

Spatial Differentiation of Urban Vitality in Guangzhou Core Area Using Mobile Phone Location Data

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Abstract: Urban vitality is an important indicator for measuring urban development, which is affected by human activities, built environment and their interconnections. Urban vitality often exhibits agglomeration effects, and adjacent blocks tend to present similar vitality values. Taking the core area of Guangzhou as the research area, this paper adopts mobile phone positioning data to explore the spatial pattern of vitality within the core area of Guangzhou. The results show that: (1) The urban vitality in the core area of Guangzhou presents obvious spatial differentiation, showing a spatial pattern of polycentric agglomeration, scattered points and linear extension; (2) The urban vitality of the core area has significant spatial agglomeration. Obvious agglomeration effects are observed around rail transit transfer stations, and urban transportation fosters multiple peaks of urban vitality. The findings can provide guidance for urban planning in Guangzhou and offer implications for cities pursuing transportation investment and transit-oriented development.

1. Introduction

Urban vitality is the external manifestation of a city's overall functions, and human activities and the built environment are the most critical factors in urban vitality[1]. Previous studies have carefully explored the impacts of the built environment on urban vitality[2]. Conducting urban vitality analysis with traffic analysis zones (TAZ)[3], blocks[4], and streets[5] as units of analysis helps to fully understand urban vitality and the relationship between urban vitality and the built environment.

The measurement of urban vitality is a key step for understanding urban vitality. Early studies on urban vitality measurement mostly adopted field surveys or questionnaire methods [6]. Such studies require substantial manpower and material resources and are difficult to conduct for large-scale assessment. With the continuous development of intelligent sensing technologies, multi-source spatiotemporal data that record massive human activities have become increasingly abundant and have become a research focus, including mobile phone data [2], social media check-in data [7], Baidu heatmap data [8], traffic trajectories, and street view data [1]. Applying such data to quantify urban vitality can greatly improve the accuracy of urban vitality analysis and facilitate building people-oriented healthy cities.

The number of people across different time periods at a given location is regarded as one of the most salient characteristics of urban vitality [9,10]. Accordingly, this study uses the cumulative number of mobile phone users over a 24-hour period as an indicator of urban vitality to explore the

spatial pattern of vitality in Guangzhou's core area, with the aim of providing a basis for Guangzhou's sustainable development.

2. Study Area and Data Sources

2.1. Study Area

This study takes the core area of Guangzhou as the study area. Bounded by the Guangzhou Ring Expressway and Guangzhou's administrative boundary, the core area has a total area of approximately 216 km². As Guangzhou's most representative central region, it covers the main portions of Yuexiu District, Tianhe District, Liwan District and Haizhu District. Featuring high population density, diverse built environments, and compact mixed functions, the core area supports the identification of urban vitality in this research. A 100 m × 100 m grid is employed as the basic analytical unit.

2.2. Data Sources

This study uses mobile phone location data provided by Beijing Hongtu Vision Technology Co., Ltd., with raw data sourced from Alibaba Spatiotemporal Big Data. The dataset consists of monthly average daily visitor data at a spatial resolution of 100 m for May 2024 and covers all 31 days of the month. Each record corresponds to the average daily number of mobile phone users generating location signals within a 100 m grid cell during the month. By counting the volume of located users within each grid over the study period, the data reflects the relative intensity of population agglomeration. It can identify urban vitality agglomeration centres and finely characterise the spatial patterns of population distribution across all times of day.

3. Research Methods

3.1. Kernel Density Analysis

Kernel density estimation (KDE), originally proposed by Rosenblatt[11] and further refined by Parzen[12], is a non-parametric probability density estimation method. This method applies a kernel smoothing algorithm to spatially interpolate discrete point data, calculates the feature density of each spatial unit within the study area, and generates a continuous density surface that reflects the spatial distribution characteristics of features. Its formula is expressed as:

$$KDE(x, y) = \frac{1}{nh^2} \sum_{i=1}^n K\left(\frac{d(x, y, x_i, y_i)}{h}\right) \quad (1)$$

where (x, y) denotes the coordinates of the grid center; (x_i, y_i) represents the coordinates of the i -th sample point; $d(x, y, x_i, y_i)$ is the distance between the grid center and the sample point; h refers to the search bandwidth; n is the total number of sample points within the study area. The Gaussian kernel function was adopted in this study, and its value decreases exponentially with rising distance d .

