

Spatial Distribution, Type Structure and Influencing Factors of China Science Popularization Education Bases (Postprint)

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Abstract

Taking the 798 science popularization education bases announced by the China Association for Science and Technology in 2022 as the research object, this study employs the average nearest neighbor index, kernel density, and imbalance index to reveal the spatial distribution and type structure characteristics of science popularization education bases, and further utilizes geographical detector and overlay analysis methods to detect the influencing factors of the spatial distribution pattern of science popularization education bases in China. The results show that: (1) The spatial distribution of science popularization education bases in China is unbalanced, exhibiting an agglomeration distribution pattern. High-density areas are mainly concentrated in the Beijing-Tianjin-Hebei region, the Yangtze River Delta, and the Pearl River Delta in the eastern part, which have better economic foundations and higher market openness, while the western region forms low-density agglomeration areas centered around provincial capitals. (2) In the type structure of science popularization education bases in China, science and technology museum-type bases account for the highest proportion, exhibiting a “dual-core, multiple points” spatial characteristic; “agriculture, rural areas, and farmers” -type bases account for the lowest proportion, showing a “one belt, multiple points” spatial structure, with different types of bases presenting distinct spatial differentiation patterns. (3) The spatial distribution of science popularization education bases in China is influenced by the superimposed effects of human factors such as socio-economic conditions, transportation infrastructure, education level, tourism resources, and policy systems, as well as natural environmental factors including elevation and rivers. The research findings provide reference significance for optimizing the spatial layout of science popularization education bases in China and promoting the efficient utilization of science popularization resources.

Full Text

Spatial Distribution, Type Structure, and Influencing Factors of Popular Science Education Bases in China

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Abstract: This study examines 798 national popular science education bases announced by the China Association for Science and Technology in 2022 as its research sample. Using average nearest neighbor index, kernel density analysis, and imbalance index, we reveal the spatial distribution patterns and typological structural characteristics of these bases. Geographic detector and overlay analysis methods are further employed to identify influencing factors shaping their spatial distribution patterns. The results demonstrate that: (1) The spatial distribution of popular science education bases in China is highly uneven and exhibits significant clustering. High-density areas are primarily concentrated in the economically developed and market-open regions of eastern China, including the Beijing-Tianjin-Hebei region, Yangtze River Delta, and Pearl River Delta. Western regions form low-density clusters centered around provincial capitals. (2) In terms of type structure, science and technology venue bases account for the highest proportion, displaying a “dual-core, multi-point” spatial pattern, while “agriculture, rural areas, and farmers” bases represent the smallest share, showing a “one-belt, multi-point” structure. Different types of bases demonstrate distinct spatial differentiation characteristics. (3) The spatial distribution pattern results from the combined effects of socioeconomic, transportation, education, tourism resources, and policy systems as human factors, together with natural environmental factors such as elevation and river systems. These findings provide valuable references for optimizing the spatial layout of China’s popular science education bases and promoting efficient utilization of science popularization resources.

Keywords: popular science education base; spatial distribution; type structure; influencing factors; geographic detector

Introduction

Science popularization represents a strategic national initiative to enhance public scientific literacy and sustainable development. In 2016, President Xi Jinping emphasized that “scientific innovation and science popularization are the two wings of innovative development, and science popularization should be placed on an equal footing with scientific innovation.” As a critical component of high-quality science popularization service systems, popular science education bases serve as essential venues for implementing the “rejuvenating the nation through

science and education” strategy, enhancing public scientific awareness, and improving scientific literacy. They also function as distinctive cultural landmarks that showcase urban heritage and elevate city image, while serving as “second classrooms” that support school education and assist in implementing the “double reduction” policy. These bases have attracted considerable academic attention both domestically and internationally.

International research on popular science education bases primarily focuses on venues such as science museums, natural history museums, forest parks, and industrial heritage sites, examining aspects including facility design, significance and impact, development models, and visitor perceptions. Anderson et al. surveyed teachers in the United States, Canada, and Germany regarding their views on science education bases, proposing that museum design should align with educational needs and pedagogical tourism principles. Soykan found that ecology-based environmental education in Turkish national parks enhanced participants’ environmental awareness. Kabanova et al. identified financial support and service quality as primary factors influencing cultural and educational tourism development in Russia. Prentice’ s research on museum visitor experiences emphasized maintaining authenticity to stimulate engagement while avoiding excessive commercialization.

