Artificial Intelligence Implementation in Rural Planning and Design

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A Thesis Submitted in Partial Fulfillment of Requirements for
degree of Doctor of Philosophy in Electrical and Computer Engineering
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ABSTRACT

Urban vitality is a crucial factor in shaping the development of cities, with the built environment playing a pivotal role in influencing this vitality. This research focuses on the city of Yinchuan, utilizing the Baidu heat map as a tool to assess urban vitality. Independent variables are drawn from the built environment, and the study employs various models, including Ordinary Least Squares (OLS), Moran's I, Geographically Weighted Regression (GWR), and Gradient Boosting Decision Tree (GBDT), to explore the intricate relationship between urban vitality and the built environment.The analysis distinguishes between weekdays and weekends, providing a nuanced understanding of temporal dynamics. The findings reveal several key insights:(1) The study underscores that the built environment in Yinchuan significantly impacts urban vitality on both weekdays and weekends. Variables such as Landscape, Hotel, Shopping, Openness, Greenness, Imageability, Road, Bus station, TPBt-500, NQPTA-500, and TPBt-1200 are identified as key influencers.(2) Positive spatial autocorrelation is observed between the built environment and urban vitality on both weekdays and weekends.(3)GWR model analysis reveals distinct spatial distribution characteristics for urban vitality during weekdays and weekends.(4)GBDT model analysis highlights different importance rankings for variables influencing urban vitality on weekdays and weekends. The research offers tailored strategies for enhancing urban vitality in different areas and time periods, serving as a crucial reference for urban planning and sustainable development in Yinchuan City.

Keyword : Built environment Urban vitality GWR GBDT，Big data

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Guifen Lyu

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Chapter 1 Introduction

1.1. Rapid Urbanization in China

Since the 1990s, China's urban areas have experienced dramatic growth. With the expansion of urban scale and space, and the concentration of population and functions, "Big City Diseases" have emerged, such as dense population, traffic congestion, environmental degradation, prominent social problems, and declining quality of life.

China's "14th Five-Year Plan" clearly proposes the implementation of urban renewal actions[1]. The implementation of urban renewal will greatly improve the quality of cities and enhance the quality of life of residents, the quality of the living environment and the competitiveness of cities in all aspects. Urban renewal includes two aspects.

The first is the renovation of the built environment. The second is the transformation and continuation of various ecological environments, spatial environments, cultural environments, visual environments, recreational environments, etc., with the goal of restoring the vitality of the old urban areas and making the cities more vital and competitive. The purpose of urban renewal and transformation is not simply to satisfy people's sense of well-being, but more importantly to activate the city center[1].

Urban vitality is a component of basic quality of life and plays an important role in the lives of its inhabitants. Many studies have concluded that urban vitality occurs when urban activities interact with spatial entities. The effect of the built environment on urban vitality has been more studied. Jacobs (1961) argued that urban vitality describes how a place stays busy and makes people feel energized at different times and places[2].

More recently, Jacobs argued that there are six main conditions that need to be attended to establish a vibrant urban environment: density, land use mix, block size, age of buildings, accessibility, and lack of boundary vacuum. Cervero (1997)

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[1] https://www.gov.cn/zhengce/2020-11/03/content_5556991.htm

argued that the 3D theory of built environments consists of density, diversity, and design. Cervero and Ewing (2010) added destination and distance to the 3D theory to form the 5D theory[3].

In recent years, Yinchuan City, Ningxia Province, has been actively promoting the organic renewal of the city, accelerating the transformation of old neighborhoods, and adding vitality by optimizing neighborhood planning and design, updating infrastructure, and upgrading neighborhoods, etc. In 2020, the "China's Cities Prosperity and Vitality 2020 Report" categorized China cities into four types.[2]

Yinchuan is considered to belong to the fourth category of cities. The overall vitality level of the city is lower than the other three categories of cities. Therefore, this paper focuses on the impact of the built environment on urban vitality in Yinchuan City.

1.2. Technical Breakthroughs in Deep Learning of the Big Data Environment

It is difficult to conduct a quantitative investigation of the built environment and urban vitality on a large scale with traditional methods[4]. In the big data environment, a large amount of spatial measurement data adds new research perspectives to the study of the built environment[5].

With the emergence and development of information and communication technologies (ICTs), a large amount of geo-open data, including social media data, cell phone data, points of interest (POIs), and smart card records, are available for quantitative and systematic studies of urban density and urban vitality.

Emerging data types such as road network data, POI data of various facilities, and population thermal data, and artificial intelligence techniques such as image recognition, semantic segmentation, and text mining based on machine learning and deep learning algorithms break through the limitations of traditional spatial data acquisition and analysis and analyze huge amounts of big data more accurately and comprehensively[6].

[2] https://www.thepaper.cn/newsDetail_forward_10636157

As a result, some recent studies have utilized these open data to validate research on urban vitality[7]. However, the data in most of the articles consist of two main aspects: one is based on neighborhood and census data; the other is city and national survey data. There is a lack of research data studies on residents' perception of the built environment.

1.3. Research Content

This paper attempts to combine the physical built environment and bottom-up residents' perceptions based on the 5D theoretical framework (**Figure 1**). A large amount of big data is used to explore the combined impact of built environment factors on urban vitality.

We measured urban spatial vitality by using Baidu heat map. We obtained Baidu heat maps for weekdays and weekends, used POI data, street view data, and constructed a framework combining linear regression model and geographically weighted regression (GWR) model to explore the relationship between the built environment and urban vitality.

On this basis, we chose the GBDT model analysis to obtain the importance of variables, which provides a priority reference for planning implementation. This study addresses the following research questions. Explore the factors affecting urban vitality by combining top-down built environment and bottom-up residents' perceptions.

The articles in this paper are organized as follows. Section 2 reviews the relevant literature. Section 3 describes the data and modeling methodology. Section 4 gives the results. Section 5 discusses the main findings. Section 6 suggests related strategies. Section 7 summarizes the full paper and suggests future research directions.

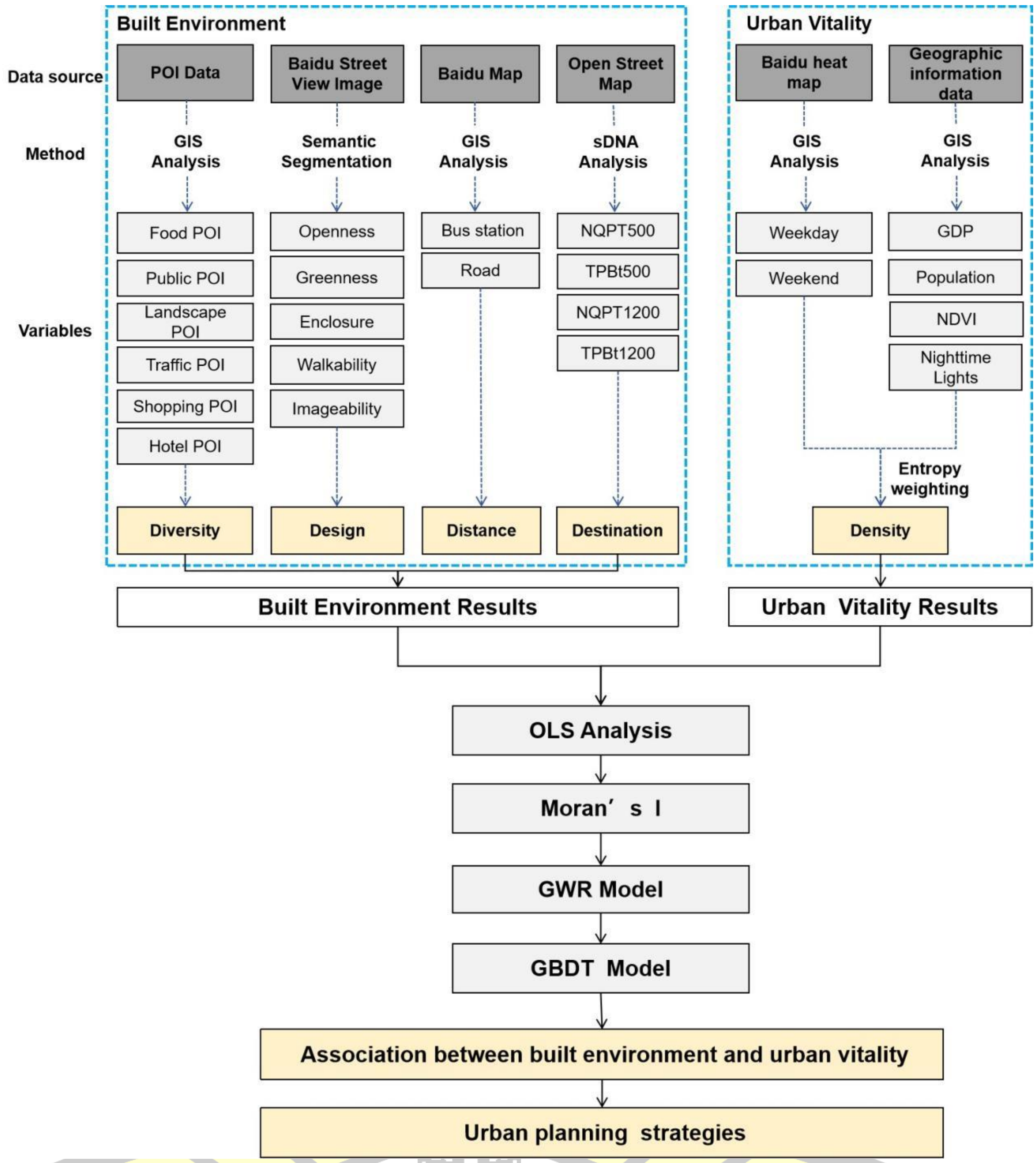

Figure 1 Thesis Framework

Chapter2 Literature review

Urban vitality is a multifaceted concept deeply intertwined with the built environment, encompassing various physical, social, and economic dimensions. A comprehensive understanding of the literature surrounding the association between the built environment and urban vitality is essential for framing the theoretical underpinnings of this research.

2.1 Current Research on Urban Vitality

Urban vitality refers to the distribution of urban populations and their activities. The built environment of a city itself cannot generate vitality; rather, people move through space for various activity needs, including employment commuting, leisure, shopping, education, healthcare, etc., thereby manifesting as the concentration and dispersion of urban vitality within city spaces[8]. This is specifically evident at two levels: time and space. Temporally, urban vitality is characterized by the sustained dynamics of urban population activities, reflecting continuous changes in activities over different periods[9]. Spatially, urban vitality is demonstrated by the richness of urban population activities, encompassing both macro and micro perspectives[10]. At the macro level, this manifests as the tendency of urban populations to engage in specific activities within a defined spatial range at the same time[11]. On the micro level, it involves the quantity and density of activities within a space, spatial clustering distribution, and the range of movement of urban populations[12].

In the study of urban vitality at the miso and micro scales, such as public green spaces and streets, traditional data collection methods include behavioral recording, activity logs, and questionnaire surveys[13]. The collected information may encompass individual attributes, activity types, and approximate activity intervals of the population. Big data-related research, on the other hand, utilizes signaling data and Baidu heat map data to represent the spatiotemporal distribution of urban populations[14]. Sung et al. used the travel volume of urban residents as a representation of urban vitality[15]. Jiang Lei characterized urban vitality based on both the number of participants and their duration of stay[16].