3.2. Getis-Ord Gi* Hotspot Index

This study adopts the Getis-Ord Gi* Hotspot Index to identify the spatial pole distribution pattern

of urban vitality within the study area. The Getis-Ord G_i^* Hotspot Index is a spatial clustering method proposed by Getis and Ord [13]. By analyzing the aggregation locations of high-value and low-value elements in space, this method can detect hotspots and cold-spot regions with statistically significant aggregation. Its calculation formula is:

$$G_i^* = \frac{\sum_{j=1}^n w_{ij}x_j - \bar{X} \sum_{j=1}^n w_{ij}}{S \sqrt{\frac{n \sum_{j=1}^n w_{ij}^2 - (\sum_{j=1}^n w_{ij})^2}{n-1}}} \quad (2)$$

where n is the total number of spatial units in the study area; x_j is the urban vitality index of spatial unit j ; w_{ij} refers to the spatial weight between spatial unit i and j , with $w_{ij} = 1$ when $j = i$; $\bar{X}$ denotes the mean attribute value of all spatial units, and S is the standard deviation of attribute values across all spatial units.

The output of G_i^* is the Z-score, which follows a standard normal distribution. Statistically significant positive values indicate clusters of high values, while significant negative values represent clusters of low values. This study adopts $p < 0.05$ ($|Z| > 1.96$) as the significance threshold to identify the spatial pattern of hot and cold spots of urban vitality within the study area.

4. Results and Analysis

4.1. Spatial Pattern of Urban Vitality Based on Kernel Density Estimation

The natural breakpoint method was adopted to classify urban vitality values in the core area of Guangzhou, yielding the spatial pattern of urban vitality across the study area. Overall, urban vitality exhibits spatial differentiation characterized by polycentric agglomeration, point-like dispersion, and linear extension. Multiple red high-value nodes are distributed sporadically in parts of the study area, forming a polycentric spatial structure. These high-value nodes are connected like beads on a chain and extend outward along linear corridors, creating an interlaced horizontal and vertical network. The remaining areas are dominated by extensive dark blue regions with generally relatively low vitality values, indicating extremely uneven spatial distribution (Figure 1).

From a local perspective, high vitality values are markedly concentrated around metro stations, especially near transfer stations. Vertically, the high-value zones on the western side roughly follow a north–south alignment, largely consistent with Metro Line 2, the major north–south transport artery of Guangzhou. The eastern high-value zones also exhibit a north–south orientation and match the alignment of Guangzhou Metro Line 3. Among the eight high-vitality nodes along Line 2, four are transfer stations; of the eight high-value nodes along Line 3, six are transfer stations. By comparison, transfer stations account for a lower proportion of high-value nodes on Line 2, yet some non-transfer stations still reach vitality levels comparable to those of transfer stations. It is therefore inferred that the built environment along Line 2 is more mature. Relying on this favourable built environment, more diverse urban functions have emerged, supporting the formation of high-vitality nodes at non-transfer stations. Horizontally, the contiguous high-vitality nodes in the south run east–west and form a bead-like chain along Guangzhou Metro Line 8. The central horizontal high-value corridor corresponds to the operational route of Guangzhou Metro Line 5. The east–west high-vitality zone in the north overlaps with sections of Guangzhou Metro Line 6.

