big data and new technologies is undoubtedly required. As a national central city in China and the core city and transportation hub in northwest China, Xi'an plays a pivotal role in the Belt and Road Initiative, serving as an important platform connecting the New Eurasian Land Bridge and the China-Mongolia-Russia Economic Corridor. It successfully bid for and hosted the 14th National Games of the People's Republic of China in 2015 and 2021, respectively. The years 2010 and 2020 correspond to the sixth and seventh national population censuses, respectively, while 2015 marked the final year of the "12th Five-Year Plan", filling data gaps in non-census years. The five-year intervals between these three years align with urban planning evaluation cycles, facilitating longitudinal comparison of evolutionary trends and ensuring the completeness and periodicity of data acquisition. Based on this, in this work, the POI data of sports venues in Xi'an from 2010, 2015, and 2020, were selected and visualized. In addition, their spatial distribution was analysed using the KDE (Kernel Density Estimation) model, and an indicator system for influencing factors from the perspectives of human activities and the natural environment was developed. The MGWR (Multiscale Geographically Weighted Regression) model was also employed to explore their impact effects, aiming to provide scientific references for research on sports resources and facilities in other cities and promote urban renewal and transformation.

Overview of the research area

As the capital city of Shaanxi Province, Xi'an governs 11 districts and 2 counties, spanning a total area of 10,108 square km (Fig. 1). It is designated as a high-level national central city under the "13th Five-Year Plan for Promoting the Rise of the Central Region" issued by the National Development and Reform Commission of China, and concurrently, it is one of the national central cities located in the Yellow River Basin. Occupying a strategic position in national strategies, Xi'an plays a pivotal role in the Belt and Road Initiative, boasting favourable resource and environmental carrying capacities, and possessing a solid foundation for economic development. It is a modern metropolis that leads regional development and represents the image of China. Therefore, a thorough investigation of the spatial distribution and spatio-temporal evolution characteristics of sports venues in Xi'an in 2010, 2015, and 2020 will provide valuable insights for further improving the quality of the available sports infrastructures.

Research data and research methods
Data sources

Multi-source data were employed here to construct the research dataset, with 2010, 2015, and 2020 serving as the research time nodes, systematically collecting sports venues and the related geospatial data in Xi'an. More specifically, the study employs government-published sports venue data, Amap POI data, and field sampling
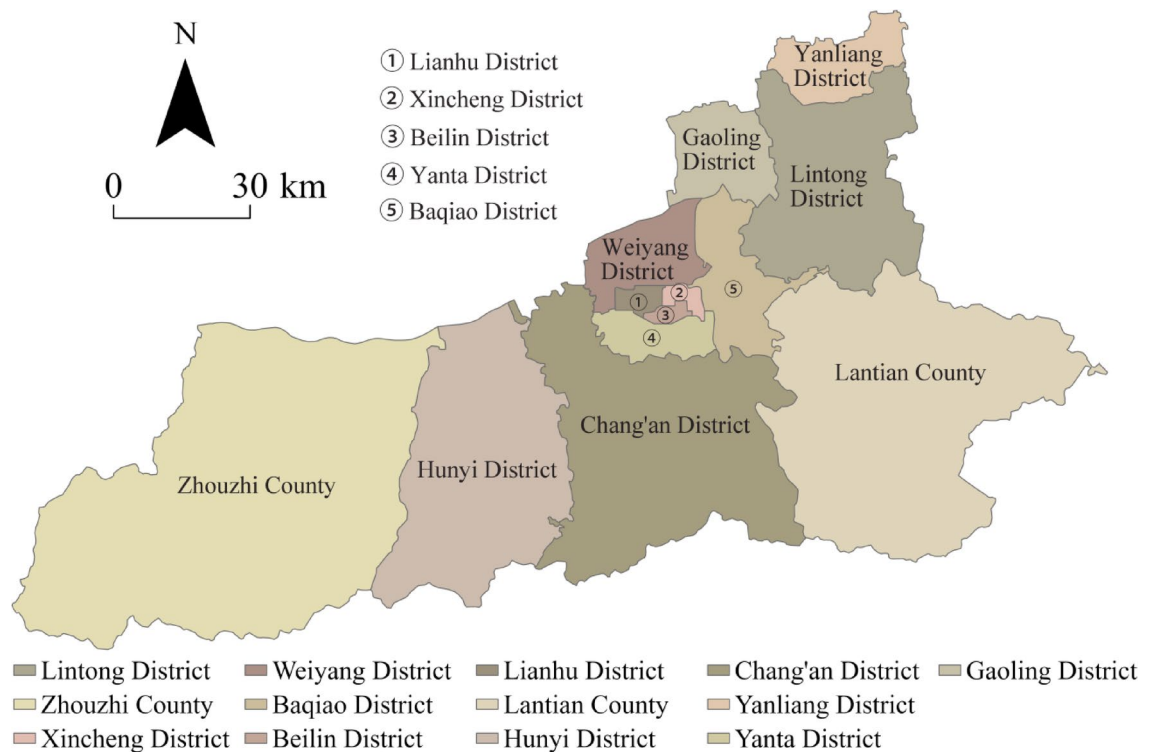
Fig. 1. Overview of the research area.

surveys to conduct tri-source cross-validation, ensuring data accuracy. Among them, the sports venue data are primarily represented as POI obtained through the API interface of the Gaode Map Open Platform, with data fields including basic information, such as venue names, detailed addresses, and geographical coordinates. During the data collection process, a specific focus was placed on verifying operational status using 2020 as the baseline year, with manual verification conducted to remove invalid sports venue data marked as "closed, relocated". After performing data cleansing (including deduplication, outlier removal, and other quality control steps), and cross-verification with public information from official channels, such as the Xi'an Municipal Sports Bureau, the final counts of sports venues in Xi'an during the study period were determined as follows: 562 in 2010, 1,108 in 2015, and 2,761 in 2020, demonstrating a significant growth trend.

Regarding the data sources and processing, a multi-source data fusion approach was adopted here: (1) The transportation network data originate from the OpenStreetMap (OSM) platform (https://www.openstreetmap.org), providing foundational support for spatial analysis by constructing a GIS road network model; (2) The population data utilize a 100 m × 100 m spatial resolution raster dataset (https://hub.worldpop.org) published by WorldPop, which boasts high spatial accuracy and reliability; (3) Based on the aforementioned data, key indicators of human activities in the study area, such as commercial intensity, industrial intensity, traffic accessibility, and population density, were calculated through spatial analysis methods.

In terms of natural environmental factors, the following two dimensions were primarily considered: (1) The air quality data employ PM2.5 concentration data from the China High-resolution and High-quality Near-surface Air Pollutant Dataset published by the team of Dr. Wei Jing and Professor Li Zhanqing[26], which feature high spatiotemporal resolution; (2) The topographic data adopt the Copernicus 30 m resolution Digital Elevation Model (DEM), from which slope information is extracted through GIS spatial analysis, providing data support for studying the topographic characteristics of sports venue distribution.