In macro-level studies of urban vitality, due to the extensive spatial scope involved, researchers focus more on the collective behavioral characteristics and demands of urban populations, i.e., the characteristics of population activities. De Nadai, Yue, Wang, and others have used the number of mobile phone users or the volume of mobile phone calls to represent urban vitality in their studies[17-19]. Long Ying and Zhou Yin characterized the vitality of street spaces using population density reflected in mobile signaling data [20]. Zhao Yi, Song Yan, Wang, and others utilized Baidu heat map data to reflect population distribution and clustering[21], and other types of big data have also been applied in macro-level urban vitality studies[22].

This study utilizes Baidu Maps heat map data to characterize urban population activities[23]. Although Baidu Maps heat map data only captures the spatiotemporal distribution of a subset of the population using electronic devices and the collected time does not cover the entire day, the widespread use of electronic devices and the vast amount of data make Baidu heat map data a suitable tool for describing the state of urban vitality[24].

2.2 Quantitative Research on Urban Space in the Context of Big Data

In the era of big data, there is still a need to increase research on quantitative methods of urban vitality. Traditional quantitative research generally obtains research data through questionnaires, field surveys, on-site interviews, photography, and so on[25]. It mainly evaluates urban vitality through comparison, semantic analysis, and expert scoring[26]. However, traditional data are static, and quantitative research cannot reveal continuous spatial-temporal behavior[27]. The rapid development of deep learning and big data technologies has brought about a paradigm shift in the physical indicators of urban vitality and the urban built environment[28]. Many spatial measurements help to characterize urban vitality. Point-of-interest (POI) data can be used to quantify urban vitality. Baidu heatmap can be used to calculate the overall vitality of the population[29]. Semantic segmentation of street view images can measure landscape features such as sky, trees, buildings, etc. in the street view[30]. Currently, in the context of new science, the study of urban vitality mainly focuses on the physical spatial environment[31]. Although it meets the requirements of high efficiency and refinement, it lacks top-down thinking about the built environment and bottom-up thinking about urban vitality[32].

In recent years, empirical research on urban vitality has primarily focused on three aspects: quantitative assessment of urban vitality, investigation of the spatiotemporal distribution characteristics of urban vitality, and research on the intrinsic mechanisms influencing urban vitality and the built environment[33].

2.2.1 Quantification of Urban Vitality

In terms of data acquisition, research on urban vitality has shifted from traditional methods to big data approaches. Traditional methods primarily relied on on-site survey statistics, including instantaneous behavior recording, questionnaire surveys, interviews, and individual GPS movement trajectories, to collect information on the characteristics of user populations, their activities, spatial locations, and individual attributes[34]. These methods can obtain individual attributes of user populations, such as gender, age group, satisfaction [35]. However, they are limited by a single data collection method, high workload, and time costs[36]. Some methods also suffer from drawbacks in terms of representativeness and relatively poor randomness[37]. For instance, questionnaire surveys are subjective and influenced by the respondents' acceptance of the interviewer and personal backgrounds, making them suitable for vitality studies in small-scale spaces[38]. On the other hand, big data technologies can capture diverse, large-volume, real-time, and dynamic data, including mobile signaling, business category Points of Interest (POI), Baidu heat map data, and more[39]. Such data exhibit characteristics of "high frequency, low cost, large sample, and high accuracy." They eliminate subjective elements introduced by survey questionnaires, providing more representative insights into group behavior[40]. However, they may overlook individual attributes of the population[41]. Additionally, the high accuracy of big data is relative, and traditional methods may offer higher accuracy for micro-scale analyses[42].

In terms of research methods, the analysis of urban vitality has gradually incorporated spatial analysis methods. Spatial analysis methods emphasize the spatial correlation, heterogeneity, and temporality of samples[43]. Considering the mutual influence of urban vitality in space, the use of spatial analysis methods in studying the interaction between the environment and people can more intuitively reflect their correlation[44]. Relevant studies have proposed evaluation models for urban vitality based on aspects such as the quality of public spaces, urban morphology and scale, and the subjective perceptions of urban populations[45].

Ye and Van summarized and categorized the research framework and elements of urban space based on urban morphology. They quantitatively assessed urban space quality using a GIS data processing platform[46]. Liu Li et al. employed a fuzzy matter-element model for urban vitality assessment, evaluating the vitality of 15 county-level cities in Jiangsu Province[47]. Wang Hai and Jiang, based on the subjective perceptions of urban populations, established a quantitative evaluation system for urban public space vitality using the Analytic Hierarchy Process (AHP) and expert scoring method. This system includes four dimensions: sensory, social, economic, and cultural[48]. Zhang, in the analysis and evaluation of urban vitality, constructed an evaluation system for vitality indicators based on the essence of urban vitality. The system includes indicators such as development level, development speed, diversity, radiation force, and attraction. Nighttime light data were utilized for empirical research[49].

2.2.2 Spatiotemporal Distribution Characteristics Research

The development of big data and spatial analysis technologies has provided a new perspective and means of support for current research on urban vitality. Various data types, such as social network data, mobile signaling data, and public transportation card data, have been applied in studies related to urban vitality. These data types are characterized by their diversity, large volume, and real-time and dynamic nature[50].

Becker, based on mobile phone data, revealed the dynamic changes in urban population activities in Morristown, USA, over a two-month period through statistical analysis and mapping[51]. Mallesons, utilizing social network data and kernel density analysis, assessed the spatial distribution and behavioral types of urban populations[52]. Sagle, by integrating mobile phone data and social media data, studied the travel pattern changes of urban populations between central city areas and suburbs at different time points[53]. Long Ying et al., using public transportation IC card data combined with resident travel surveys, identified the residential areas, employment locations, and commuting activities of bus cardholders in Beijing [20]. Wang De categorized urban population activities into specific types such as residence, commuting, and leisure, and used mobile signaling data to evaluate the urban built environment[10].

Wang, analyzing spatial vitality distribution characteristics from the dimensions of time, space, and function, utilized mobile signaling data[15]. Zhang, studying spatial vitality changes in the central urban area of Hangzhou, utilized multiple data sources, including Baidu heat maps and Points of Interest (POI) data[54]. The mentioned studies, utilizing big data such as mobile signaling or social network data, have made new explorations and reflections from the perspective of the spatiotemporal distribution of urban population activities, providing new ideas and technological foundations for the quantitative study of urban vitality.

2.2.3 Research on the Mechanisms of Urban Vitality and the Built Environment

The research focus has expanded from the miso and micro levels to the macro level of urban spaces, and related studies have become increasingly systematic[55]. In miso and micro-level space studies, the emphasis is largely on understanding how micro-elements within a space attract more people[56]. For example, factors such as the variety and number of features in a square, planting ponds, and green area sizes influence users[57]. Such studies, guided by the intrinsic mechanisms of environmental design elements and spatial vitality, aim to enhance space quality through specific designs, thereby promoting the generation of spatial vitality[58].

In macro-level space studies, the focus is primarily on the impact of urban built environment elements, such as urban spatial morphology, road networks, and building systems, on urban vitality[59]. For instance, factors like the street topology, distribution of business types, and commercial interfaces within street spaces influence street vitality[60]. This type of research primarily explores deep structural issues in urban spatial development and urban systems, seeking ways to optimize urban space quality and enhance urban operational efficiency[61]. Whether at the macro or miso and micro levels, the goal is to improve the quality of urban spaces[62].

With the expansion of data volumes, theories related to the creation of urban vitality are gradually being quantitatively validated. For example, Ning Xiaoping utilized Hill Numbers indices to analyze real-time pedestrian flow and land use information, confirming the impact of land use diversity on enhancing urban vitality [63]. Sung et al. conducted a study on the urban vitality of Seoul and its built environment using a multiple linear regression model, validating Jane Jacobs' theory of enhancing overall urban vitality[64]. De Nadai et al., using data from mobile signaling, OpenStreetMap, land use, and more, measured the explanatory power of Jane Jacobs' four urban diversity conditions on urban vitality[65].

2.2.4 Shortcomings in Urban Vitality Research

Despite the progress made in urban vitality research, there are some notable shortcomings.

i. Data Limitations:

While the advent of big data has enriched urban vitality research, there are still limitations in terms of data coverage and representativeness. Certain population groups or activities may be underrepresented, leading to potential biases in the findings[66].

ii. Methodological Challenges:

The integration of various data types and the development of robust methodologies for urban vitality research pose challenges. Methodological consistency and standardization across studies may be lacking, making it difficult to compare results and draw generalizable conclusions[67].

iii. Temporal Considerations:

Many studies focus on specific time periods or snapshots of urban activity, and there is a need for more comprehensive longitudinal studies that capture temporal dynamics and variations in urban vitality over different seasons, days of the week, or times of day[68].

iv. Spatial Scale Issues:

Urban vitality research often faces challenges related to the appropriate spatial scale for analysis. Different studies may adopt different spatial units, and there is a need for a more standardized approach to ensure comparability and generalizability of results[46].

v. In-depth Understanding of Mechanisms:

While studies have explored the impact of urban form, land use, and other factors on urban vitality, there is room for a more nuanced understanding of the underlying mechanisms and interactions that contribute to or hinder urban vitality[69].

vi. Socioeconomic Considerations:

Urban vitality research should further consider socioeconomic factors, such as income levels, social equity, and community engagement, to better understand how these factors influence and are influenced by urban vitality[70].

Addressing these limitations will contribute to the refinement and advancement of urban vitality research, providing more accurate insights into the factors shaping the dynamic and complex nature of urban life.

2.3 Current Research on Built Environment

Built environment mainly refers to the planned and remodeled man-made environment. Research on built environment has been a hot topic. According to different scales, the study of built environment is divided into three scales: micro, mesa and macro[71]. The micro-scale is mainly through the perception of the built environment, the meso-scale is based on community and census, and the macro-scale is based on city and national survey data. There are many scholars who have studied the mesoscale-built environment. The main studies include two aspects of variable studies of the built environment and evaluation studies of the built environment. The variable system of built environment is mainly 5D theory, including density, diversity, design, distance to transit, and destination[72]. Built environment evaluation mainly focuses on subjective evaluation, also known as built environment satisfaction evaluation, which focuses on the kind of environment in which people can obtain a greater state of satisfaction.

Built environment, a term introduced by Amos Rapoport, is categorized into three types based on the nature of spatial components: immovable element complexes, partially movable complexes, and movable element complexes[73]. Cervero and Kock Elman (1997) define the built environment as the physical characteristics of the urban landscape, describing it based on the "3D" model (Density, Diversity, Design)[74]. Handy et al. (2002) define the built environment as a comprehensive pattern consisting of human activities, urban design, land use, and transportation systems[71]. This includes various dimensions such as urban built environment, regional built environment, residential area-built environment, and architectural built environment. Cervero et al. expanded the "3D" model by incorporating the distance to public transit stations (Destination accessibility) and transit accessibility (Distance to transit), forming the "5D" model for describing the urban built environment. In this context, the study focuses on the urban built environment, specifically referring to the artificial environment provided for human activities in large urban settings[75]. The quantification of the 5D indicators for the built environment is detailed as follows.