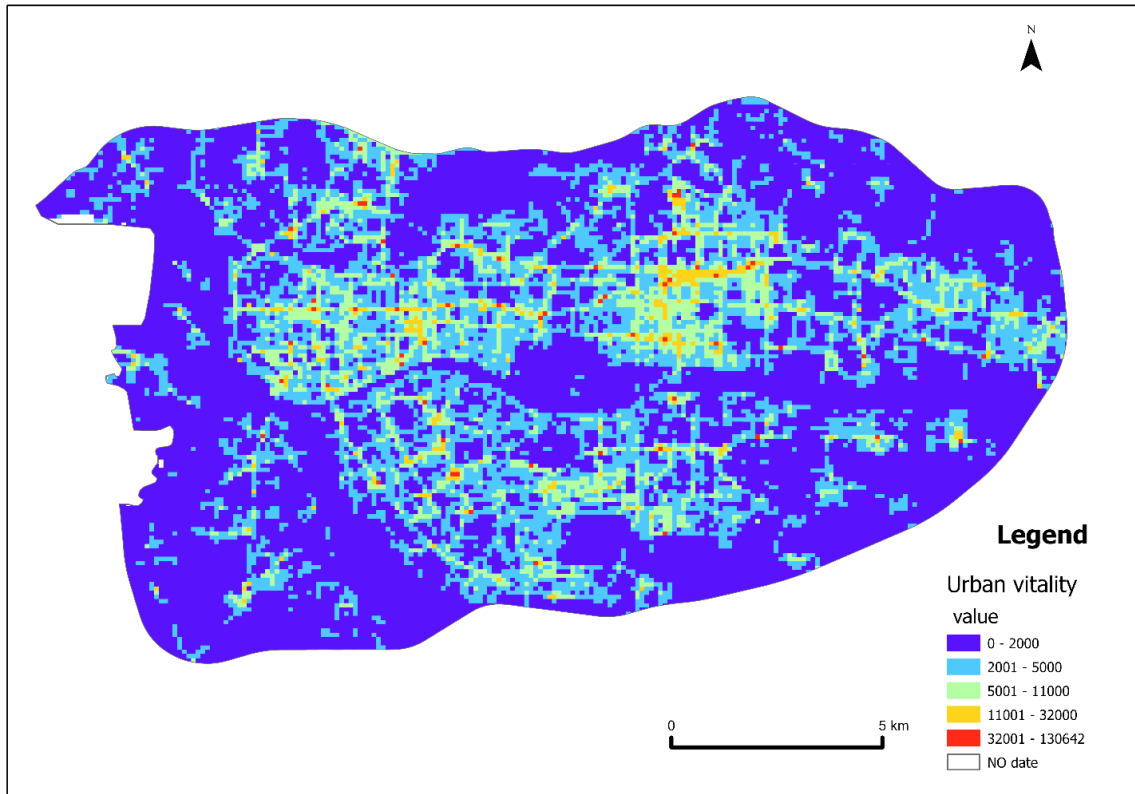


Figure 1: Spatial distribution of graded urban vitality in the study area.