Research methods
Kernel density estimation

Kernel Density Estimation (KDE) is a method that is used to estimate the probability density of sample data, commonly applied in calculating the density values of neighbouring elements to represent the geographical characteristics of research objects. Consequently, it has been extensively employed in spatial distribution studies. By measuring the spatial density of sports venues in Xi'an, the spatial distributions of sports venues in these two cities were mapped in this work. Higher values indicate a higher concentration of sports venues in the region, while lower values suggest a more dispersed distribution. The formula is as follows[27]:

$$f(X_t) = \frac{1}{nh} \sum_{i=1}^{n} K\left(\frac{X_{it} - X_t}{h}\right) \tag{1}$$

where h represents the threshold, n is the number of points within the threshold range, k refers to the kernel function, h is the bandwidth, X_{it} and X_t denote the independently and identically distributed observations and mean values, respectively, and $f(X_t)$ represents the density function of the random variable X in the t-th year.

MGWR Multi-scale geographically weighted regression

Geographically Weighted Regression (GWR) is a local regression model constructed based on a spatial weight matrix. This method takes into account the non-stationarity of spatial processes and is commonly used to explore their spatial effects. Although GTWR (Geographically and Temporally Weighted Regression) considers both temporal and spatial weights, it is assumed that the effects of all variables are globally consistent in space and time, failing to address the spatial heterogeneity of different variables across different scales. Nevertheless, MGWR extends this model by relaxing the assumptions, making it applicable across varying spatial scales. MGWR allows variables to vary on their individual spatial scales, enabling a more precise capture of the spatial process characteristics of each variable. By adopting a multi-bandwidth approach, MGWR generates a spatial process model that is closer to reality. The formula is expressed as follows[28]:

$$y_i = \beta_0\left(u_i, v_i\right) + \sum_{j=i}^{k} \beta_{bwj}\left(u_i, v_i\right) x_{ij} + \varepsilon_i \tag{2}$$

where y_i represents the dependent variable of the i-th element, x_{ij} is the attribute value of the independent variable j at position i, β_{bwj} stands for the bandwidth used for the regression coefficient of the j-th variable, (u_i, v_i) denotes the spatial coordinates of the i-th element, $\beta_0(u_i,v_i)$ represents the intercept of the i-th element, and ε_i is the residual error.

$$\hat{\varepsilon} = y - \sum_{j=1}^{k} \hat{f}_j \tag{3}$$

MGWR initializes based on the classical GWR and then proceeds to calculate the initial residuals $\hat{\varepsilon}$, gradually selecting bandwidths to optimize the computation.

In Eq. (3), the initial residuals $\hat{\varepsilon}$, the additive term $\hat{f}_j$, and the independent variable x_i undergo GWR weighting at $i=1...n$ to identify the optimal parameter β_{bwj} for each variable. Following this, an iterative calculation was performed until all variables k have undergone a complete selection process. Finally, the continuous cycle of selection and estimation iterates until convergence to a pre-defined convergence criterion is achieved.

Accessibility analysis

Accessibility analysis is a method used to quantify the convenience of spatial location to obtain specific services or resources, and usually evaluates the efficiency of facility service coverage by integrating transportation network topology, time cost, and supply and demand relationship, so it has important application value in the equalization of urban public services layout and transportation planning optimization. The formula is expressed as follows:

$$A_i = \frac{1}{n-1} \sum_{j=1, j\neq i}^{n} d_{ij} \tag{4}$$

where A_i represents the reachability of node i; n is the total number of nodes in the network; d_{ij} indicates the minimum impedance of nodes i to j.

Spatio-temporal evolution characteristics of sports venues
Temporal evolution characteristics

Based on statistical analysis of POI data for sports venues in Xi'an in 2010, 2015, and 2020, the number of sports venues in Xi'an and its districts and counties exhibits significant spatial distribution characteristics and temporal variation patterns (Table 1). In terms of spatial distribution, in 2010, the sports venues in Xi'an were mainly concentrated in Beilin District (19.22% of the total) and Yanta District (30.60% of the total). By 2015, Xincheng District (5.11%) and Lianhu District (7.06%) gradually developed into new clusters of sports venues. By 2020, the spatial distribution of sports venues showed a multi-centered characteristic, with Yanta District continuing to lead in the number of sports venues, accounting for nearly one-third of the city's total. In terms

Year	Weiyang district	Xincheng district	Beilin district	Lianhu district	Baqiao district	Yanta district	Yanliang district	Lintong district	Chang'an district	Gaoling district	Huyi district	Lantian county	Zhouzhi county	Total
2010	67	50	108	38	15	172	17	16	20	15	20	16	8	562
2015	74	124	191	148	56	270	26	28	95	28	32	21	15	1108
2020	479	141	283	195	177	808	52	78	322	66	94	29	37	2761

Table 1. Number of sports venues in various districts in 2010, 2015 and 2020.

of temporal variation, Xi'an's successful bid to host the 14th National Games of the People's Republic of China in 2015 significantly accelerated the construction of sports venues. The data show that the growth rate of sports venues between 2015 and 2020 was significantly higher than that between 2010 and 2015, with all districts and counties experiencing growth. Notably, the growth rate of sports venues in municipal districts reached 401%, 2.29 times that of counties (175%), indicating notable regional differences. In terms of regional development, the construction of sports venues in Weiyang District accelerated, with a growth rate from 2015 to 2020 significantly higher than that from 2010 to 2015. This development is closely related to the implementation of policies, such as the Weiyang District National Fitness Implementation Plan (2016–2020) and the Xi'an Weiyang District National Games Benefit-the-People Project Implementation Plan. Meanwhile, Chang'an District, Yanta District, and Baqiao District also experienced significant growth in the number of sports venues between 2010 and 2020. This growth can be partly attributed to the gradual improvement of infrastructure in universities within the university town and reflects the positive driving effect of higher education institutions on the construction of regional sports facilities.

Spatial evolution characteristics

Using the kernel density analysis tool in ArcGIS 10.2, the density of sports venues in Xi'an for the years 2010, 2015, and 2020 was calculated. To ensure longitudinal comparability of the visualization results, the obtained density images were manually adjusted and classified into six categories each for the two locations, based on the natural breaks method (Fig. 2).

Distribution of sports venues in 2010
As illustrated in Fig. 2a, the distribution of sports venues in Xi'an in 2010 exhibits notable spatial differentiation characteristics. The core areas with high values are primarily concentrated in Beilin District and Yanta District, extending in a "Π"-shape towards Xincheng District and Lianhu District, with the extracted values being positively correlated with the number of sports venues. Regarding the distribution of secondary high-value areas, the high-value zones in Yanliang District (peak value: 0.6), Lintong District (peak value: 0.8), Gaoling District (peak value: 0.7), and Huxian County (peak value: 0.8) are all located within the built-up areas where the district governments are situated, with values ranging from 0.5 to 1.0. Notably, Weiyang District demonstrated unique spatial distribution features, with its high-value area not only encompassing the built-up area where the municipal government is located but also forming a significant concentration in the Xi'an Weihe Urban Sports Park (peak value: 1.5, range: 1.0–3.0). This result is closely related to the park's functional positioning as the only comprehensive sports theme park in Northwest China. In contrast, Lantian County and Zhouzhi County as a whole have not formed distinct high-value areas, with only the built-up areas where the county governments are situated showing relatively higher numerical characteristics; Bazhou District, on the other hand, exhibits a scattered distribution of low-value areas (0.2–0.5).