2.3.1 Density

Density refers to the degree of concentration of a certain element in spatial distribution, and population density, building density, and floor area ratio (FAR) are the most used indicators to characterize density elements in the built environment. In areas with higher population density, urban vitality tends to be more active. Research findings suggest that higher population density is associated with promoting walking and cycling activities[76]. Barnet et al. explored the relationship between land use variables (population density, employment density in retail businesses, and overall employment density) and travel behavior through a comprehensive daily travel survey of residents. They found that residents in areas with higher population density were more likely to engage in walking trips[77]. In a subjective perception study of the built environment in urban areas of Hangzhou, Liu Qingming et al. found that areas with higher population density received higher scores[78]. These research findings underscore the importance of population density as a key indicator of built environment density and its correlation with urban vitality.

2.3.2 Diversity

Diversity refers to the complexity of land use function changes, and indicators such as land use mix, green space ratio, water body ratio, and the density of single land use types are commonly used to reflect diversity. In recent years, many scholars have utilized Points of Interest (POI) data to describe the built environment and further characterize the diversification of land use based on its functional classification. This indicator is used to characterize the degree of mix of all land use properties within a certain range in the city. It expresses the complexity of land use properties in the region, with lower mix indicating a more homogeneous built environment in terms of land use types, and vice versa indicating a more diverse range of land use types. Researchers like Frank et al. used land use mix entropy to explore the relationship between urban land use mix and travel behavior[79]. Zhou et al.'s study found that land use mix significantly influences the physical activity levels of urban residents[80]. El-Assi et al.'s research demonstrated a higher usage rate of public bicycle stations around school areas, highlighting the impact of educational and cultural land use or campus areas on public bicycle usage[81]. Wang et al.'s study illustrated that bike-sharing stations closer to the central business district had higher usage rates for bike borrowing and returning [82].

2.3.3 Design

Design is an element that describes the characteristics of the built environment within a region. Current research primarily characterizes relevant design elements related to urban human activities using factors such as road network density, public facility density, parking lot density, etc. Additionally, scholars use elements such as green coverage, road width, and material spatial elements constituting the urban environment to characterize urban design elements. Street density is a crucial indicator representing the degree of street crowding. In research on the impact of street networks on walking and cycling, Dill J. and colleagues found a positive correlation between street density and physical activity [83]. Miao's research, based on the Analytic Hierarchy Process (AHP), discovered that road network density has a significant impact on improving street quality[84]. Calthorpe, Downs, Deacons, and others argue through their studies that shading facilities, parking lot settings, entertainment facilities, and other factors influence the mobility of urban populations[85]. In a study on the impact of the built environment of commercial pedestrian streets on pedestrian distribution, Fu Yiyi suggested that public facility elements affect the inherent perceptions of users within the space and play a crucial role in realizing the functions of commercial pedestrian streets [49].

2.3.4 Distance to Transit

Distance to transit is defined as the "number of selectable routes through a space" [16]. On the other hand, destination accessibility primarily refers to the convenience for travelers from the starting point to their destination. In related studies, specific indicators of destination accessibility overlap with design elements, particularly the indicator of street density. According to Jan Gehl, a well-designed road network with reasonable density and efficient public transportation organization is a prerequisite for creating spatial vitality[86].

2.3.5 Destination Accessibility

Destination accessibility refers to the convenience of urban populations reaching transportation hubs, typically measured by the density of public transit stations such as bus stops and subway stations. In a study on the impact of the built environment on residents' motor vehicle travel, Vance and Hedel included the accessibility of public transit (the distance residents walk from their residence to the nearest bus stop) as a built environment indicator. They pointed out that the distance residents walk to public transit stations has a certain influence on the mileage of residents' motor vehicle travel [87]. Research by Pushkar et al. indicates that the distance from urban populations to transportation transfer points affects household motor vehicle travel. In other words, the farther the distance from the population to transportation transfer points, the higher the mileage of household motor vehicle travel[88].

2.4 Built Environment and Urban Vitality

The built environment can be seen as the foundation of urban vitality[89]. It refers to the built environment that provides space for daily human activities. Some studies have found a significant relationship between urban vitality and 5D built environment factors. From the perspective of urban vitality, the built environment includes psychological factors ranging from buildings and neighborhoods to land use. Mixed land use allows for a mixture of urban functions to meet the various needs of the population, thus stimulating a constant flow of human activities for different purposes. Human activity is a proxy for the degree of human interaction and participation in urban life and is widely used as a measure of urban vitality. Human-environment interaction refers to development strategies or urban planning that aim to better serve people and have a significant impact on the built environment. According to Lynch (1984), urban vitality is an important indicator of how well the settlement form supports people's lives and needs[90]. Montgomery and John (1998) emphasized the importance of human activities for urban vitality[89].

2.5 Research on Residents' Activities and the Built Environment

Research on residents' activities and the built environment mainly focuses on the built environment and residents' living space, residents' health, residents' lifestyle choices, and residents' living experience. Most of the results have focused on the study of residents' mobility and physical and mental health at the community scale[91]. The choice of residents' traveling mode is one of the more concerned topics in the field of urban built environment, and most of the empirical researches on the urban built environment and residents' traveling are based on 5D theories[92]. In traditional research on residents and the built environment, questionnaires, in-depth interviews, or participatory observation by the researcher are more often used. This is more subjective and requires a lot of time and capital costs. In recent years, with the development of big data, data such as cell phone records[93], smart cards, and travel records have been widely used to study the spatial-temporal behavior characteristics of urban residents[49, 94]. Residents' spatial-temporal behavior is influenced by demographic characteristics, time, location and other factors[95]. Residents' spatial-temporal behavior differs between weekdays and days off. The activities of urban residents are also different in a day[96]. However, there are relatively few studies on the relationship between urban space and population movement. Therefore, it is of great significance to study the spatial-temporal evolution characteristics of urban residents' activities from the perspective of built environment.

2.6 Technical Breakthroughs in Deep Learning

Deep learning has made great breakthroughs in recent years, which also provides new ideas for solving new and old problems in urban and rural planning. The technology represented by convolutional neural networks has also achieved breakthrough results in the field of image analysis, and has also been widely used in natural language processing[97]. Compared with traditional machine learning algorithms, convolutional neural networks save a lot of pre-processing procedures, and have more excellent performance in the processing of audio, image, video, and other data. In the future, urban planning will rely on the development of new generations of artificial intelligence technology to develop new technological possibilities for urban perception, urban awareness, urban analysis, urban simulation, and urban decision-making.

With the continuous development of information technology, deep learning algorithms have gradually entered the field of view of many scholars, providing new opportunities for the study of urban vitality. Machine learning, guided by autonomous improvement principles, can solve the weight coefficients of evaluation indicators through nonlinear mapping, largely avoiding the subjectivity of manually assigning weights[98]. Among these, logistic regression (LR) is easy to construct and implement, allowing for convenient acquisition of probability scores for observed samples, making it one of the earlier used machine learning algorithms. Support vector machine (SVM) is a model based on statistical theory. With the development of information technology, ensemble learning algorithms, by integrating multiple base learners, have achieved more stable predictions. Random Forest (RF), based on the principle of random sampling (bagging), achieves higher accuracy and generalization capabilities by combining the voting results of multiple decision trees in the evaluation of tourism suitability and attractiveness. Extreme Gradient Boosting Tree (XGB), based on the boosting principle of weighted iteration, demonstrates high prediction accuracy and fast computational speed, particularly excelling in predicting tourism evaluation problems[99].

This paper employs the GBDT (Gradient Boosting Decision Trees) model. The application of Gradient Boosting Decision Trees (GBDT) in the fields of built environment and urban vitality has garnered widespread attention, with numerous literature reviews available. In the realm of the built environment, researchers employ the GBDT algorithm to analyze and predict the impact of various built environment factors on urban vitality. These factors include building density, greenery ratio, transportation networks, among others. GBDT allows for nonlinear modeling of these factors, capturing their intricate interrelationships more accurately and assessing the quality of the built environment's impact on urban vitality. Concerning urban vitality, the GBDT algorithm is utilized to forecast the spatiotemporal distribution of urban population activities, encompassing aspects such as employment commuting, leisure, shopping, and more. By leveraging extensive data related to urban vitality, GBDT aids in better understanding and predicting behavioral patterns of urban populations, providing a scientific basis for urban planning and management.

Tao investigated the nonlinear correlation between architectural environments and travel distance through driving, public transit, and active travel. The study applied the GBDT model to regional travel survey data from the Twin Cities in the United States, comparing the relative contributions of local and regional architectural environment characteristics[100]. Wenjie et al. utilized the 2017 travel survey dataset from Beijing, China, along with web crawling heat maps and Point of Interest (POI) data. They employed the Gradient Boosting Decision Tree (GBDT) algorithm to assess the relative importance and nonlinear impact of local accessibility, regional accessibility, and public transit accessibility on household car ownership[101].

In summary, the application of GBDT in studies related to the built environment and urban vitality provides researchers with a powerful tool to comprehensively comprehend the complexity of urban systems. It offers more accurate insights for urban planning and design. Literature reviews on this topic typically cover specific applications of GBDT, its advantages, and challenges in both fields.

2.7 Summary

Given the existing issues and shortcomings in urban vitality research, this paper addresses urban vitality's essence. It utilizes the spatiotemporal distribution of urban populations as a representation of urban vitality. Based on related studies, the paper establishes a quantifiable indicator system and specific quantifiable indicators for urban built environments. Multiple data sources are used to investigate the spatiotemporal distribution patterns of urban vitality in the central area of Yinchuan

City. The study also explores the intrinsic mechanisms linking urban vitality with the urban built environment. On one hand, the paper quantitatively describes the spatiotemporal distribution and patterns of urban vitality using the spatiotemporal distribution of urban populations. On the other hand, by employing global spatial autocorrelation, the study verifies that urban vitality does not exhibit a random spatial distribution but rather demonstrates certain spatial clustering characteristics. The Geographically Weighted Regression (GWR) model is employed to establish connections between urban vitality and the urban built environment, exploring the intrinsic mechanisms influencing urban vitality. Finally, the paper applies the Gradient Boosting Decision Tree (GBDT) method to rank the importance of factors. The exploration of the spatiotemporal distribution of urban vitality and the intrinsic mechanisms linking urban vitality with the urban built environment represents a novel attempt in urban vitality research.

Chapter3 Data and methodology

3.1 Study Area

The case of this study is Yinchuan City, China (Figure 2). It is a famous historical and cultural city in China, with a history of more than 2,100 years. Yinchuan City was selected as one of the "Top 20 Smart Cities in the World"[3] by Juniper Research, a UK-based market research organization, in 2017. The city ranked in the top 20 in the health, safety, and productivity scores. This means that Yinchuan City's smart city construction has been recognized by the world.

This study adopts administrative townships as the unit of analysis for a total of 365 research units. As of the end of 2022, the permanent population of Yinchuan City was 2.8968 million. Among them, the urban population was 2.3678 million, accounting for 81.74% of the total population (yinchuan.gov.cn).

The population of the three districts in Yinchuan City is 1,901,793. Among them, Xing Qing District has a population of 808,282, Xi Xia District has a population of 449,559, and Jinfeng District has a population of 643,952, as shown in Table 1.