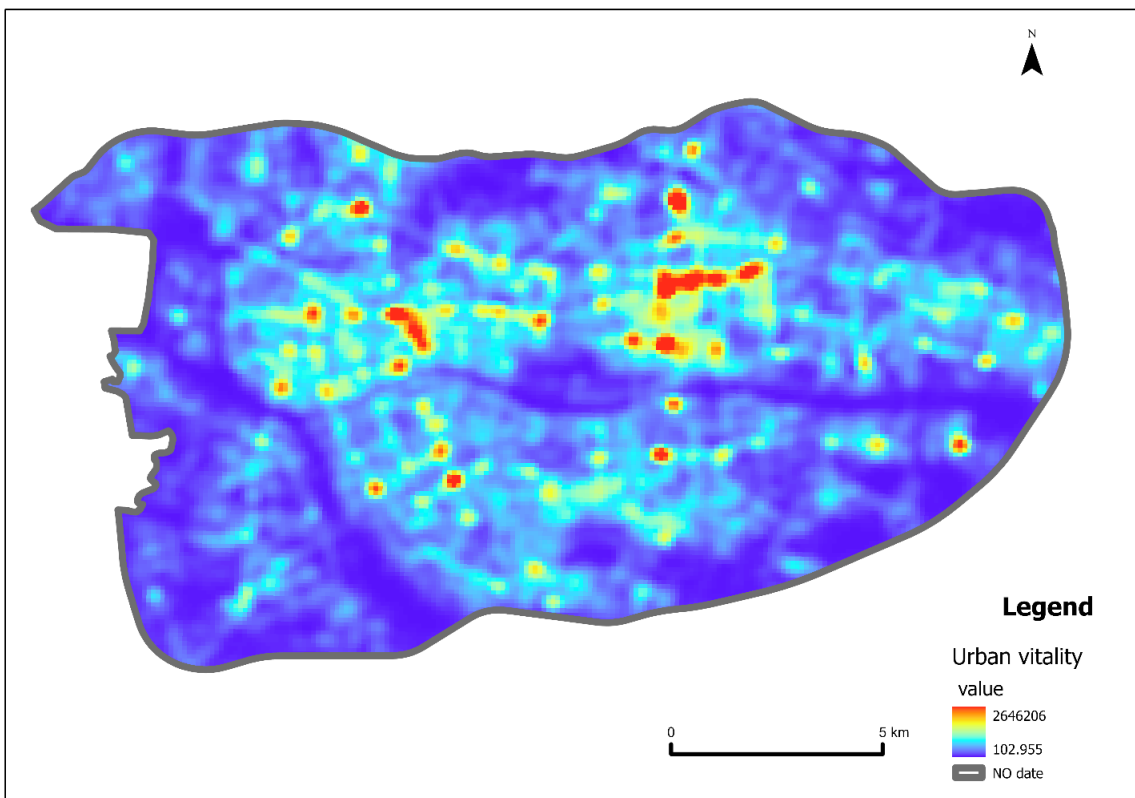


Figure 2: Spatial distribution of kernel density in the study area.

On this basis, kernel density estimation with a search radius of 300 m was applied to identify vitality distribution within the study area (Figure 2). The identified spatial pattern of vitality is largely consistent with the preceding classification results of urban vitality. Dark red denotes areas with high kernel density, which are concentrated in the traditional old urban centre of Yuexiu District and the Zhujiang New Town area of Tianhe District. High-vitality areas in Haizhu District are distributed as point-based nodes centred on metro stations and extend in a bead-like pattern along rail transit lines such as Line 8.