Distribution of sports venues in 2015
As depicted in Fig. 2b, the spatial distribution pattern of sports venues in Xi'an in 2015 has undergone significant changes compared to 2010, evolving from a "Π"-shaped distribution to a typical single-core "center-periphery" concentric circle structure. The core high-value areas are still concentrated in traditional central districts such as Lianhu District, Xincheng District, Beilin District, and Yanta District. Nonetheless, they exhibit notable spatial expansion characteristics. Compared to 2010, the areas with high values within the built-up areas where the district and county governments are situated have significantly expanded, and the trend of numerical gradients decreasing from the center to the periphery is more pronounced, indicating a further enhancement of the spatial agglomeration effect of sports venue resources. Notably, several emerging high-value areas have appeared in the study region: first, new high-value areas have formed in suburban areas due to the construction of the Jingwei Sports Center; second, significant high-value areas have emerged in Yanta District (peak value: 5.0), Baqiao District (peak value: 1.5), and Chang'an District (peak value: 2.6), which highly coincides with the spatial distribution of university towns. From the data analysis, it was revealed that the agglomeration and development of higher education institutions are important driving factors promoting the spatial expansion of sports venues, with infrastructure construction in universities directly facilitating the rapid growth of sports venue resources in the region.
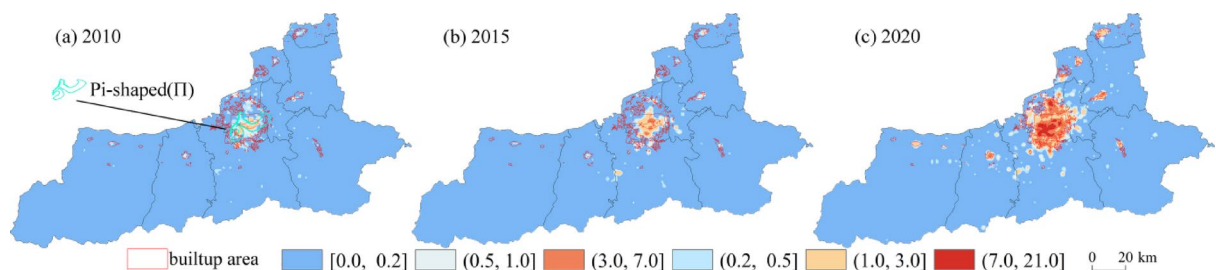

Fig. 2. Spatial distribution of sports venues in Xi'an in 2010, 2015, and 2020,

Distribution of sports venues in 2020

As illustrated in Fig. 2c, the spatial distribution of sports venues in Xi'an in 2020 exhibits a prominent single-core "center-periphery" concentric circle structure. Compared to 2015, the scope of high-value areas was further expanded, with numerical gradients becoming more pronounced. Core high-value areas continue to concentrate in traditional central districts such as Xincheng, Beilin, Lianhu, and Yanta, while Weiyang District emerges as a new high-value area, forming a multi-center diffusion pattern. Peripheral districts and counties (including Zhouzhi, Huxian, Lantian, Lintong, Yanliang, Gaoling, and Eyi) still maintain a relatively low-density distribution; however, the area and numerical values of high-value zones within the built-up areas where their governments are situated have significantly increased compared to 2015, indicating a hierarchical characteristic in the spatial diffusion of sports venue resources. Notably, higher education agglomeration areas present a significant impact on the distribution pattern of sports venues. Obvious high-value zones have formed in regions with dense higher education institutions, such as Chang'an University Town, Bailuyuan University Town, Lintong University Town, and Weiyang University Town. Among them, Yanta District, serving as the spatial carrier for multiple university towns, has become the city's highest value area (> 5.0). This spatial distribution feature confirms the synergistic effect between the higher education resources and the development of sports facilities, providing an important spatial decision-making basis for optimizing the layout of urban sports facilities.

Spatial distribution characteristics

The spatial analysis based on Fig. 2 reveals that the distribution of sports venues in Xi'an exhibits a prominent single-core "center-periphery" concentric circle structure with evident spatio-temporal evolution characteristics. According to the research results between 2015 and 2020, the numerical values and spatial scope of high-value areas for sports venues in Xi'an demonstrated a significant growth trend, which is temporally aligned with Xi'an's successful bid to host the 14th National Games in 2021. In terms of spatial distribution characteristics, high-value areas for sports venues are mainly concentrated in two types of regions: first, the built-up areas where district and county governments are located; and second, the peripheries of higher education agglomeration areas (university towns) and large sports facilities (such as sports centers).

By performing further analysis, a significant spatial correlation between the spatial distribution of sports venues and the urban built environment was found. Urban built-up areas and university town regions, with their well-developed municipal infrastructure, convenient transportation networks, and high population densities, have formed "hotspots" for the layout of sports venues. This spatial distribution characteristic not only reflects the spatial logic of urban sports facility supply but also embodies the synergistic development relationship between the layout of sports venues and the urban spatial structure. The aggregated distribution of sports venues effectively enhances the accessibility and convenience of public sports services, positively promoting the conduct of mass sports activities.

Analysis of influencing factors
Indicator system construction

The existing works in the literature have indicated that the spatial distribution of sports venues is closely intertwined with human activities[29] and natural environments[30]. In urban planning, the layout of sports venues is often determined by various factors, such as population density and transportation convenience to cater to residents' fitness needs[31]. Concurrently, consideration is given to natural environmental factors, including air pollution, topography, and landforms, to ensure the provision of comfortable and safe venues for athletic activities[32]. This comprehensive approach ensures the harmonious integration and sustainable development of sports venues within the urban ecosystem. Among them, commercial intensity, commonly referred to as the intensity and economic vitality of commercial activities, is generally regarded as a crucial indicator of economic development. Industrial intensity, on the other hand, reflects the level of industrialization within the economy. Population density, to a certain extent, represents the demand for sports facilities among the local populace. Meanwhile, transportation, as the medium connecting residential areas and sports venues, significantly affects the participation rate in sports activities and the service scope of sports venues. With regard to the natural environment, the rate of change in PM2.5 not only creates concerns about health and environmental factors but also encompasses considerations for market demand and athletic performance. The slope, meanwhile, can influence multiple aspects, such as the selection of venue locations, spectator experiences, and athlete performance. Based on the preceding analysis, six secondary indicators, incorporating both quantitative and qualitative assessments, have been constructed from two aspects—human activities and the natural environment—to investigate the primary driving factors behind the spatio-temporal evolution of sports venues (Table 2).