The study area of this research is the three districts of Yinchuan City. The administrative divisions include 20 towns, 6 townships, 27 neighborhood offices, 293 residents' committees, and 282 villagers' committees, as shown in Table 2.

The population of the three districts of Yinchuan is 1901793, of which the population of Xing Qing District is 808,282, the population of Xi Xia District is 449,559, and the population of Jinfeng District is 643,952. The annual GDP in 2022 is worth 2535.63 billion yuan.[4]

[3] https://m.thepaper.cn/newsDetail_forward_2245097

[4] yinchuan.gov.cn

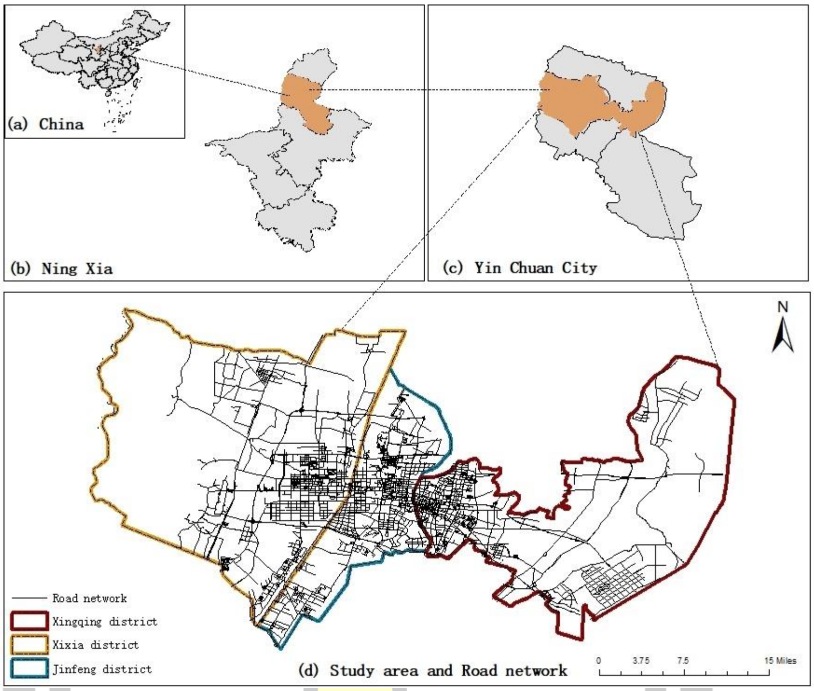

Figure 2 Study Area

Table 1 Information of Downtown Area in Yinchuan

Region	**Area (square kilometers)**	**Population (10,000 people)**	**Administrative Jurisdictional Area**
Xing Qing District	982	81.3	Daxin Town; Zhang Zheng Town; Tong Gui Township; Yue Ya Hu Township; Wenhua Street Sub-district Office; Feng Huang North Street Sub-district Office; Yu Huang Ge North Street Sub-district Office; Funning Street Sub-district Office; Jie Fang West Street Sub-district Office; Qianjin Street Sub-district Office; Xinhua Street Sub-district Office; Zhongshan South Street Sub-district Office; Yin Gu Road Street Sub-district Office; Li Jing Street Sub-district Office; Sheng Li Street Sub-district Office
Jinfeng District	1847	65.2	Liang Tian Town; Feng Deng Town; Chang Cheng Middle Road Sub-district Office; Beijing Middle Road Sub-district Office; Huang He East Road Sub-district Office; Man Cheng North Street Sub-district Office; Shanghai West Road Sub-district Office; Helan Mountain Middle Road Sub-district Office
Xi Xia District	403	45.3	Xing Jing Town; Zhen Bei Pu Town; Wen Chang Road Sub-district Office; Bei Jing West Road Sub-district Office; Xi Hua Yuan Road Sub-district Office; Ning Hua Road Sub-district Office; Shuo Fang Road Sub-district Office; Helan Mountain West Road Sub-district Office; Huai Yuan Road Sub-district Office

Table 2 Information of Downtown Area in Yinchuan

Jurisdiction	Town	Township	Sub-district Office	Residents' Committee	Village Committee	Administrativ e Area
Xing Qing District	2	2	11	105	43	828.26
Jinfeng District	2	0	6	63	20	353.00
Xi Xia District	2	0	7	64	19	1124.60
Total	**6**	**2**	**24**	**232**	**82**	**2305.86**

3.2Data Sources

3.2.1Data Sources

The study used 8 types of data, as shown in Table 4,including Geographic information data, NDVI, POI data, Baidu heat map, GDP, Nighttime Lights, Baidu Street view, Open Street map.

i. Geographic information data

The basic geographic information data is sourced from the National Geographic Conditions Census (http://www.ngcc.cn/), including administrative boundaries of cities and districts, hydrological data, and road network data (Figure 3).

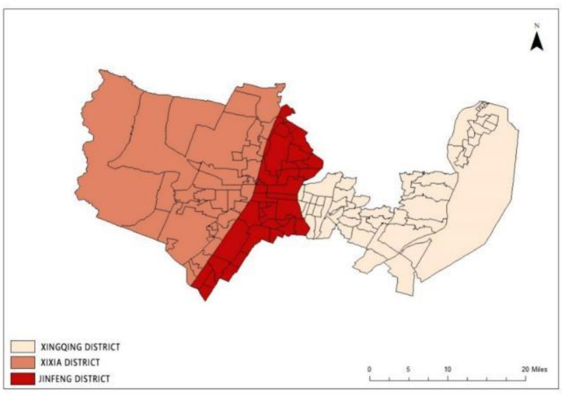

Figure 3 Geographic Information Data

ii. NDVI

The Normalized Difference Vegetation Index (NDVI) is used to monitor the growth status of vegetation, vegetation coverage, and to eliminate some radiation errors. NDVI can reflect the background influences of the vegetation canopy, such as soil, moist ground, snow, dried leaves, roughness, etc., and is related to vegetation coverage. This paper chooses the 2020 precision 30-meter NDVI data from the Institute of Geography, Chinese Academy of Sciences (Figure 4).

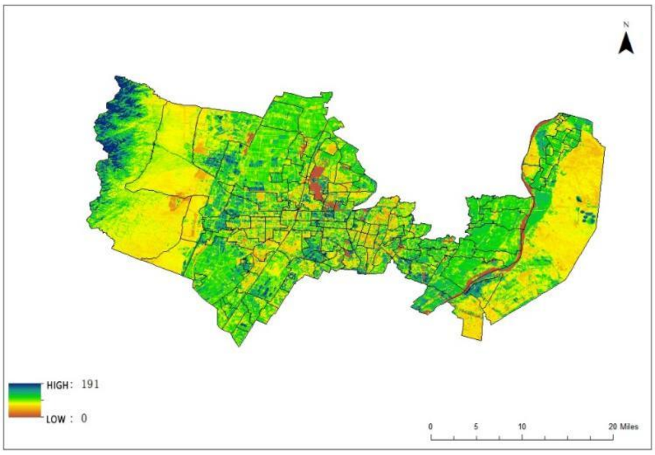

Figure 4 NDVI Data

iii. POI data

The POI data was crawled from A-map at the end of 2022. The POI data is classified based on A-map POI categories and the "Urban Land Use Classification Specification and Development Land Planning Standards" (GB50137-2011). The obtained POI data for Yinchuan includes all types of facilities. The POI database contains 223,595 POIs, categorized into 14 major groups and 81 subcategories. These 14 major categories include: Retail and Wholesale, Companies and Enterprises, Public Facilities, Attractions, Restaurants, Hotels and Entertainment Facilities, Government and Organization Places, Medical and Healthcare, Sports and Cultural Facilities, Textile and Food, Residences, Research and Educational Buildings, Financial and Insurance Offices, and Transportation. This study focuses on exploring POIs related to the built environment, primarily Accommodations, Scenic Spots, Transportation Facilities, Green Spaces, Public Services, and Catering Services (Figure 5).

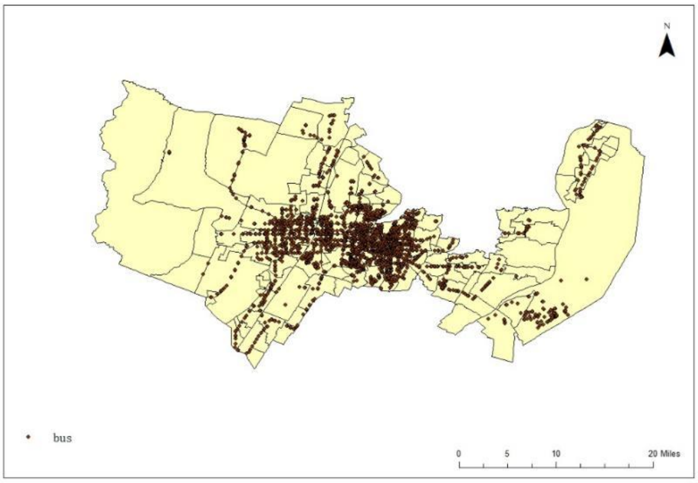

Figure 5 POI Data

iv. Baidu Heat Map

This article utilizes Python to develop a web scraping program, fetching Baidu heat map data every 2 hours. The data has a spatial resolution of 25 meters and includes four fields: acquisition time, longitude, latitude, and count. The "count" field incorporates population weight information (Figure 6).

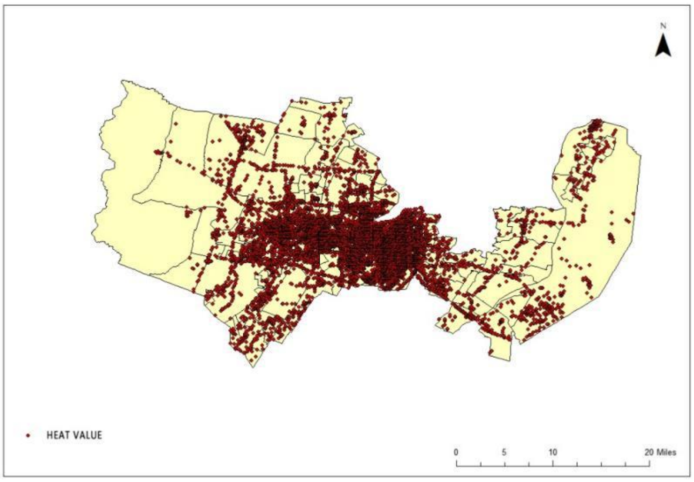

Figure 6 Baidu Heat Map Data

v. GDP and Population

The socio-economic data employed in this study primarily encompasses the resident population count for each village or community as a population indicator, along with Gross Domestic Product (GDP). GDP is used in this paper as an indicator of the economic level of a country or region. Population indicators and GDP data can be obtained from the 2022 Yinchuan City Statistical Yearbook (Figure 7,Figure 8).