4.2. Spatial Pattern of Urban Vitality Based on Getis–Ord G_i^* Statistic

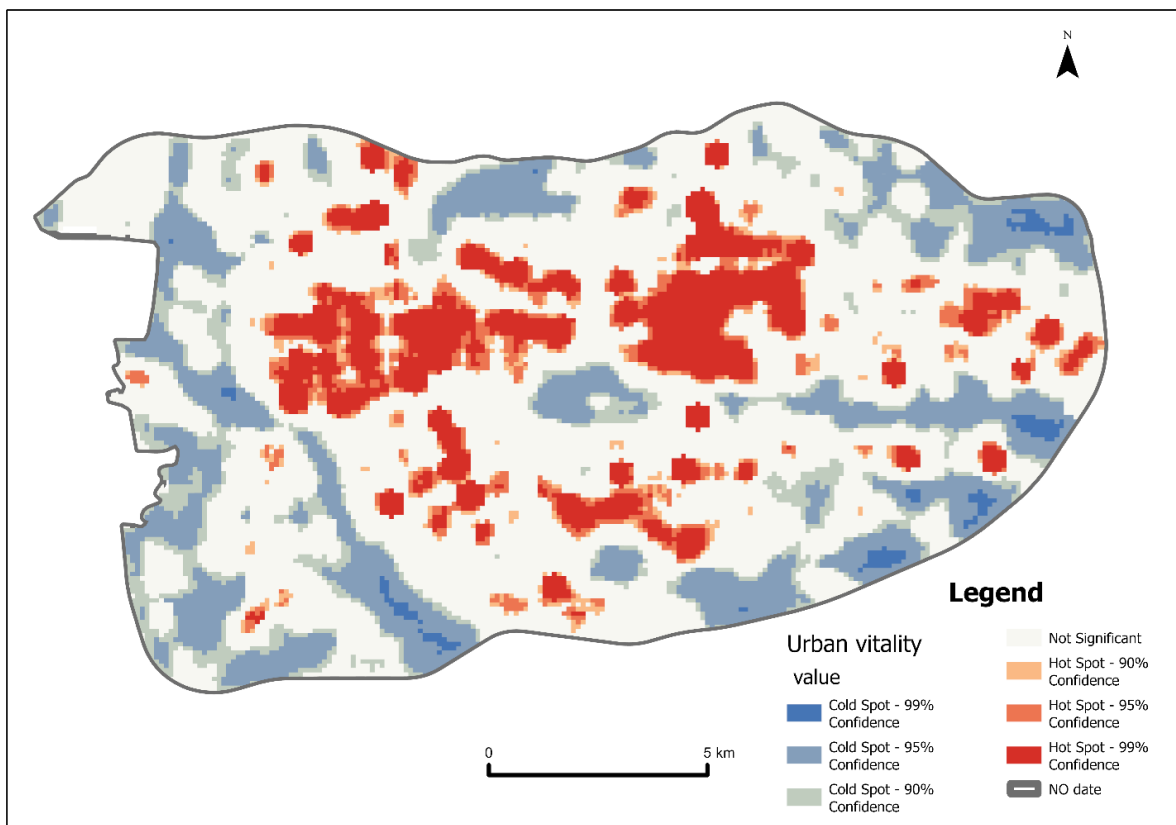


Figure 3: Spatial distribution of cold and hot spots in the study area.

The Getis–Ord G_i^* statistic was further employed to identify vitality poles within the study area (Figure 3). The results indicate that cold spots are predominantly concentrated over the Pearl River waters, large urban green spaces, and peripheral areas with low built-up density. Hotspots exhibit a multi-cluster spatial distribution aligned with metro lines: (1) Yuexiu old town core. The area spanning from the Guangzhou Municipal Government to the Guangdong Provincial People's Congress forms the largest contiguous hotspot cluster. As a traditional urban centre, this area features intensive mixing of public services, commercial facilities, and residential land. Crossed by Metro Line 1, the district achieves a high degree of jobs-housing integration, sustaining continuous agglomeration of urban vitality. (2) Tianhe District. Hotspots consist of two major clusters: Tiyu West Road–Guangzhou East Railway Station and Tangxia–Chebei. The Tiyu West Road and Guangzhou East Railway Station area constitutes a mixed urban centre formed by overlapping business districts, retail facilities, and comprehensive transportation hubs. In contrast, Tangxia and Chebei are high-density residential areas with large resident populations, representing typical residence-dominated

vitality hotspots.(3) Haizhu District. Hotspots are distributed around Zhongda, Lujiang, Kecun and Pazhou. Benefiting from mature residential communities, abundant university resources and well-developed commercial amenities, Zhongda, Lujiang and Kecun form a continuous vitality hotspot belt along Metro Line 8. As a convention and business district, Pazhou forms an independent hotspot patch driven by exhibition industries and rail transit accessibility.(4) Transportation hub hotspots. Represented by Guangzhou Railway Station, this area attracts massive passenger flows through integrated railway and metro transfer systems, forming an independent hotspot cluster.Overall, nearly all vitality hotspots at the 99% confidence level are located within 100–300 meters of metro stations. Blocks with mixed residential, commercial, and public service functions are more prone to high vitality agglomeration, whereas single-functional land uses such as pure urban green spaces hardly generate contiguous vitality hotspots.

5. Discussion

This study employs the cumulative number of mobile phone users to characterize urban vitality and depicts the spatial pattern of vitality in Guangzhou's core area. The results are partially consistent with previous findings: transit-oriented development (TOD) plays a significant role in stimulating regional vitality and advancing sustainable urban development. However, this study further reveals that rail stations are not the sole determinant of vitality formation. A comparison of Guangzhou Metro Line 2 and Line 3 indicates that eight stations along each line were identified as high-vitality nodes. Nevertheless, Line 2 has a lower proportion of transfer stations among these eight nodes, whereas its non-transfer stations have likewise developed into high-value nodes at levels comparable to those of transfer stations. It is therefore inferred that the built environment along Line 2 is more mature, and that this well-developed built environment has fostered more diverse urban functions, thereby enabling non-transfer stations to evolve into high-vitality nodes. This demonstrates that the functional diversity of the built environment can likewise drive vitality enhancement at the local scale.

From the cold-hotspot distribution, ecological green spaces and river waters consistently emerge as vitality cold spots, which does not signify low spatial value. Such spaces fulfil urban ecological regulation and leisure recreation functions and are not intended for large-scale population aggregation; accordingly, planning should avoid the blind pursuit of high-intensity human activities in these areas. Conversely, although transportation hubs such as Guangzhou Railway Station form prominent vitality hotspots, their population aggregation stems primarily from transit through-flows. Future planning and development should prioritize the enhancement of public space quality to prevent the phenomenon of "high pedestrian flow with low spatial quality."