Primary indicator	Numbering	Secondary indicator	Method	VIF	T
A.Human activities	A-01	Commercial intensity	KDE	1.584	0.631
	A-02	Industrial intensity	KDE	1.357	0.736
	A-03	Population distribution	Population size/Area	1.239	0.807
	A-04	Traffic accessibility	Network analysis	1.259	0.794
B.Natural environment	B-01	PM2.5	Tiff Extraction[26]	1.435	0.697
	B-02	Slope	Height increment / Horizontal increment	1.362	0.734

Table 2. Influencing factors Indicator system.

Analysis of influencing factors

In this work, three regression analyses were attempted: Ordinary Least Squares (OLS), GWR, and MGWR. As can be seen from Table 3, the R² values of MGWR for Xi'an in 2010, 2015, and 2020 were all greater than those of the OLS and GWR models, with respective values of 0.76 for 2010, 0.52 for 2015, and 0.87 for 2020. Concurrently, the adjusted R² values of MGWR for Xi'an were consistently lower than those of the traditional GWR and OLS models. Moreover, in terms of AICc values, the MGWR models for Xi'an over these three years, with values of 319.03, 213.56, and 1508.30, respectively, were significantly smaller than those of the other two traditional models. These findings indicate that the MGWR model offers more scientific and reliable regression results, as well as superior goodness-of-fit.

A comprehensive comparison of the parameters of the above models demonstrates that the MGWR model outperforms the traditional GWR and OLS models in this work. Therefore, the MGWR model was selected for our analysis.

As shown in Fig. 3a, the regression analysis results of the relationship between the distribution of sports venues and the commercial land use intensity in Xi'an indicate a significant spatial correlation between the two. From a temporal perspective, the regression coefficients within the study area generally presented positive values in 2010, suggesting a positive impact of commercial land use intensity on the distribution of sports venues. More specifically, high-value areas were primarily concentrated in Weiyang District, Lianhu District, Yanta District, Chang'an District, Eyi District, and Zhouzhi County, among others. These regions exhibited notable characteristics, in terms of commercial activity density, economic development level, and urban planning layout, leading to a strong spatial dependency of sports venue distribution on commercial land use intensity. By 2015, the regression coefficients reached their peak during the study period (with a maximum value of 0.031), and the high-value areas demonstrated a clear spatial displacement towards the southwest, concentrating in areas such as Yanta District, Chang'an District, Eyi District, and Zhouzhi County. This shift in the spatial distribution pattern may be closely related to adjustments in Xi'an's urban spatial structure and the subsequent changes in the focus of regional economic development. Notably, the regression coefficients showed a significant decline in 2020, approaching zero with fluctuations, indicating a weakening spatial impact of commercial land use intensity on the distribution of sports venues. The location choice of sports venues was no longer significantly constrained by differences in regional economic development levels. Through vertical comparison of the spatial regression analysis results for 2010, 2015, and 2020, it can be observed that the spatial correlation between the distribution of sports venues and commercial land use intensity in Xi'an exhibits clear spatio-temporal evolution characteristics: in terms of spatial dimension, the regression coefficients exhibited a decreasing distribution trend from west to east; in terms of temporal dimension, they began to decline after reaching a peak in 2015. This evolution trend is closely related to Xi'an's economic and social development process, especially in 2015 when Xi'an, as an important node city in the "Belt and Road" strategy, saw a significant improvement in its urban economic development level against the backdrop of policies for comprehensively deepening reforms. Meanwhile, based on the hierarchical characteristics of urban public service demand, the supply and layout of the available sports venues gradually tended towards rationalization.

Based on the spatial regression analysis results presented in Fig. 3b, a significant spatial correlation between the distribution of sports venues and industrial land use intensity in Xi'an can be observed. The research data indicate that the regression coefficients are predominantly positive, suggesting a positive promotional effect of industrial intensity on the distribution of sports venues. From the perspective of spatio-temporal evolution characteristics, in 2010, high-value areas of the regression coefficients were mainly distributed in Weiyang District, Lianhu District, Beilin District, Xincheng District, Chang'an District, Eyi District, and Zhouzhi County. The unique economic structure and urbanization process of these regions constitute the core high-tech industrial belt of Xi'an, while the land use planning characteristics result in a strong spatial dependency of sports venue distribution on industrial intensity. By 2015, the high-value areas of the regression coefficients underwent spatial displacement, concentrating in Xincheng District, Baqiao District, Gaoling District, Yanta District, and Beilin District. This shift in spatial pattern is closely related to the implementation of Xi'an's industrial green transformation strategy. In 2020, the regression coefficients tended to stabilize and exhibited a spatial differentiation characteristic of "higher in the west and lower in the east." Through vertical comparison of the spatial regression analysis results for 2010, 2015, and 2020, it can be observed that the spatial correlation between the distribution of sports venues and the industrial intensity in Xi'an exhibits distinct phased characteristics: a decreasing trend from west to east was demonstrated in both 2010 and 2020, while a "center-periphery" spatial structure was presented in 2015. This spatio-temporal evolution is significantly correlated with adjustments to Xi'an's industrial development strategy. Since the 11th Five-Year Plan period (2006–2010), when China first proposed energy conservation, emission reduction, and sustainable development strategies, Xi'an further intensified its policy orientation towards industrial transformation and upgrading, as well as green development

Parameter	2010			2015			2020		
	OLS	GWR	MGWR	OLS	GWR	MGWR	OLS	GWR	MGWR
R^2	0.32	0.68	0.76	0.08	0.50	0.52	0.11	0.85	0.87
Adjusted R^2	0.32	0.67	0.73	0.08	0.45	0.48	0.11	0.82	0.86
AICc	662.2	425.01	319.03	502.13	326.21	213.56	2683.15	1632.62	1508.30