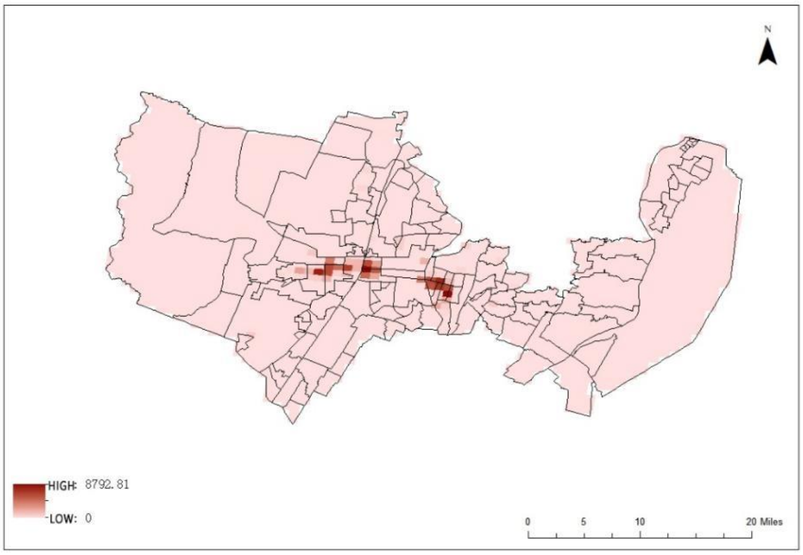

Figure 7 GDP Data

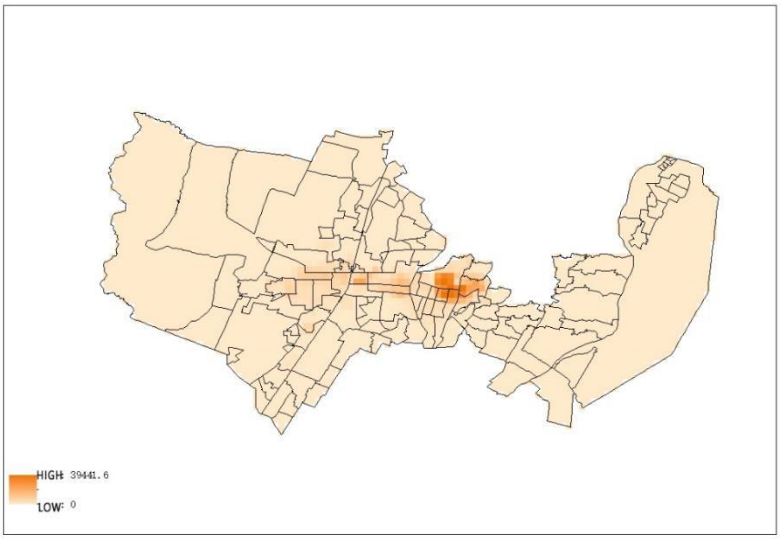

Figure 8 Population Data

vi. Nighttime Lights

The nighttime light data used in this study is the 2022 annual average radiance composite image produced by the NOAA/NCEI Earth Observation Group (https://ngdc.noaa.gov/eog/viirs/). The spatial resolution is 15 arc-seconds (approximately 500 meters), and it is based on the VIIRS Day/Night Band (DNB) nighttime lights data. NPP-VIIRS nighttime light data has the advantage of capturing low-intensity lights from small-scale residential areas, traffic flow, and fires, making it an effective data source for monitoring human activities on the Earth's surface. It has been widely applied in various research areas, including urban expansion, economic assessments, population density, and energy consumption[102, 103]. This paper refers to the officially released 2022 NPP-VIIRS nighttime light image (Figure 9).

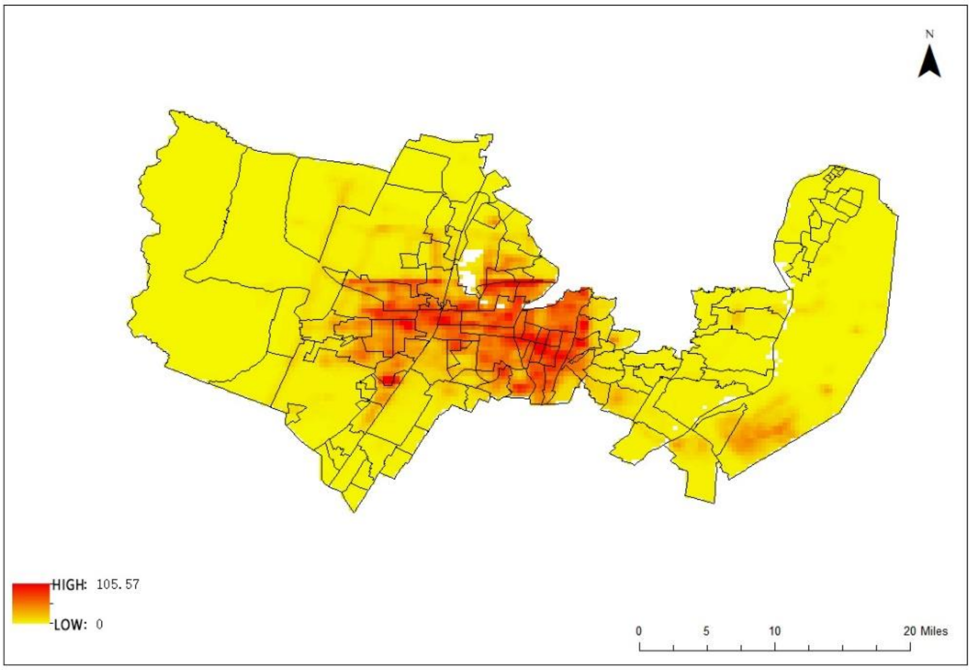

Figure 9 Nighttime Lights Data

vii. Baidu Street View

The Baidu Street View data is sourced from Baidu Online Maps (https://map.baidu.com). It is obtained through web scraping using Python and has undergone data cleaning processes (Figure 10).

Figure 10 Baidu Street View Data

viii. Open Street Map

The road network data is downloaded from the Open Street Map (OSM) open-source mapping platform, as shown in Figure 11. OSM is a large Volunteered Geographic Information (VGI) project known for its real-time and extensive coverage, as well as being freely shareable. Scholars have extensively researched the quality and reliability of OSM data, comparing it with other mapping platforms such as Google Maps, Baidu Maps, survey maps, and navigation maps. The results show that OSM's road data quality is high in both Chinese and international urban areas. The OSM road data includes fields such as road ID, class, name, and more. The "Class" field contains information about road levels, with a total of 24 road types in the main urban area of Yinchuan. For specific road categories and descriptions, refer to Table 3.

Figure 11 OSM Road

Table 3 OSM Road Classifications

Road Level	**Description**
Expressway	Major roads with high-speed capabilities, typically used for long-distance traffic.
Major Road	Main roads in major cities or regions, carrying a significant traffic flow.
Minor Road	Less significant city roads used to connect major roads and smaller streets.
General Road	Regular roads in urban or rural areas.
Pedestrian Street	Areas designed exclusively for pedestrian walking.
Sidewalk	Areas on both sides of the road designated for pedestrian walking.

Table 4 Data Sources

Data	**Sources**	**Definition**
Geographic information data	http://www.ngcc.cn/	Includes administrative boundaries of cities, districts and counties, water system data and road data.
NDVI	http://www.gscloud.cn/	Reflects the condition of vegetation cover and natural landscape in urban areas.
POI data	https://ditu.amap.com/	Represents various types of functional facilities that contain information, categories, and other attributes of the location.
Baidu heat map	http://map.baidu.com/	Through the degree of color change intuitive response to the distribution of hot spots, regional aggregation, and other data information, can reflect the degree of concentration of pedestrian flow, etc.
GDP	http://www.resdc.cn/	Reflecting the level of economic development.
Nighttime Lights	https://ngdc.noaa.gov/eog/viirs/	The Changing Nighttime Lights of the World poster depicts the lights from cities, gas flares, fishing boats, the southern aurora, and fires.
Baidu street view	https://map.baidu .com	High-definition panoramic images of selected city streets can be viewed.
Open Street map	https://www.openstreetmap.org	Digital map of Yinchuan's urban road network.

3.2.2 Data Preprocessing

For data from different sources, various preprocessing steps are applied, including coordinate transformation, data cleaning, conversion to vector point data, and topological checks. The geographical coordinate system is first standardized to the WGS84 coordinate system and then projected into the UTM projection coordinate system. Data cleaning involves removing outliers, handling missing values, and similar tasks. Topological checks are primarily applied to line and polygon data. Depending on the research requirements, preprocessing for road network data and POI involves additional steps such as supplementary merging, adjustment of the POI classification system, and the establishment of road network structures.

i. Establishment of Road Network Structure

Topological relationships are established for the original road network, creating a topological layer. Using topological tools, roads are broken at intersections. Based on this, a network dataset is created, resulting in a point dataset containing intersection points and hanging points, along with a line dataset for road segments. Spatial connections are established separately between generated point data and original road data and between generated line data. The resulting point data includes a "Join count" field indicating the number of roads connected to each point. The difference between two "Join count" fields is calculated, and points with a difference of 2 are removed, representing points where roads intersect in three dimensions, such as overpasses, pedestrian bridges, and subways. Points with a connection count less than 2 are also removed, representing road endpoints (hanging points). This process results in a point layer containing only road intersection points.

ii. Reclassification of POI Data

The POI data obtained for Yinchuan in 2022 includes attributes for various functions such as dining services, road-related facilities, geographical names and addresses, scenic spots, public facilities, companies, shopping services, transportation facilities, financial and insurance services, education and cultural services, motorcycle services, automobile services, automobile maintenance, automobile sales, business residences, life services, indoor facilities, sports and leisure services, passageway facilities, healthcare services, government institutions and social groups, and accommodation services, totaling 22 categories. In accordance with urban land classification and research requirements, some irrelevant data is excluded, and the POI function types are further divided into six categories: residential land use, government and public facilities land use, education and cultural land use, commercial and financial land use, administrative office land use, and commercial consumption land use[104], as shown in **Table 5** for specific types.

Table 5 Table of POI Classification

Main Category	**Subcategory**
Residential Land Use	Geographical Names and Addresses, Residential Areas, Business Residences
Government and Public Facilities Land Use	Government Institutions and Social Groups, Healthcare Services
Education and Cultural Land Use	Scenic Spots, Public Cultural Facilities, Education and Cultural Services, Education and Training
Commercial and Financial Land Use	Financial and Insurance Services, etc.
Administrative Office Land Use	Companies and Enterprises
Commercial Consumption Land Use	Dining Services, Shopping Services, Motorcycle Services, Automobile Services, Automobile Maintenance, Automobile Sales, Life Services, Sports and Leisure Services, Accommodation Services

3.3 Data Processing

By studying the literature, this paper takes the built environment 5D indicators (Density, Diversity, Design, Distance to transit, Destination accessibility) as the basis of the framework. This paper utilizes Arc GIS10.7 spatial data analysis platform and machine learning to study the factors affecting urban vitality in Yinchuan City.

As shown in **Figure 12**, the data processing process has three stages. It includes data collection, feature extraction, and influence factor analysis to extract urban vitality influencing factors. First, in the data collection stage, the Baidu map open platform API interface is utilized to collect city network data, POI data, population thermal data, street view image data, etc. The basic database is constructed through these big data. Second, the factors affecting urban vitality are extracted from the basic database. Finally, get the influencing factors through GIS and machine learning. (1) Extract the heat data of active people on weekdays and days off through Baidu heat map to measure the crowd density index. (2) Utilize the Geode POI data and analyze the density through GIS Kernel Density Analysis. And derive six indicators of public facilities, food, landscape, transport facilities, shopping, and hotel. (3) Open Street Map extracts the road network structure of Yinchuan City and obtains Baidu Street View images from Baidu Maps through Python. Use DeepLabV3 to extract elements from the street view image and utilize the semantic segmentation technology of street view image. Obtain the five measurement factors of openness, greenness, enclosure, walkability, and imageability. (4) Obtain the distance to transit indicator by using Baidu Map to obtain the bus stops and bus routes. (5) The structure of road network in Yinchuan City was extracted by Open Street Map. Analyze the traffic accessibility by using SDNA in GIS platform and get the destination indicator. A total of 17 influencing factors are obtained.