Domestic research spans education, sociology, and management disciplines, focusing on development status, talent team building, management and evaluation systems, and development models. From a geographical perspective, limited studies have examined the spatial layout of science popularization industries or specific facilities. Yang et al. measured the agglomeration degree of science popularization venues in China using location quotient methods, finding highest concentration in Beijing, followed by Shanghai, Ningxia, Anhui, and Jiangsu. Yu and Zhang analyzed the spatial distribution of museums, gymnasiums, and exhibition halls in Beijing, revealing spatial differentiation characteristics influenced by both spatial and non-spatial factors. Xin et al. demonstrated that revolutionary memorial sites exhibit significant spatial orientation and clustering patterns that align closely with China’ s revolutionary history.

While existing literature on popular science education bases is increasingly mature, most studies focus on construction and development rather than geographical perspectives. As point spatial elements, the development of these bases is intimately connected to regional geographical environments and socio-human factors, necessitating in-depth analysis of their overall spatial distribution characteristics and influencing factors to inform national and local development strategies. Moreover, despite the diverse types of science popularization resources, few scholars have investigated the typological structure and spatial differentiation of these bases. Addressing this gap, this study examines the 2022 first batch of national popular science education bases, analyzing their spatial distribution and typological characteristics. By introducing Krugman’ s “two natures” theory, we investigate influencing factors and mechanisms shaping their spatial patterns, aiming to provide scientific guidance for optimizing

spatial layout and promoting efficient resource utilization.

1. Data and Methods

1.1 Data Sources The sample data were obtained from the first batch of national popular science education bases announced on the official website of the China Association for Science and Technology (<https://www.cast.org.cn/>). Due to missing data for Hong Kong, Macao, and Taiwan, this study selected 798 bases covering 31 provinces, autonomous regions, and municipalities in mainland China. Geographic coordinates were obtained using Baidu coordinate extraction system and Google Earth, with ArcGIS 10.6 software for data processing. China's administrative division map was sourced from the National Geomatics Center of China (<http://www.ngcc.cn/ngcc/>). Elevation and river data were obtained from the Chinese Academy of Sciences Resource and Environmental Science Data Center (<https://www.resdc.cn/>). Provincial demographic and economic data were extracted from the *China Statistical Yearbook (2022)*, provincial statistical yearbooks, and *China City Statistical Yearbook (2022)*, as well as government official websites. Data on A-level scenic spots were collected from the Ministry of Culture and Tourism website (<https://zwfw.mct.gov.cn/scenicspot>).

1.2 Research Methods

1.2.1 Average Nearest Neighbor Index The average nearest neighbor index determines the spatial distribution pattern of point features. This method was employed to analyze whether popular science education bases exhibit spatial clustering. The average nearest neighbor index (R) is defined as:

$$R = \frac{\bar{d}_{\text{obs}}}{\bar{d}_{\text{exp}}}$$

where \bar{d}_{obs} represents the mean observed nearest neighbor distance, calculated as $\bar{d}_{\text{obs}} = \frac{1}{n} \sum_{i=1}^n d_i$; \bar{d}_{exp} represents the expected mean nearest neighbor distance, calculated as $\bar{d}_{\text{exp}} = \frac{0.5}{\sqrt{n/A}}$; d_i is the nearest neighbor distance for point i ; n is the number of popular science education bases; and A is the study area. When $R < 1$, the distribution is clustered; when $R = 1$, it is random; and when $R > 1$, it is uniform.

1.2.2 Kernel Density Analysis Kernel density analysis visualizes the distribution of discrete measurements across continuous areas. This method was applied to characterize the spatial distribution patterns of popular science education bases. The calculation formula is:

$$f(x) = \frac{1}{nh^d} \sum_{i=1}^n k\left(\frac{x-x_i}{h}\right)$$

where $f(x)$ is the kernel density estimate; k is the kernel function; $x-x_i$ represents the distance from estimation point x to sample point x_i ; h is the bandwidth (search radius); n is the sample size; and d is data dimensionality. Higher $f(x)$ values indicate greater spatial clustering.

1.2.3 Imbalance Index The imbalance index analyzes the provincial distribution equilibrium of popular science education bases, calculated using the Lorenz curve concentration index method:

$$S = \frac{\sum_{i=1}^n |Y_i - 50|}{2(n-1)}$$

where n is the number of provinces; Y_i is the cumulative percentage at rank i . The S value ranges between 0 and 1, with $S = 0$ indicating perfect equilibrium and $S = 1$ indicating extreme imbalance.