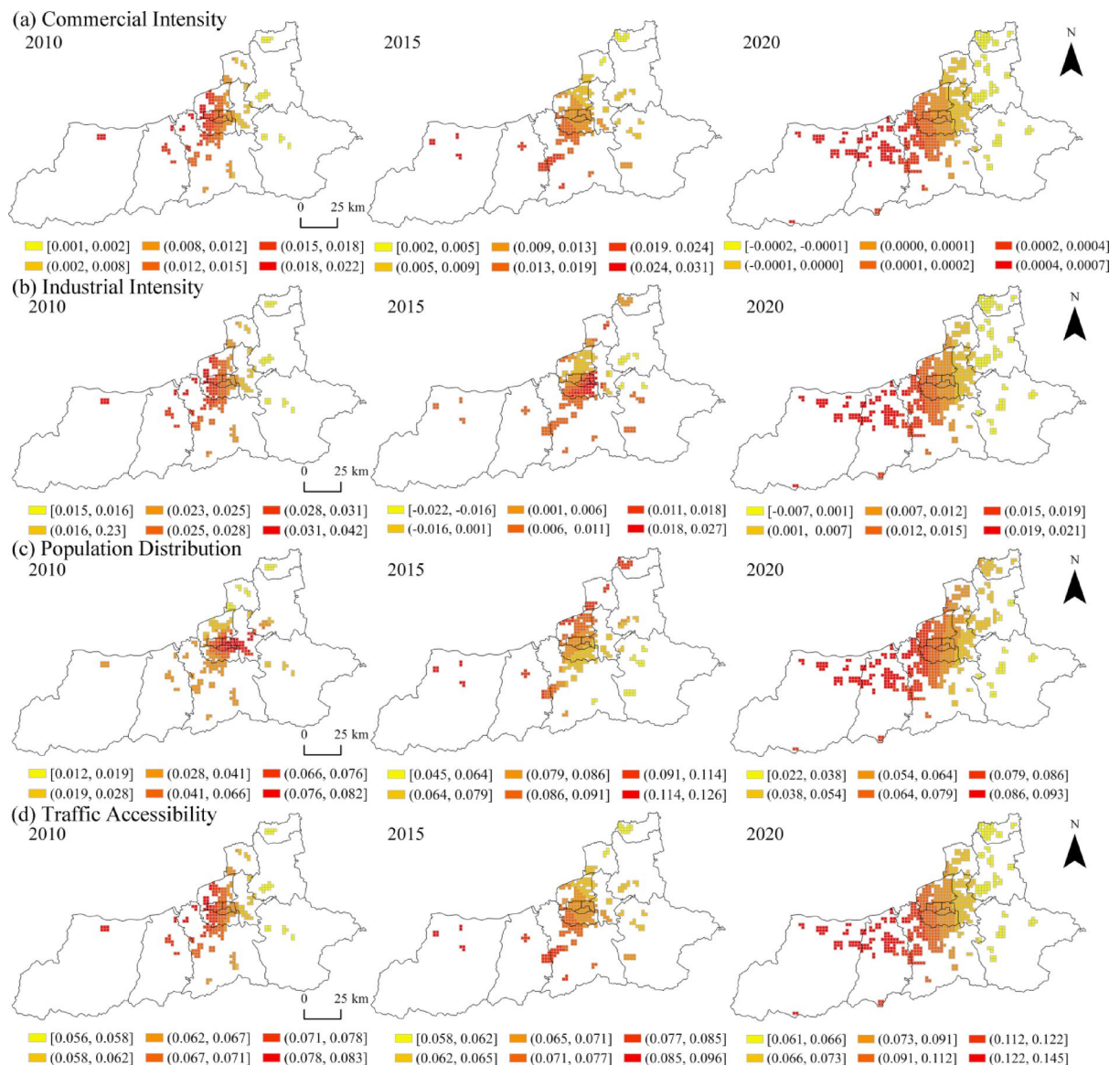**Table 3.** Parameter information for OLS, GWR and MGWR regression fitting.

Fig. 3. Regression coefficient map of sports venues and human activities based on the MGWR model.

during the 12th Five-Year Plan period. At the same time, prioritized the promotion of green and low-carbon development strategies during the 13th Five-Year Plan period.

As evident from Fig. 3c, there exists a positive regression relationship between the sports venues and population distribution, aligning with previous research findings that demonstrated the positive influence of population distribution on sports venues. In 2010, high-value areas for regression coefficients were primarily concentrated in Baqiao District, Weiyang District, Xincheng District, Beilin District, Lianhu District, and Yanta District, which constitute the urban areas of Xi'an with relatively high population densities. The heightened demand for sports venues in this region, coupled with a greater emphasis on the efficient use of space, has contributed to the centralized distribution of sports venues. In 2015, the regression coefficients peaked (with a maximum value of 0.126), and high-value areas were mainly distributed in Yanliang District, Gaoling District, Weiyang District, Hu County, and Zhouzhi County. As the population in various districts and counties converged towards built-up areas, economic development drove significant population influxes and increases, thereby increasing the demand for sports venues within the region. Concurrently, the coefficients within the old urban areas of Xi'an began to decline, where the service scope of sports venues had already been comprehensive, resulting in a weakened driving effect of population size changes on sports venues. With the rationalization of population mobility and distribution, residents' demand for sports venues gradually shifted, and the comprehensive development of sports venues somewhat diminished the influence of population distribution on them. From a "center-periphery" structure in 2010, the trend evolved to a gradual increase from southeast to northwest in 2015, and by 2020, it transformed into a characteristic of being higher in the west and lower in the east, indicating a gradual marginalization of the influence center.
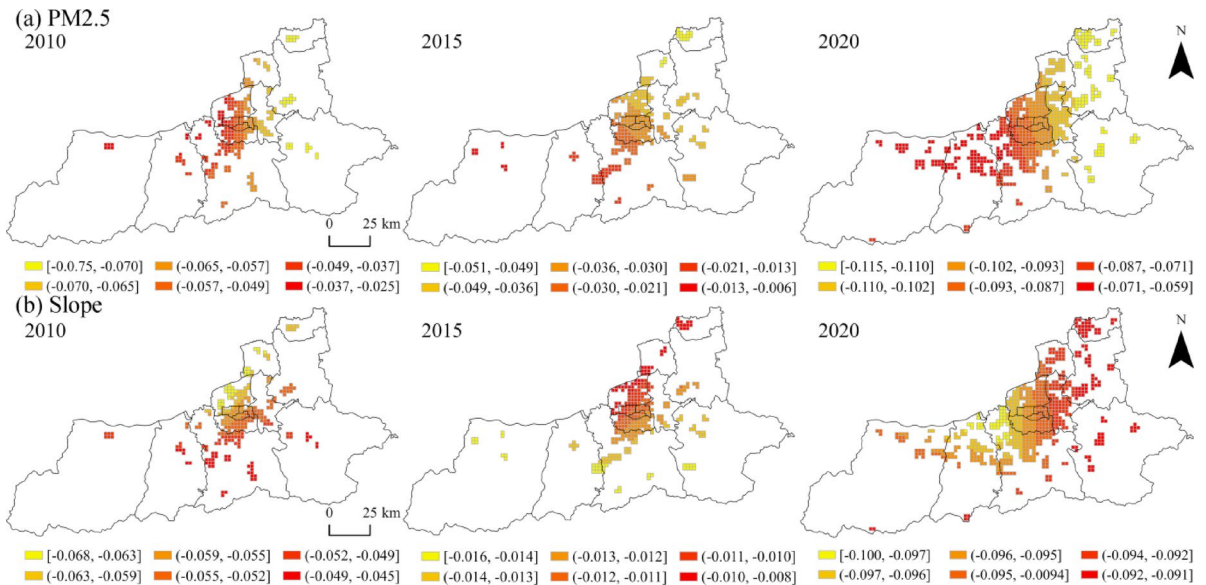
Fig. 4. Regression coefficient map of sports venues and natural environment based on MGWR model.