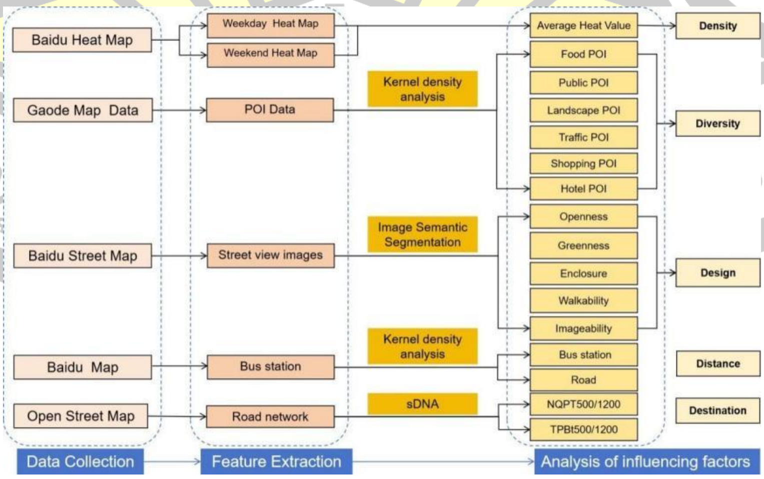

Figure 12 Data Collection and Processing

3.4 Conceptual Framework

This paper takes the township/street as the unit of analysis and combines multi-source urban data. Based on constructing the influencing factors of built environment in Yinchuan City, machine learning and spatial analysis techniques are utilized to reveal the relationship between built environment and urban vitality. The first steps taken in this paper are as follows (**Figure 13**):(1) Calculate the variables and analyze the correlation to find the appropriate variables. Calculate the dependent variable urban vitality by using entropy method. (2) Analyze the global relationship between built environment and urban vitality by using OLS model. (3) Calculate Moran's I of the residuals of the OLS model using GIS software to test the spatial autocorrelation. (4) If there is spatial autocorrelation, it is necessary to explore the spatial change relationship using spatial regression model. (5) The GWR spatial regression model is used to explain the spatial variation relationship. (6) The GBDT model was used to rank the importance of the variables affecting the urban vitality.

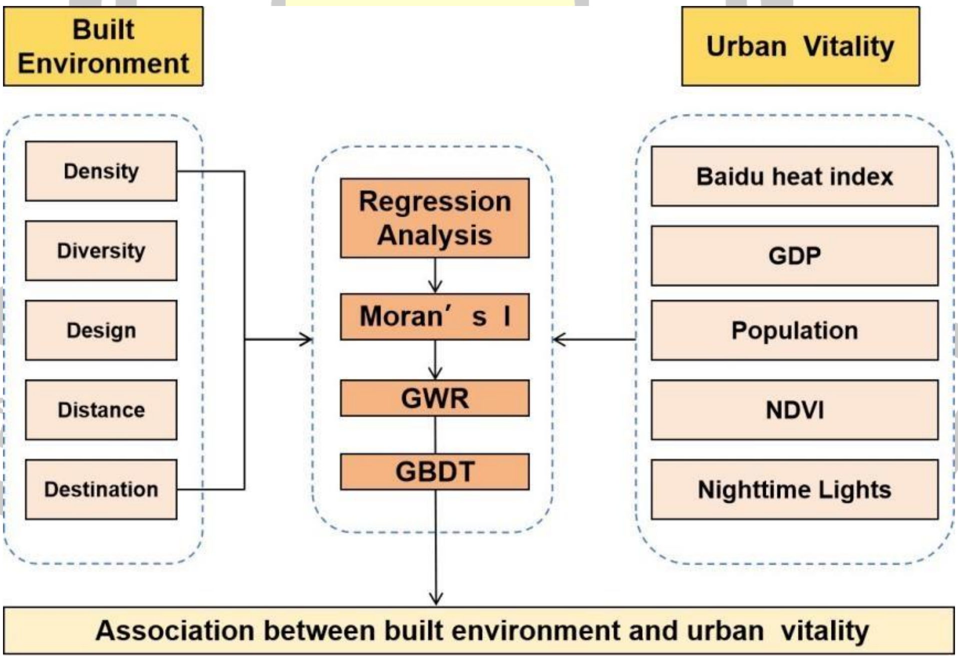

Figure 13 Conceptual Framework

3.5 Selection of Variables

This paper further constructs a model to study the relationship between urban built environment and urban vitality. Urban spatial vitality indicators are constructed from the 5D variables (Density, Diversity, Design, Distance to transit, Destination accessibility) of the built environment. The dependent variable is urban vitality. The independent variables are the indicators that characterize the built environment of the city.

3.5.1 Dependent Variables

The dependent variable in this paper is urban vitality, which is mainly the density variable in 5D. It includes five variables for NDVI, GDP, Population, Baidu heat map, and night lighting data. After the variable data were processed with abnormal values and data standardization, the five dependent variables were weighted by the entropy method. The entropy method is the calculation of the weight (importance) of each variable.

Urban vitality is mainly measured from the active population density. Crowd density refers to the concentration of active people, this paper uses Baidu heat value to measure the density of crowd activity. Baidu heat index comes from Baidu heat map. Baidu Heat Map data reflects the population concentration in different areas with different colors and brightness. The brighter the red area, the higher the population density. The brighter the blue area, the lower the population density. Baidu Heatmap is updated every 15 minutes to get real-time dynamic information on population distribution. As a big data application with hundreds of millions of users, Baidu Heatmap is valuable for urban research[105]. Baidu heat map can measure the mobility of people in urban space or the vitality of different areas[105-107].

This paper takes the three districts of Yinchuan City as an example. On the Baidu heat map, the population heat value of Wednesday, July 19, 2023, is selected, and the value is taken every two hours from 8:00 to 20:00, totaling seven times, as shown in Figure 14. The population heat value for Saturday, July 22, 2023, was selected and again taken every two hours from 8:00 to 20:00, for a total of seven times, as shown in Figure 15. Thus, the population thermal values were taken for a total of 14 data occasions. The average heat values for July 19 and July 22 were calculated using Arc GIS 10.7 software, and for the purpose of calculating the population spillover, the average heat value for July 22 was subtracted from the average population heat value for July 19. We used the average density of the collected Baidu heat index to calculate this.