1.2.4 Geographic Detector The geographic detector method measures spatial distribution consistency between independent and dependent variables to assess explanatory power. This technique is immune to multicollinearity among independent variables. The factor detector was employed to analyze influencing factors, calculated as:

$$q = 1 - \frac{1}{N\sigma^2} \sum_{m=1}^L N_m \sigma_m^2$$

where q is the detection value of influencing factors on spatial distribution, ranging $[0, 1]$. Larger q values indicate stronger influence. L represents strata of independent or dependent variables; N_m and σ_m^2 are the unit count and variance of subregion m ; N and σ^2 are the unit count and variance of the entire region.

2. Results and Analysis

2.1 Spatial Distribution Characteristics of Popular Science Education Bases

2.1.1 Regional Differentiation Features Quantitative analysis using the average nearest neighbor index revealed an observed mean nearest neighbor distance of 23.24 km, an expected distance of 65.07 km, and an index value of $R = 0.36 < 1$, indicating a clustered distribution pattern nationwide. Using the Hu Line as a boundary, the southeastern side contains significantly more bases (93.36% of the national total) than the northwestern side (6.64%). Across China's three major economic belts, the distribution shows an “east-more, central-west-less” pattern, with eastern regions accounting for 54.76% of all bases, while western and central regions comprise 23.06% and 22.18%, respectively. Among China's seven geographical divisions, East China has the highest proportion at 30.08%, while Northeast China has the lowest at 6.77%—a nearly fivefold difference.

At the provincial level, Beijing dominates with 94 bases (11.78% of the national total), leveraging its advantages as the capital in technology, education, and culture. Guangdong, Shandong, Jiangsu, Zhejiang, and Shanghai each have 41-53 bases. In contrast, Inner Mongolia, Tibet, Ningxia, Gansu, Qinghai, and Xinjiang form low-density clusters centered on provincial capitals. The imbalance index $S = 0.64$ further confirms the non-equilibrium distribution with significant inter-provincial disparities that become more pronounced at finer spatial scales.

2.1.2 Spatial Density Characteristics The national average density is 0.831×10^{-4} bases per km^2 , with Shanghai showing the highest density at 55.952×10^{-4} bases per km^2 , followed by Beijing at 65.079×10^{-4} bases per km^2 . Inner Mongolia and Tibet have the lowest densities at 0.033×10^{-4} and 0.037×10^{-4} bases per km^2 , respectively. Kernel density analysis using ArcGIS 10.6 reveals an “east-dense, west-sparse, south-concentrated, north-scattered” pattern with a clear “core-periphery” structure [Figure 2: see original paper].

Four high-density cores emerged: the Beijing-Tianjin-Hebei region centered on Beijing and Tianjin; the Yangtze River Delta centered on Shanghai, Hangzhou, Nanjing, and Hefei; the mid-Yangtze region centered on Wuhan; and the Pearl River Delta centered on Guangzhou. Seven sub-density zones formed around provincial capitals including Shijiazhuang, Shenyang, Xi'an, Zhengzhou, Wuhan, Changsha, Chengdu, and Chongqing. Additionally, multiple low-density points appeared in Heilongjiang, Jilin, Fujian, Guangxi, Yunnan, Ningxia, Gansu, Qinghai, and Xinjiang.

2.2 Typological Structure of Popular Science Education Bases

2.2.1 Type Classification According to the *National Popular Science Education Base Recognition and Management Trial Measures*, bases are classified into six categories: science and technology venues; education, research and major engineering; “agriculture, rural areas, and farmers” ; enterprises; natural resources; and others .

Science and technology venues account for the largest share (38.60%), serving as popular destinations for families. Education, research and major engineering bases comprise 30.58%, while natural resources bases represent 15.66%, increasingly important for science popularization. Enterprise bases account for 7.89%, primarily showcasing technological achievements and R&D resources. “Agriculture, rural areas, and farmers” bases are the smallest category at 3.01%, relying on advanced agricultural technologies and demonstration parks. Other bases, utilizing cultural, historical, and artistic resources, comprise 4.26%.

2.2.2 Spatial Structure by Type Kernel density analysis of different base types reveals distinct spatial patterns [Figure 3: see original paper]:

Science and technology venues exhibit a “dual-core, multi-point” structure. The dual cores are the Beijing-Tianjin-Hebei and Yangtze River Delta regions, with multi-point sub-clusters in Jilin, Shandong, Henan, Hubei, Fujian, and Sichuan. These regions feature diverse specialized bases covering environmental protection, earthquake disaster mitigation, meteorology, and aerospace, such as Beijing Drainage Science Popularization Hall and Shanghai Aerospace Science Popularization Center.