As depicted in Fig. 3d, the regression coefficients between the sports venues and traffic accessibility in Xi'an are all positive, indicating a positive promotional effect of traffic accessibility on the distribution of sports venues. Moreover, sports venues exhibit a high degree of sensitivity to changes in traffic accessibility (with a maximum value of 0.145), which becomes increasingly pronounced over time. The high-value areas of regression coefficients between the sports venues and traffic accessibility in 2010, 2015, and 2020 share rough similarities, mainly concentrated in Weiyang District, Lianhu District, Beilin District, Yanta District, Chang'an District, Hu County, and Zhouzhi County. In these areas, convenient transportation enhances residents' physical activity levels, thereby increasing the demand for sports venues. Furthermore, good transportation connectivity better supports the distribution of sports venues and affects the location selection for their construction. Over the three-year period, the regression coefficients generally follow a pattern of being higher in the west and lower in the east. Since 2015, Xi'an has made remarkable progress in subway construction, significantly enhancing intra-city transportation convenience and coverage. The expansion of roads, the construction of expressways and ring roads, the improvement of urban traffic capacity, the development of intelligent transportation, and the continuous optimization of bus routes have all contributed to enhancing the overall efficiency of urban transportation. As a result, residents have more transportation options, and the influence of traffic accessibility on the distribution of sports venues has become more pronounced. Sports venues located in areas with more convenient transportation tend to experience higher demand.

As depicted in Fig. 4a, PM2.5 has an inhibitory effect on the distribution of sports venues in Xi'an. A higher absolute value of the regression coefficient leads to a more pronounced reduction in sports venues in the area due to increasing PM2.5 levels. PM2.5 poses potential health hazards, prompting the government to restrict the construction of sports venues in regions with high PM2.5 concentrations. Moreover, training and competitions in highly polluted environments can negatively affect athletes' performance and physical condition. Most crucially, citizens prefer to engage in sports activities in venues with good air quality. Lastly, highly polluted environments incur additional management and maintenance costs for sports venues. The regression coefficients exhibit a decreasing trend from southwest to northeast, reaching their lowest value (-0.115) in 2020. Over this decade, the absolute values of the regression coefficients underwent a rapid increase from 2015 to 2020, indicating a more pronounced impact of PM2.5 on the distribution of sports venues. There is a growing awareness in sports venue planning of the importance of surrounding environments and their impact on athletes' health. In 2017, the 19th National Congress of the Communist Party of China first articulated that the principal contradiction facing Chinese society had evolved into one between the ever-growing needs of the people for a better life and unbalanced and inadequate development. This marked a phased change in people's demands for living environment quality and their awareness of ecological protection. Consequently, sports venues have become increasingly sensitive to environmental changes.

As illustrated in Fig. 4b, the slope exhibits a significant negative impact on the distribution of sports venues ($p < 0.01$). From a geographical perspective, the slope indicates the steepness of a surface unit; a steeper slope indicates a greater topographic relief. A larger slope can lead to increased construction costs for sports venues and, to some extent, limit the scale and layout of these venues. Areas with significant topographic relief typically have underdeveloped road networks, which affect the utilization rate of venues and the convenience of audience access. Additionally, such areas suffer from low land utilization efficiency, hindering the centralized management and operation of sports venues. Consequently, the slope significantly inhibits the distribution of sports venues. In terms of temporal evolution characteristics, the absolute value of the regression coefficient decreased from 2010 to reach a low in 2015, followed by an increase thereafter. In parallel, the focus of impact was shifted

from northeast to southwest forming a "center-periphery" structure with high values in the center and low values around 2020. Notably, the differences in regression coefficients among regions across the three years were minimal, suggesting that the impact of slope on sports venue site selection exhibits little spatial heterogeneity.

A comprehensive analysis of Figs. 3 and 4 reveals that traffic accessibility and population density, which can be both described as key components of human activity, have a more prominent impact on the layout of sports venues, while ecological factors and terrain, part of the natural environment, exhibit similar influences. The influence of commercial, industrial, and population scales on sports venues has shown a declining trend, whereas the effect of transportation remains robust and continues to grow rapidly.

Discussion

Overall, from our analysis, it was found that sports venues tend to be distributed in urban built-up areas and university towns. The urban infrastructure in these locations is relatively well-developed, with convenient transportation, high urbanization rates, and strong social vitality. The dense concentration of sports venues in these areas enhances the accessibility and convenience for mass sports and leisure activities. This observation is aligned with the findings of various works in the literature, such as Sun, Feng, Jiang, Yong, and others[33,34], who reported that sports venues are primarily located in urban downtown areas. However, the pattern of distribution center changes differs from that of Sun, Feng, as their study revealed an evolution from urbanization to suburbanization and then re-urbanization. However, no significant evolution in the distribution center of sports venues was found in this work, with only a gradual expansion of the scope over time. This discrepancy arises from the fact that Sun, Feng's research focused solely on fitness venues, whereas all types of sports venues were taken into account in our analysis, resulting in a more comprehensive scope of research objects. Consequently, our study is better equipped to highlight the changing dynamics of sports venues during urban development.

It was also revealed that human activities and the natural environment exert varying degrees of influence on the spatial layout of sports venues, with traffic accessibility and population density being particularly significant factors. Conversely, the impact of commercial, industrial activities, and population size on the distribution of sports venues demonstrated a declining trend. Within the natural ecological environment, both ecological conditions and terrain factors have similar inhibitory effects on the layout of sports venues. This aligns with the findings of various reported works in the literature, such as Huang, Min, Zhang, Shulin, Zhang, Yueting, and others[8,32,35], who observed that the spatial distribution of sports venues is affected by economic, demographic, and transportation factors. Notably, studies by Zhang Yueting and Shi Bing reveal that climate change has a measurable yet comparatively limited effect on sports facilities when contrasted with other environmental determinants[32]. Since this study focuses on Xi'an as the research area where climate change is not significant, the effects of factors such as temperature and precipitation were not addressed. By adopting a long-term sequential approach, the influence of human activities and the natural environment was systematically analysed here and we further delved into the changing trends of these influences. In line with continuous economic development and the improvement of sports venue construction, the influence of commerce, economics, and population on sports venues has exhibited a declining trend. Slope, as one of the critical factors considered in sports venue construction, exhibits spatial heterogeneity in its impact on sports venues. However, altering the slope is not always easily achieved. Nonetheless, the site selection of sports venues can be flexibly planned through technological means, minimizing the spatial heterogeneity of the slope's influence on sports venue location. Additionally, regarding transportation, the results of this study are directly aligned with the conclusions of Tang Yukun, emphasizing that transportation accessibility has the most significant impact on the distribution of sports venues, with residents preferring those located in areas with convenient transportation and good environmental quality.