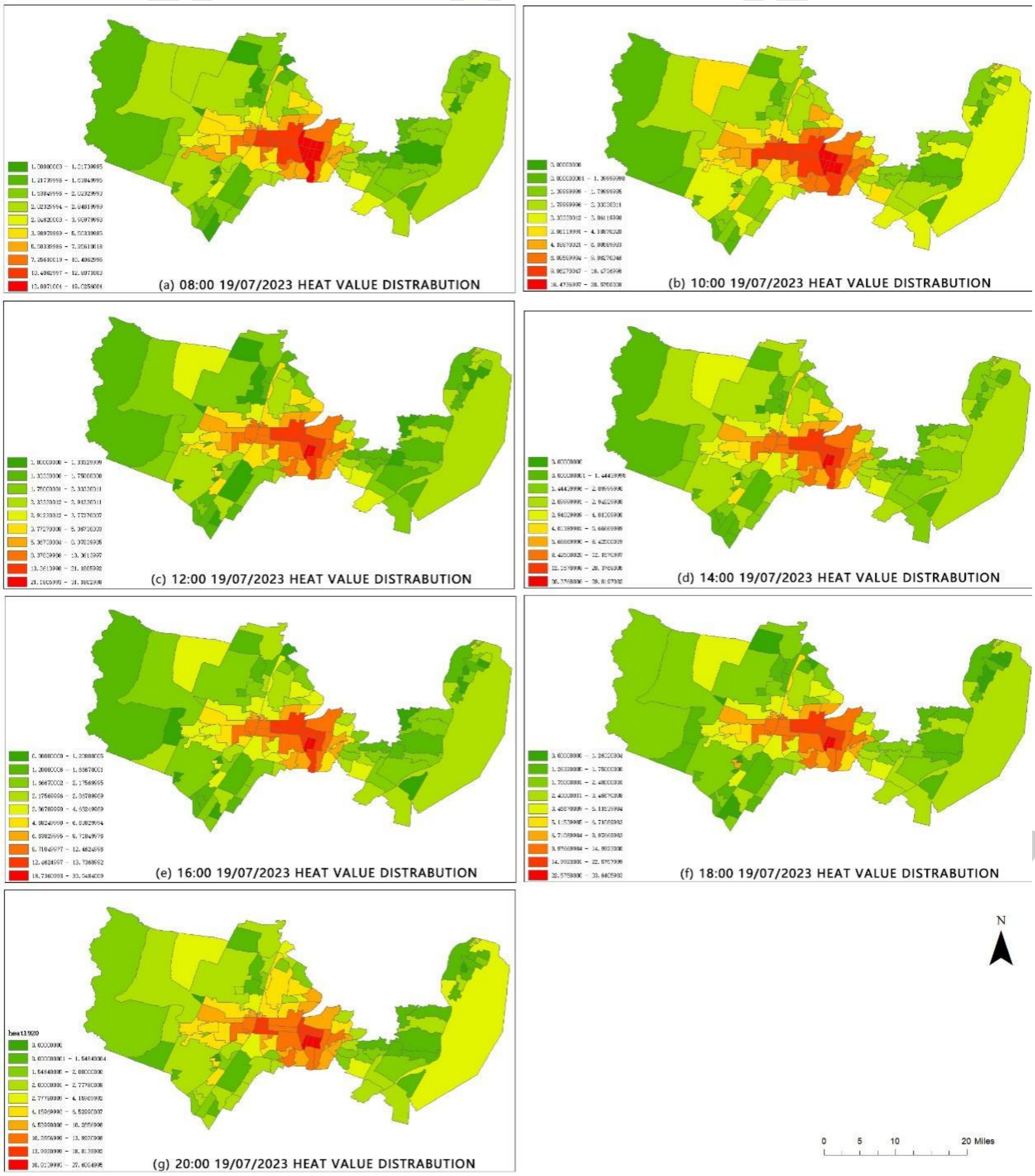

Figure 14 Weekday (07/19/2023) Heat Value Distribution

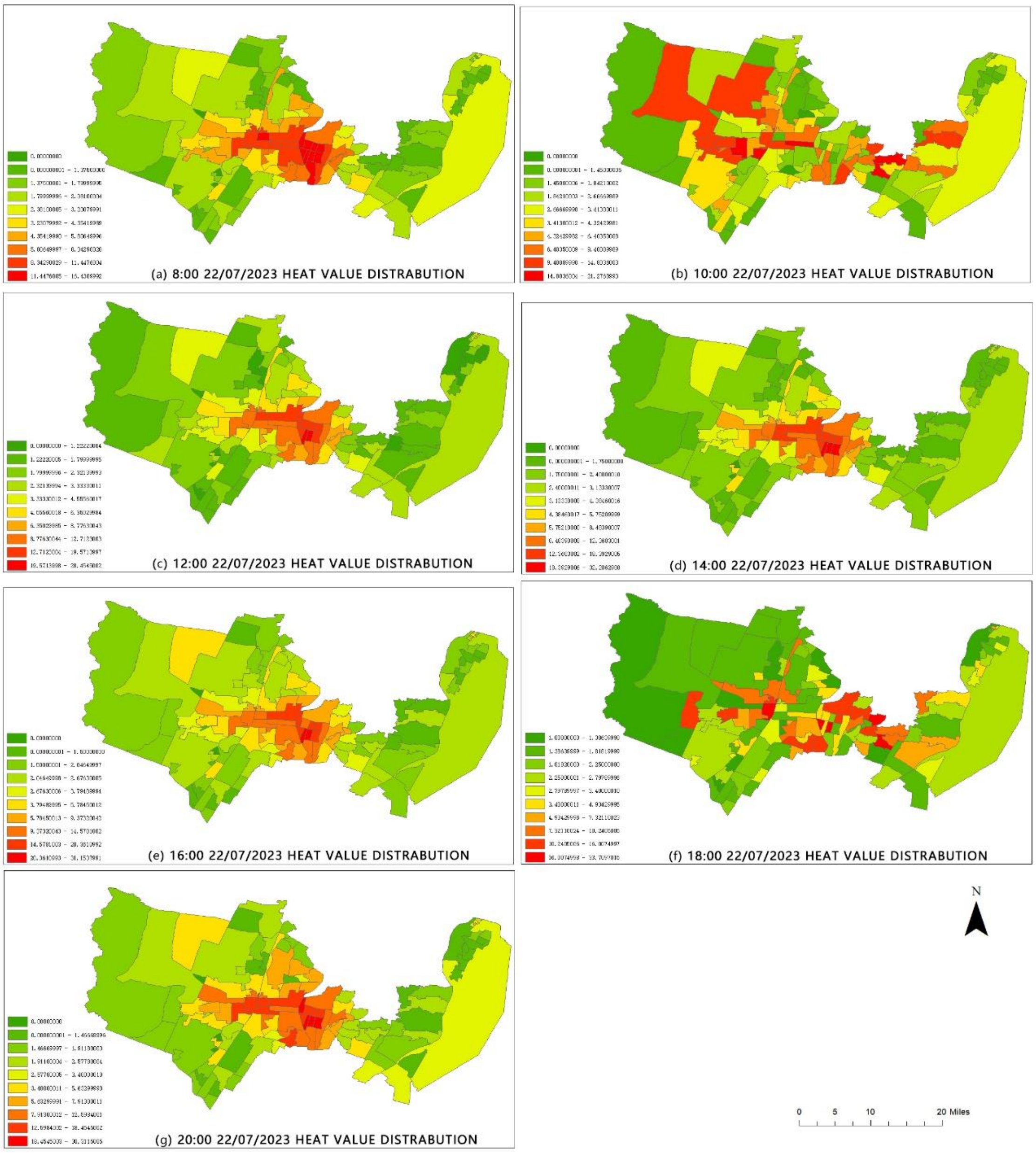

Figure 15 Weekend (07/22/2023) Heat Value Distribution

3.5.2 Independent Variables

3.5.2.1 Diversity

According to the POI classification code of Geode Map, a total of 23 categories of POI data in Yinchuan City are obtained, which are catering, shopping, landscape, public facilities, companies, financial and insurance services, science, education and culture services, traffic facilities, business housing, living services, sports and leisure services, accommodation services, healthcare services, and governmental institutions or social organizations. In this paper, we choose 6 POI data of public services, hotel services, shopping services, food services, traffic services, and landscape services, which total 25,270 POI points (Table 6).

Table 6 Numbers of POI

Type	Counts
Food POI	21392
Traffic POI	82
Public POI	365
Hotel POI	2384
Shopping POI	365
Landscape POI	682
Total	25270

3.5.2.2 Design

This paper uses a human perception-based metric to measure-built environment design from urban space. The street view data used for the study was obtained from Baidu online map. Observation points were set along the road approximately every 30 meters in Baidu map, and Baidu Street View was obtained from Baidu map via Python, as shown in Figure 16. Elements were extracted from the street view images using Deep Lab V3+ and the corresponding ADE20K pre-trained scene resolution dataset for image segmentation. Eventually, a total of 139,684 street view images were collected in the study area. Then, a deep learning based semantic segmentation technique was applied to segment the street scene images into common features, as shown in Figure 17. A total of 150 common features such as wall, building, sky, floor, tree, ceiling, road, grass, sidewalk, person, mountain, car, water, and house are segmented. Finally, the street visual perception metrics are calculated based on the optimized formula. In this paper, based on previous studies, we mainly extracted five design metrics, including openness, greenness, enclosure, walkability, and imageability. Greenness refers to the proportion of green pixels in an image, which reflects the number of green plants such as trees and shrubs in urban space[108]. Openness indicates the proportion of blue pixels in the image. Enclosure represents the human scale. The vertical element describes the degree of enclosure[109]. Walkability is the outdoor walkable environment, in this case the proportion of sidewalks [109] . Imageability represents reflects the richness of the built environment and street furniture[110]. The calculation formula is shown in Table 7.

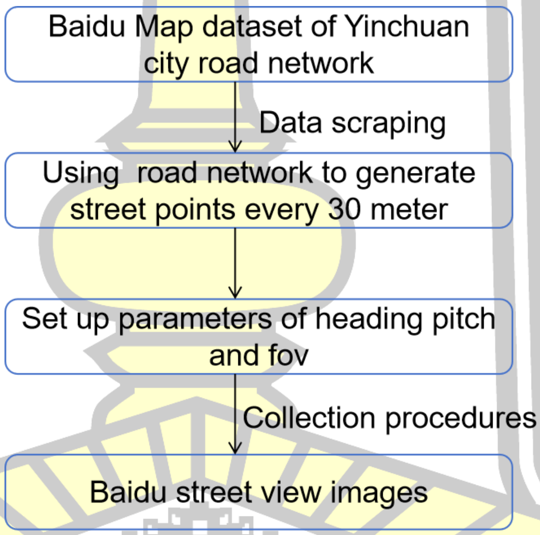

Figure 16 Baidu Street View Images Collection Processing

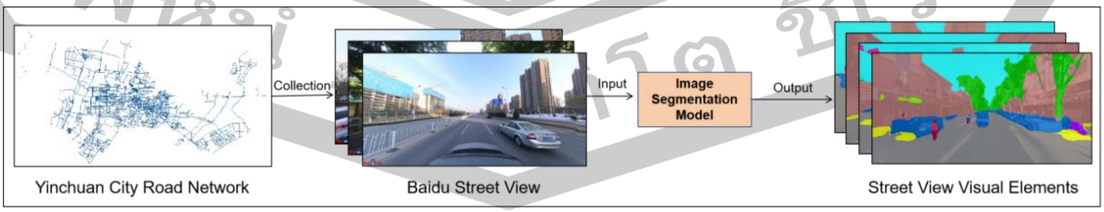

Figure 17 Baidu Street View Images Image Segmentation

Table 7 Variables Formulas and Explanations for Scores of Indices

Variables	**Name**	**Max**	**Min**	**Mean**	**S.D.**	**Formula**	**Explanation**
Design	Openness	46.394	0	15.684	16.918		
	Enclosure	0.499	0	0.152	0.171	$E_i = \frac{\sum_{i=1}^{2}(B_i + T_i + W_i + F_i)}{\sum_{i=2}^{2}(1 - S_i)}$	Bi denotes the proportion of building pixels, Ti denotes the proportion of tree pixels, Wi denotes the proportion of wall pixels, Ri denotes the proportion of road pixels, and P1i denotes the proportion of sidewalk pixels. Fi denotes the proportion of fence pixels.
	Walkability	0.162	0	0.007	0.024	$W_i = \frac{\sum_{i=1}^{2} Pl_i}{\sum_{i=1}^{2}(R_i + Pl_i)}$	
	Greenness	46.078	0	9.252	11.275	$G_i = \frac{\sum_{i=1}^{2} GP_i}{\sum_{i=1}^{2} P_i}$	G Pi denotes the proportion of green pixels, including plant, tree, and grass; Pi is the total number of pixels in image I.
	Imageability	8.218	0	1.22	1.869	$I_i = \frac{1}{2}\sum_{i=1}^{2}(S_i + Sl_i + B_i + P2_i + Bl_i)$	Si denotes the proportion of signboard pixels, S1i denotes the proportion of sculpture pixels, P2i denotes the proportion of person pixels, B1i denotes the proportion of bench pixels.

3.5.2.3 Distance to Transit

According to the literature, we use bus stop density, road density to measure Distance to transit variable. Road network is a common indicator for evaluating urban accessibility. A good road network enhances communication within the city, reduces transportation costs, and provides commuting options for citizens. Bus stops are considered as the main pillars of the public transportation system. The road network data was obtained from the Open City Map (OSM) website. The road network data of Yinchuan City in 2022 was collected from the map website using Python, and the road network data was cleaned and simplified using Arc GIS. The original road network data were first simplified to obtain single-lane roads, and the roads were interrupted at the folding points to form sections without intersections. Then the simplified road network is topologically processed to extract the road centerline, and finally the road network dataset is generated.

Jacobs pointed out that a thriving community requires dense population distribution and economic connectivity[111]. Transportation infrastructure forms the basis of individuals' mobility within urban spaces. According to the literature, we measure transportation accessibility using bus station density, road density, and the distance to the nearest public transportation station.

i. Road network Data

We obtained road network data for Yinchuan City in 2022 from the Open Street Map (OSM) website. OSM data for major Chinese cities are regularly updated with relatively high quality. Previous studies have utilized this data to measure the built environment and characterize urban morphology and functionality. The road network data used in this study was collected using Python web scraping techniques from map websites[57].

The road network data was cleaned and simplified using Arc GIS. Initially, the raw road network data was simplified to obtain single-line roads, breaking them into segments without intersections at bend points. Then, the simplified road network underwent topological processing to extract road centerlines, ultimately creating the road network dataset.

Therefore, this study identified 62 streets, comprising 2 express roads, 3 main roads, 8 secondary roads, 10 branch roads, and 38 alleys, totaling 215 road segments as the sample road network data for the study of street spatial quality.

ii. Bus Stations

Based on existing research, convenient external transportation systems (such as rail transit or public transportation, favorable for residents' long-distance travel) can lead to a decrease in community vitality[112]. Additionally, it is necessary to measure the accessibility of bus services.

Bus transportation accessibility primarily refers to the distribution of bus stations within the village. This study uses the number of bus stations to measure bus accessibility, totaling 349 bus stations.