Education, research and major engineering bases show a “one-ring, three-center” pattern. The “one-ring” comprises a dense belt formed by the Yangtze River Delta, Hubei, and Hunan. The “three centers” are Beijing-Tianjin-Hebei, Guangdong, and Shaanxi—regions with strong higher education and research institutions like Zhejiang University Science Popularization Base and the Hybrid Rice National Key Laboratory at Wuhan University.

Natural resources bases concentrate in four major areas: Beijing-Tianjin-Hebei, Yangtze River Delta, Sichuan-Chongqing, and Guangxi-Guangdong, leveraging rich fauna, flora, forests, wetlands, and geological landscapes. Examples include Beijing Fangshan Global Geopark and Chengdu Giant Panda Breeding Research Base.

Enterprise bases form a “tripod” structure in the economically developed eastern regions of Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta, relying on innovation-capable enterprises like Lenovo Future Center in Beijing and Qingda Zhongchuang Technology Education Base in Hefei.

“Agriculture, rural areas, and farmers” bases display a “one-belt, multi-point” structure along the eastern coastal region from Beijing to Hainan, including provinces like Tianjin, Hebei, Shandong, Jiangsu, and Guangdong. These areas benefit from favorable hydrothermal conditions and advanced agricultural technologies, forming numerous agricultural demonstration parks and ecotourism gardens. Additional low-density points appear in Xinjiang, Yunnan, Sichuan, and Gansu.

Other bases cluster most densely in Beijing-Tianjin-Hebei, Shandong Peninsula, Yangtze River Delta, Pearl River Delta, and Chengdu-Chongqing regions,

aligning with cultural zones like Yan-Zhao, Jing-Chu, Wu-Yue, and Ba-Shu cultures. These bases leverage rich cultural, historical, and artistic resources, such as Pingjin Campaign Memorial Hall and Guanghan Sanxingdui Museum.

Overall, eastern coastal regions, particularly Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta, are agglomeration areas for all base types. Science and technology venues, enterprise bases, and education/research bases concentrate in economically developed regions, while natural resources and “agriculture, rural areas, and farmers” bases cluster in areas with strong natural endowments, and other bases locate in regions rich in historical and cultural resources.

2.3 Influencing Factors of Spatial Distribution Building on Krugman’s “first nature, second nature” theory from the early 1990s, this study examines how natural endowments (“first nature”) and human-created conditions (“second nature”) jointly shape spatial patterns. “First nature” comprises elevation, terrain, and water resources, while “second nature” includes transportation, population, and capital agglomeration. The spatial distribution of popular science education bases reflects the combined influence of geographical environment and socio-human factors.

2.3.1 “First Nature” Elements Elevation: Terrain affects human activities and living spaces, thereby influencing base distribution. Overlay analysis of national elevation data with the 798 bases shows clear distribution differences across China’s three topographic steps. Bases are mainly located in plains of the third step and hills/basins of the second step. Using natural breaks classification, 83.64% of bases concentrate in low-altitude areas below 717 m, while high-altitude regions above 4,311 m contain only sparse bases like the Alpine Science Tree Planting Demonstration Base in Nagqu, Tibet. This negative correlation indicates that harsh climate and terrain at high elevations are unfavorable for base development.

River systems: Rivers are fundamental to socioeconomic development and important natural resources for bases. Spatial overlay with major rivers shows concentrated distribution along the middle-lower Yellow River, Yangtze River, Huai River, and lower Pearl River [Figure 4: see original paper]. Buffer analysis of third-level and above rivers/lakes using ArcGIS 10.6 reveals that 70.18% of bases fall within 10 km buffers and 80.33% within 20 km buffers, demonstrating clear “water affinity.” This stems from: (1) numerous hydrological stations, water conservancy projects, and research institutes built along waterways, such as Nanjing Hydraulic Research Institute River and Lake Governance Research Base; and (2) natural tourism resources developed into national bases for ecological education, like Hunan Hengdong Mishui National Wetland Park.

2.3.2 “Second Nature” Elements Socioeconomic factors: Economic development level and population density are dominant determinants. Geographic

detector results show that per capita GDP (X_1) and population density (X_2) passed significance tests at the 0.01 level with q values of 0.64 and 0.58, respectively, indicating strong explanatory power. High per capita GDP regions like Beijing, Shanghai, and Jiangsu show significantly higher base density, as robust economies provide material foundations. According to the 2020 Seventh National Census, base distribution strongly correlates with population density, with dense clusters in Beijing, Tianjin, Shanghai, Jiangsu, Guangdong, and Shandong, while sparsely populated western regions like Tibet, Qinghai, and Xinjiang have low base density and singular type structures.