Based on the above-mentioned analysis, the following recommendations can be drawn. (1) In the planning of sports venues, a transportation accessibility framework should serve as the foundation, prioritizing areas adjacent to major transportation nodes such as subway stations and bus hubs, while simultaneously improving barrier-free connecting facilities (e.g., accessible pathways, tactile paving systems, low-floor buses, etc.)[36]. Site selection planning should establish a dynamic population database, focusing on analyzing the distribution characteristics of vulnerable groups including elderly populations, disabled communities, and low-income neighborhoods. The "15-minute fitness circle" spatial algorithm should be employed to precisely identify areas with facility supply gaps, prioritizing the supplementation of basic fitness infrastructure in public service-deficient zones[8]. It is recommended to develop a "transportation-population-equity" three-dimensional evaluation model, incorporating accessibility facility coverage rates and vulnerable group accessibility indices into land reservation decision-making systems. Collaboration with transportation departments should be strengthened to implement accessibility retrofitting of public transport routes, ensuring pedestrian-friendly access for all population groups within a 500-meter radius of newly constructed venues. Additionally, a community sports facility co-construction mechanism should be established, safeguarding the decision-making participation rights of vulnerable groups during the planning phase through public hearings and demand mapping surveys. (2) In the selection of sports venue sites, it is essential to adopt a differentiated strategy that aligns with Xi'an's urban positioning of "cultural-tourism integration" and its core requirement of "heritage conservation." First, priority should be given to emerging development zones such as the Xixian New Area and the International Trade & Logistics Park (following the model of the 14th National Games' main venue, the Olympic Sports Center). These areas feature flat terrain, relatively better air quality, and fewer constraints from the old city's heritage protection policies, effectively reducing construction costs and risks to cultural relics[37,38]. Second, if sites are required near cultural heritage protection zones such as the Ming City Wall or the Han Dynasty Chang'an City ruins, a dual-assessment mechanism should be implemented in collaboration with cultural heritage authorities. This mechanism should include not only conventional environmental assessments (e.g., air quality monitoring and topographic mapping) but also a specialized evaluation of cultural heritage impacts. Technical measures such

as underground surveys and delineation of heritage buffer zones should be applied to mitigate construction risks (referencing the cultural heritage preservation model used in Xi'an's metro construction). Additionally, a "venue + cultural tourism" hybrid approach could be explored. For example, when planning event venues in the Qujiang New Area, sports-tourism complexes could be developed by integrating with cultural tourism hubs like the Big Wild Goose Pagoda and the Tang Dynasty Ever-Bright City, meeting the demands of international sporting events while revitalizing urban cultural and recreational spaces. (3) In response to national energy conservation, emission reduction, and sustainable development policies, sports venue planning in Xi'an must align with the requirements of the city's 14th Five-Year Plan regarding "coordinated development of historic and cultural city preservation and urban renewal."[39] A smart venue utilization monitoring system should be established to dynamically assess operational efficiency through big data analysis. For underutilized venues, priority should be given to strategies such as functional repurposing and composite transformations—for example, converting them into cultural-sports complexes integrating Qin and Han cultural exhibitions, public fitness facilities, and event training facilities. This approach not only aligns with Xi'an's vision as a "City of Museums" but also revitalizes existing resources. The renovation process should adhere to green construction principles by adopting prefabricated energy-saving technologies, locally sourced eco-friendly materials, and intelligent operation platforms for precise energy consumption management, thereby forging a Xi'an model that blends historical heritage with modern low-carbon smart solutions[18].

Concurrently, this work acknowledges several limitations. First, it solely focused on analysing past years' data, neglecting to investigate the future distribution trends of sports venues. Second, the number of influencing factors considered in this work is relatively limited. Finally, conducting citywide field research proved extremely challenging, thus making it impossible to incorporate unregistered venues into the study. Consequently, future research necessitates refining both the temporal scope and the research scale. From both qualitative and quantitative perspectives, deepening the investigation into the underlying mechanisms of influence will enable the simulation and modelling of future sports venue distributions. Furthermore, incorporating various policy scenarios is anticipated to provide invaluable guidance for the proper urban layout of sports venues.

Conclusion

In this work, based on POI data of sports venues in Xi'an, KDE and MGWR were employed to reveal the spatiotemporal evolution characteristics and influencing factors of sports venues in Xi'an. The main conclusions are as follows:

(1) The spatiotemporal evolution characteristics indicated that the number of sports venues in Xi'an has shown a trend of continuous growth, with a significantly higher growth rate from 2015 to 2020 compared to 2010–2015. The spatial distribution pattern has gradually evolved from a "Π"-shaped configuration to a concentric circle structure with a "center-periphery" layout, with the area of high-value zones continuously expanding and extreme values constantly rising. High-value zones are mainly concentrated in the built-up areas where district and county governments are located, while secondary high-value zones are centered around university towns and sports centers. Overall, sports venues are centered around Xincheng, Beilin, and Lianhu districts, spreading outward with a decreasing density towards the periphery.

(2) The analysis of influencing factors revealed that the spatial distribution of sports venues in Xi'an is affected by multiple factors. Among them, the influence of traditional factors such as commerce, industry, and population is gradually weakening, while transportation accessibility and environmental quality have emerged as dominant factors. It is noteworthy that the impact of slope on the distribution of sports venues exhibits spatial consistency.

(3) Based on the research findings, it is recommended to prioritize areas with convenient transportation and dense population in the planning of sports venues, laying emphasis on environmental quality and topographical conditions, and advance green transformation and dynamic planning. This will contribute to enhancing venue utilization efficiency and service levels, reducing construction and operational costs, and promoting sustainable urban development. Scientific planning and dynamic adjustments will ensure the rationality and forward-thinking of sports venue layouts, meeting residents' increasingly growing fitness demands.

This complex interplay between human activities, natural environments, and the spatial distribution of sports venues was revealed, providing crucial insights for policymakers and urban planners. It is suggested that in future planning of sports venues, full consideration should be given to the characteristics of spatial heterogeneity, with rational layouts in areas where positive correlations are significant to maximize the social benefits of sports venues. Meanwhile, subsequent research can further explore the long-term impacts of these trends so as to better integrate sports infrastructure construction into urban development and sustainability goals.

Data availability
All data generated or analysed during this study are included in this published article.

References
1. Yao, P. & Jia, Z. The logic, dilemma and path of the transformation of public stadiums into sports service complex. *Sports Cult. Guide.* **229**, 84–90 (2021).

2. Chen, Y., Zhou, B. & Ji, Q. The practical progress, promotion path and development prospect of China's stadium operation reform. *J. Xi'an Univ. Phys. Educ.* **39**, 284–291 (2022).

3. Liu, H. & Wang, Y. Research on monitoring of gymnastics facilities and intelligent optimal distribution of gymnastics venues based on internet of things. *Computational intelligence and neurosci.* 6164448 (2022). (2022).

4. Graham, R., Ehlenz, M. M. & Han, A. T. Professional sports venues as catalysts for revitalization? Perspectives from industry experts. *J. Urban Affairs.* **45**, 1841–1859 (2021).

5. Zhang, W. Investigation of intelligent service mode of digital stadiums and gymnasiums in the context of smart cities. *Int. J. Data Warehouse. Min.* **19**, 1–14 (2023).