This study has certain limitations. First, it uses the daily cumulative number of mobile phone users to characterize urban vitality, without distinguishing temporal variations between weekdays and weekends; thus, it cannot capture the dynamic changes of urban vitality at diurnal and holiday scales. Second, the study only reveals the spatial pattern of urban vitality and its spatial correspondence with rail stations, and has not yet quantitatively examined the extent to which various built environment factors influence vitality. Future research could further delineate different time periods and introduce variables such as land use, road network density, and facility density to quantitatively identify the driving contributions of individual built environment factors to urban vitality.

6. Conclusion

This study takes Guangzhou's core area bounded by the Guangzhou Ring Expressway and Guangzhou's administrative boundary as the research scope, adopts 100 m × 100 m grids as analytical units, and uses mobile phone location data. Kernel density estimation and the Getis-Ord Gi* statistic are applied to identify the spatial pattern of urban vitality. The main conclusions are as follows:

(1) Urban vitality within Guangzhou's core area exhibits obvious spatial differentiation, presenting an overall pattern of polycentric agglomeration, point-like dispersion and linear extension. High-vitality nodes are scattered across the study area, forming multiple vitality cores and extending outward in a bead-like pattern along metro lines.

(2) Cold and hot spots of urban vitality in the core area show prominent spatial differentiation. Cold spots are distributed in the Pearl River waters, large urban green spaces, and peripheral areas with low built-up density. Hotspots display a multi-cluster distribution aligned with metro lines.

(3) Urban rail transit serves as a vital carrier shaping the spatial framework of urban vitality. High vitality values are spatially concentrated around metro stations, especially near metro transfer stations.

References

- [1] Li Q, Cui C, Liu F, Wu Q, Run Y, Han Z. Multidimensional Urban Vitality on Streets: Spatial Patterns and Influence Factor Identification Using Multisource Urban Data. *ISPRS International Journal of Geo-Information*. 2022; 11(1):2.
- [2] Gao F, Deng X, Liao S, Liu Y, Li H, Li G, Chen W. Portraying business district vibrancy with mobile phone data and optimal parameters-based geographical detector model. *Sustainable Cities and Society*. 2023; 96:104635.
- [3] Yang Y, Yan Z, Yeh GO, Xie J, Ma C, Li Q. Measurements of POI-based mixed use and their relationships with neighbourhood vibrancy. *International Journal of Geographical Information Science*. 2017;31(4):658-675.
- [4] Zhang Z, Liu J, Wang C, Zhao Y, Zhao X, Li P, Sha D. A spatial projection pursuit model for identifying comprehensive urban vitality on blocks using multisource geospatial data. *Sustainable Cities and Society*. 2024;100:104998.
- [5] Li M, Pan J. Assessment of Influence Mechanisms of Built Environment on Street Vitality Using Multisource Spatial Data: A Case Study in Qingdao, China. *Sustainability*. 2023; 15(2):1518.
- [6] Azmi DI, Abdul Karim H. Implications of Walkability Towards Promoting Sustainable Urban Neighbourhood. *Procedia - Social and Behavioral Sciences*. 2012;50:204-213.
- [7] Tu W, Zhu T, Xia J, Zhou Y, Lai Y, Jiang J, Li Q. Portraying the spatial dynamics of urban vibrancy using multisource urban big data. *Computers, Environment and Urban Systems*. 2020;80:101428.
- [8] Yang J, Cao J, Zhou Y. Elaborating non-linear associations and synergies of subway access and land uses with urban vitality in Shenzhen. *Transportation Research Part A: Policy and Practice*. 2021;144:74-88.
- [9] Jacobs J. *The Death and Life of Great American Cities*. Random House; 1961.
- [10] Montgomery, J. Making a city: Urbanity, vitality and urban design. *Journal of Urban Design*, 1998;3(1) : 93–116.
- [11] Rosenblatt, M. Remarks on Some Nonparametric Estimates of a Density Function. *The Annals of Mathematical Statistics*. 1956; 33: 832-837.
- [12] Parzen, Emanuel. On Estimation of a Probability Density Function and Mode. *Ann. Math. Statist.* 1962;33(4):1065-1076.
- [13] Getis, A. and Ord, J.K. *The Analysis of Spatial Association by Use of Distance Statistics*. *Geographical Analysis*.1992;24:189-206.