Transportation conditions: Transportation infrastructure affects base development patterns. While highway mileage (X_3) passed the 0.05 significance test ($q = 0.31$), high-speed railway mileage (X_4) did not, suggesting highways have greater influence. With growing demand for short-distance leisure travel, highways' high accessibility and flexibility make them the preferred transportation mode. Most bases primarily serve local residents, indicating that enhanced highway construction could promote base development.

Education level: Higher education levels determine base development quality. Both regular higher education institution count (X_5) and education funding (X_6) passed the 0.01 significance test with q values of 0.53 and 0.47, respectively. Universities possess professional talent and teaching facilities advantageous for science popularization. Many institutions have established dedicated bases or opened laboratories to the public, such as Beihang University' s Aerospace Museum and Lushi-Jia Laboratory. Education funding also strongly influences spatial distribution by supporting infrastructure and service scale.

Tourism resources: A-level scenic spot count (X_7) passed the 0.01 significance test ($q = 0.42$), indicating that tourism resource abundance relates to base distribution. Most A-level spots become field classrooms for science education and eco-tourism due to unique landforms and biodiversity, such as Jiangsu Suqian Santai Mountain Scenic Area, a 5A-level scenic spot and national forest park selected as a national base for its scientific value. This suggests potential for developing "science popularization + tourism" models.

Policy systems: The number of relevant policy documents (X_8) passed the 0.05 significance test ($q = 0.28$), demonstrating policy influence. Beijing, with the most policy documents, enacted the *Beijing Science and Technology Popularization Regulations* in 2000, integrating science infrastructure into urban planning. Recent policies like the *Beijing Citizen Science Literacy Action Plan (2021-2035)* and *Beijing Science Popularization Base Management Measures* have further promoted base development, highlighting policy' s crucial role.

3. Discussion

The uneven distribution of popular science education bases closely relates to regional economic foundations, historical culture, and resource endowments. Eastern regions like Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta possess geographical advantages, robust economies, dense populations, and convenient transportation, providing solid material foundations. Central and western regions have fewer bases, predominantly clustered around provincial capitals. Therefore, eastern regions should lead in creating influential, demonstrative, and innovative base brands, while increased funding and policy support should leverage central-western regions' unique resources and cultural heritage to accelerate their development.

Currently, science and technology venues and education/research bases dominate, while enterprise, "agriculture, rural areas, and farmers," and other categories account for less than 20%. Different base types require tailored development: enterprise bases should increase government guidance to encourage participation and build brand recognition; "agriculture, rural areas, and farmers" bases should connect with high-quality farmer training programs, providing practical training venues to support rural revitalization; other bases should improve infrastructure, expand talent pools, and explore distinctive development paths through "Internet+" promotion; natural resources bases must uphold green development principles and ensure development scale aligns with ecological carrying capacity.

This study systematically analyzes the spatial distribution and typological structure of national-level popular science education bases, enriching geographical research and providing scientific guidance for development. By introducing Krugman's "two natures" theory, it offers a systematic multi-level analysis of natural and human factors, providing valuable references. However, due to data limitations, comparative analysis of different base scales awaits future research. Future studies should incorporate provincial-level base data and conduct finer-scale analyses at street/township levels to explore optimal allocation of urban-rural science popularization resources.

4. Conclusions

- (1) China's popular science education bases exhibit uneven spatial distribution with significant clustering, becoming more pronounced at provincial scales. Geographically, they form one high-density core and seven sub-density cores. High-density areas concentrate in eastern China's Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, and mid-Yangtze regions, while western regions form low-density clusters around provincial capitals.
- (2) Typologically, science and technology venue bases dominate at 38.60%, while "agriculture, rural areas, and farmers" bases are the smallest at

3.01%. Spatially, science and technology venues, enterprise bases, and education/research bases concentrate in economically developed regions; natural resources and “agriculture, rural areas, and farmers” bases cluster in areas with strong natural endowments; other bases locate in regions rich in historical and cultural resources.

- (3) The spatial pattern results from interactions between “first nature” and “second nature” elements, primarily influenced by the combined effects of socioeconomic conditions, transportation, education, tourism resources, and policy systems as human factors, together with natural environmental factors including elevation and river systems.

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