6. Yan, H. & Huang, Z. Innovative planning and design of sports teaching venues under audience's emotional experience. *Open. House Int.* **44**, 100–103 (2019).

7. Tian, Y. et al. National fitness evaluation of urban parks in the National ecological garden City: A case study in Baoji, China. *Land* **11**, 889 (2022).

8. Zhang, S., Zhang, X. & Liu, Y. A study of the influence of sports venues on the intra-city population layout based on multi-source data-Taking Xi'an City and Zhengzhou City as examples. *PLOS ONE.* **15**, e0285600 (2023).

9. Zeng, J. & Wang, J. Study on Spatial layout of large stadiums in China. *Sports Sci.* **34**, 63–72 (2014).

10. Rahman, G. R., Jasani, G. N. & Liang, S. Y. Terrorist attacks against sports venues: emerging trends and characteristics spanning 50 years. *Prehosp. Disaster Med.* **38**, 366–370 (2023).

11. Arif, I. et al. New sports facilities do not drive migration between US cities. *Econ. Gov.* **23**, 195–217 (2022).

12. Li, S. An analysis of the value of sports park construction based on the concept of ocean ecological environment. *J. Coastal Res.* **104**, 921–924 (2020).

13. Choi, L. S. & Won A stadium tower: decongestion of congestion. Master's thesis, Harvard Graduate School of Design (2020).

14. Tabassum, Y. et al. Effect of playing venue on pre-competition cortisol level and competitive state anxiety in university basketball players. *Br. J. Pharm. Res.* **33**, 248–255 (2021).

15. Ahlfeldt, G. & Maenning, W. Stadium architecture and urban development from the perspective of urban economics. *Int. J. Urban Reg. Res.* **34**, 629–646 (2010).

16. Ahlfeldt, G. M. & Kavetsos, G. Form or function?? The effect of new sports stadia on property prices in London. *J. Royal Stat. Soc. Ser. A: Stat. Soc.* **177**, 169–190 (2014).

17. Glebova, E. et al. Sports venue digital twin technology from a spectator virtual visiting perspective. *Front. Sports Act. Living.* **5**, 1289140 (2023).

18. Xiong, D., Cheng, K. & Chen, J. Climate-adaptive design strategies of sports stadia in a hot summer and cold winter zone: A case study of Nanjing. *Buildings* **13**, 2238 (2023).

19. Heck, S. V., Valks, B. & Heijer, A. D. The added value of smart stadiums: a case study at Johan Cruijff Arena. *Journal of Corporate Real Estate* ahead-of-print(ahead-of-print) (2021).

20. Wang, J., Li, J. & Cheng, J. Spatial disparity of sports infrastructure development and urbanization determinants in China: evidence from the sixth National sports venues census. *Appl. Spat. Anal. Policy.* **17**, 573–598 (2024).

21. Jiang, Y. et al. Spatial distribution characteristics of public fitness venues in the main urban area of Dalian from the perspective of urban accessibility. *Sustainability* **14**, 12728 (2022).

22. Charles, C. & Tu How does a new sports stadium affect housing values?? The case of Fedex field. *Land Econ.* **81**, 379–395 (2005).

23. Liu, Y. et al. Spatial pattern of leisure activities among residents in Beijing, China: exploring the impacts of urban environment. *Sustainable Cities Soc.* **52**, 101806 (2020).

24. Lin, L. et al. The impact of large sports venues on the Spatiotemporal patterns of leisure sports behavior among urban residents: A case study of three cities in China. *Hum. Geogr.* **37**, 116–125 (2022).

25. Lei, L. Research on the Spatial distribution characteristics of sports field in China based on the data of the 6th sports field survey. *Int. J. New. Developments Eng. Soc.* **2**, 2 (2018).

26. Wei, J. et al. Reconstructing 1-km-resolution high-quality PM2.5 data records from 2000 to 2018 in China: Spatiotemporal variations and policy implications. *Remote Sens. Environ.* **252**, 112136 (2021).

27. Jin, L., Wang, Z. & Chen, X. Spatial distribution characteristics and influencing factors of traditional villages on the Tibetan plateau in China. *Int. J. Environ. Res. Public Health.* **19**, 20 (2022).

28. Tong, Z. et al. Multiscale impact of environmental and Socio-economic factors on low physical fitness among Chinese adolescents and regionalized coping strategies. *Int. J. Environ. Res. Public Health.* **19**, 20 (2022).

29. Wang, J., Li, J. & Cheng, J. Spatial disparity of sports infrastructure development and urbanization determinants in China: evidence from the sixth National sports venues census. *Appl. Spat. Anal. Policy.* **17**, 1–26 (2023).

30. Chen, Y., Ren, T. & Ji, Q. Research on the evaluation and promotion strategy of Spatial vitality of public stadiums based on multi-source data. *China Sports Sci. Technol.* **60**, 81–89 (2024).

31. Tang, Y., Zhang, J. & Wang, B. Analysis of Geospatial distribution characteristics and influencing factors of urban leisure sports:a case study of Beijing. *China Sports Sci. Technol.* **58**, 106–113 (2022).

32. Zhang, Y., Ming, Y. & Shi, B. Spatial distribution characteristics and causes of public sports venues in China. *Sci. Rep.* **13**, 15056 (2023).

33. Sun, F. et al. Evolution of the Spatial-Temporal pattern and social performance evaluation of community sports and fitness venues in Shanghai. *Int. J. Environ. Res. Public Health.* **19**, 274 (2022).

34. Jiang, Y. et al. *Spat. Distribution Characteristics Public. Fit. Venues: Urban Accessibility Perspective Sustain.* **15**, 601 (2023).

35. Huang, M. et al. Does COVID-19 Affect the accessibility of outdoor sports venues? A case study in Nanchang, China. *Land* 12, 158 (2023).

36. Wang, F. & Li, Q. Research on the correlation between the positioning of large and medium-sized sports venues and traffic accessibility: A case study of Guangzhou-Foshan area. *South. China Archit.* **6**, 100–106 (2021).

37. Liang, H. Modern stadium design: an adaptive renovation or urban renewal. *Open. House Int.* **42**, 50–54 (2017).

38. Xue, Z., Ma, D. & Gao, S. Goals, problems and countermeasures of the construction of urban sports venues and facilities in China during the 14th Five-Year plan period. *Sports Cult. Guide.* **8**, 44–51 (2023).

39. Li, J. et al. Context investigation, experience reflection and local strategy of promoting urban renewal of sports venues in the united Kingdom and the united States. *Sports Res.* **36**, 34–44 (2022).

Acknowledgements

Author contributions

Y.L. contributed to the conceptualization and methodology of the study. Y.Z was responsible for the data collection and initial analysis. D.Y. played a significant role in the interpretation of the data and the drafting of the manuscript. S.Z., as the corresponding author, provided overall guidance, supervised the research, and revised the manuscript critically for important intellectual content. All authors have read and approved the final version of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to S.Z.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.