3.5.2.4 Destination Accessibility

Table 8 Descriptive Statistics of SDNA Variables

NAME	MAX	MIN	MEAN	S.D.
NQPDA-500	1.057	0.001	0.044	0.109
TPBT-500	3.289	0.333	0.682	0.481
NQPDA-1200	1.324	0.001	0.037	0.091
TPBT-1200	7.135	0.203	1.705	1.136

In this paper, the SDNA (Special Design Network Analysis) network analysis tool developed by Alain Chiaradia et al. from Cardiff University, UK, is used to analyze the accessibility, aggregation and other indicators of the road network based on the Arc GIS 10.7 platform. According to the research needs, 0.5km and 1.2km were used as the research radius to simulate the activity range of walking and driving in Yinchuan City Road network. Network Quantity Penalized by Distance of Angular (NQPDA); Two Phase Betweenness (TPBT) were finally selected as the two main indicators. In SDNA, a larger value of NQPDA represents more distance, which means less accessibility, as shown in Table 8. Road networks with high NQPDA values have greater aggregation and accessibility's is usually used to measure the probability of traffic flow crossing within the search radius of a road network and can reflect the potential of people to engage in traversing activities in an urban network. A higher value means that the road network is more passable and will carry more passive pedestrian and vehicular traffic.

All dependent and independent variables are as shown in the table below, as shown in Table 9.

Table 9 Variables Formulas and Explanations for Scores of Indices.

Variables	Name	Max	Min	Mean	S.D.
Density	Weekday Average Baidu heat	17.558	0	4.025	4.007
	weekend Average Baidu heat	18.064	0	4.576	3.642
	Average Baidu heat	1.69	-1.095	0.264	0.436
	NDVI	122.36	60.886	90.659	11.514
	GDP	10.314	0	2.136	1.418
	Population	10.425	0	2.198	1.515
	Nighttime Lights	9.319	0	2.076	1.366
Distance	Road	8.949	0	2.171	1.576
	Bus station	232899.236	0	11501.097	28805.073
Diversity	Landscape POI	8078.905	0	1195.819	1480.324
	Food POI	499551.794	0	19488.477	59555.69
	Public POI	19000.471	0	1460.621	2775.859
	Hotel POI	51599.994	0	1501.369	5269.166
	Shopping POI	1316021.413	0	64409.869	171860.849
	Traffic POI	167237.744	0	9502.934	21628.692
Design	Openness	46.394	0	15.684	16.918
	Enclosure	0.499	0	0.152	0.171
	Walkability	0.162	0	0.007	0.024
	Greenness	46.078	0	9.252	11.275
	Imageability	8.218	0	1.22	1.869
Destination	NQPDA-500	1.057	0.001	0.044	0.109
	NQPDA-1200	1.324	0.001	0.037	0.091
	TPBT-500	3.289	0.333	0.682	0.481
	TPBT-1200	7.135	0.203	1.705	1.136

3.6 Regression Model

This paper uses a linear regression model. The dependent variable is urban vitality, and the independent variables include the 5D built environment indicators. The global regression uses Ordinary Least Squares (OLS) regression model to measure the impact of 5D variables on urban vitality. Linear regression reveals the relationship between the dependent and independent variables[113].

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$$y = \beta_0 + \sum_{i=0}^{n} X_i Y_i + \varepsilon \tag{1}$$

where y is the dependent variable, X_i and Y_i are the independent variables, and ε is the residual.

3.7 Spatial Autocorrelation

Spatial autocorrelation analysis is an indicator reflecting spatial distribution, including spatial global autocorrelation and spatial local autocorrelation. Global autocorrelation analysis can reveal the spatial correlation situation of urban vitality, including three states of discrete, random and agglomeration, which is usually expressed by Moran's I index. The formula is as follows.

$$I_1 \frac{n}{\sum_{i=1}^{n}(X_i-\overline{X})^2} \frac{\sum_{i=0}^{n} X_i \sum_{i=0}^{n} X_i w_{ij}(X_i-\overline{X})(X_j-\overline{X})}{\sum_{i=0}^{n} X_i \sum_{j=0}^{n} X_i w_{ij}}$$

(2)

Local spatial autocorrelation analysis can further explain the discrete or agglomeration status of urban spatial vitality on a local spatial scale. It is usually represented by LISA agglomeration map. The formula is as follows.

$$I_2 = \frac{n(X_i-\overline{X})\sum_{j=1}^{n}(X_i-\overline{X})}{\sum_{i=1}^{n}(X_i-\overline{X})^2} \tag{3}$$

Where: n is the number of cities; x_i and x_j are the spatial vitality of the city; x is the average value of the vitality of urban tourist places; w_{ij} is the spatial weight matrix. When $-1 < I < 0$, there is a negative correlation and a discrete distribution; when $I = 0$, there is no correlation and a random distribution; when $0 < I < 1$, there is a positive correlation and a clustered distribution.

3.8 GWR Model

The spatial heterogeneity of the individual variables of the Ordinary Linear Regression (OLS) model cannot be captured. To make the obtained results more realistic, this paper uses Geographically Weighted Regression (GWR) for analysis. This model is a local regression model in which the geographic coordinates of the samples to be studied are added to the regression parameters. It can capture the spatial heterogeneity of the impact of the respective variables on urban vitality. It has a better goodness of fit and observational effect than the OLS model. The specific expression of the GWR model is as follows.

$$y = \beta_0(a_i, b_i) + \sum_{i=1}^{n}\beta_k(a_i, b_i) + \varepsilon_i; i = 1,2, \dots\dots n \tag{4}$$

Eq:

y_i ——the value of the i dependent variable.

(a_i, b_i) ——coordinates of the i space.

$\beta_0(a_i, b_i)$—— the regression constant for the i-th space;

$\beta_k(a_i, b_i)$ —— coefficient of the j-th independent variable in the i-th space;

X_{ik} —— the k-th independent variable in the i-th space.

m —— number of independent variables.

ε —— random error.

3.9 GBDT Model

A gradient-enhanced decision tree (GBDT) is used to examine the relationship between built environment variables and urban vitality. The GBDT method, originally developed in computer science [114] , has strong predictive power and the ability to account for nonlinear relationships between variables. The relative importance of predictors can be presented. Relative importance measures the contribution of the independent variable to predict the dependent variable and it helps to compare the contribution of built environment variables to urban vitality.

$$f(x)=\sum_{m=1}^{M} f_m(x)=\sum_{m=1}^{M} \beta_m h(x;a_m) \tag{5}$$

The algorithm for gradient boosting, as proposed by Friedman (2001) and summarized in subsequent works, involves the following analysis steps:

i. Establish a Gradient Boosting Decision Tree (GBDT) regression model using the training set data.

ii. Calculate the feature importance using the established GBDT.

iii. Apply the established GBDT regression model to both training and testing data to obtain model evaluation results.

iv. Due to the inherent randomness of Gradient Boosting Decision Trees (GBDT), the results may vary in each computation. To address this, saving the current training model allows for subsequent direct uploading of data to perform calculations and predictions with the saved model. GBDT does not yield a deterministic equation like traditional models. Therefore, model evaluation is typically conducted based on the predictive accuracy on test data.

3.10 Entropy Weight Method

The entropy value method is based on the degree of change of each index item in the system, using the information entropy tool to calculate the weight of each index[21] , and finally get the value of urban vitality evaluation. The weights determined by the entropy method are derived from the data, effectively avoiding the subjectivity in the determination of weights. It has been widely used in systematic evaluation in various fields[115, 116].

$$w_i = \frac{1-E_i}{\sum_{i=1}^{m} 1-E_i} \tag{6}$$

The method first involves the standardization of measurement values. In the second step, the ratios of each indicator under different scenarios are calculated. The third step entails determining the information entropy for each indicator, computed using the information entropy formula. Lastly, the weights of each indicator are derived through the calculation of information entropy.

Chapter4 Results and Analysis

4.1 Dependent Variable Results

As shown in **Figure 18**,The population and GDP exhibit a predominant concentration in the central urban areas. The region with the highest population is Xing Qing District, followed by Jinfeng District, and the lowest population is in the Xi Xia District. The distribution of GDP closely mirrors the population distribution, with Xing Qing District having the highest GDP, followed by Jinfeng District, and Xi Xia District having the lowest. The areas with the highest population and GDP are primarily concentrated in the street offices of Yu Huang Ge North Street, Zhongshan South Street, Wen Hua Street, Xinhua Street, Sheng Li Street, Qianjin Street, Jie Fang West Street, Fu Ning Street, and Feng Huang North Street in Xing Qing District. Next are the street offices of Shanghai West Road, Beijing Middle Road, Great Wall Middle Road, Man Cheng North Street, and Yellow River East Road in Jinfeng District, with the least in Xi Xia District.

Xing Qing District, being the old urban area and the region with the highest economic development level in Yinchuan City, verifies the close relationship between population size and economic development level. The distribution of nighttime lights is also concentrated in the central urban areas, with fewer lights in other regions. The highest aggregation of NDVI occurs in areas such as Yinchuan Landscaping Farm and Ping Ji Bao Dairy Farm in Xi Xia District, as well as the village committees of Zhang Zheng, Yong Nan, and Wu Bo Qiao in Xing Qing District. In Jinfeng District, the prominent areas include Ying Nan Village and Wei Jia Qiao Village. Additionally, significant NDVI concentrations are observed in regions like the Helan Mountain Nature Reserve.

Overall, areas with the largest vegetation cover are in rural regions, followed by the Helan Mountain Nature Reserve, while the central urban areas exhibit comparatively lower vegetation cover. Nighttime lights are primarily concentrated in the central urban area of Yinchuan City.

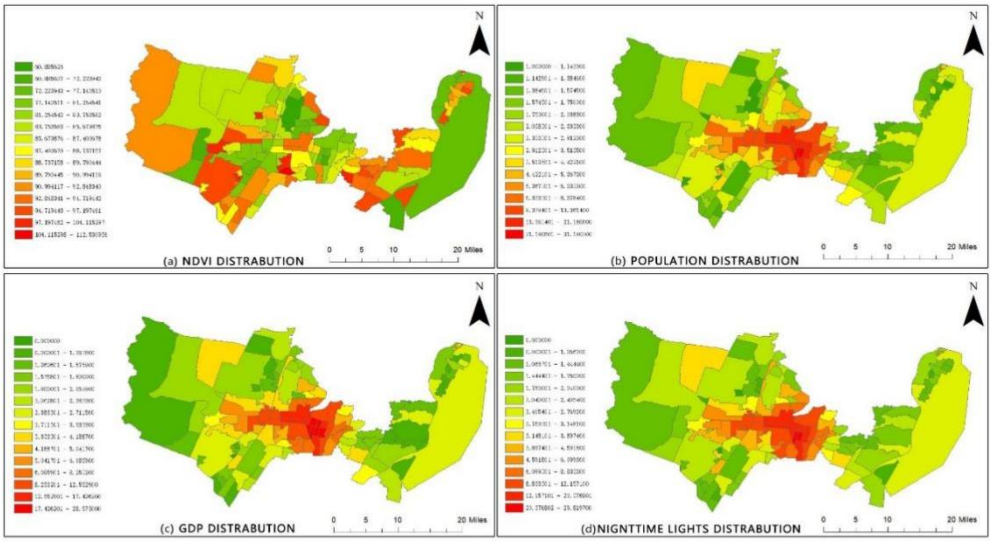

Figure 18 Dependent Variable Results

4.2 Entropy Weighting

After the variable data were subjected to outliers and data standardization, the five dependent variables were weighted by entropy method. The weights of entropy weighting method show that the weight of NDVI is 3.243%, the weight of GDP is 26.699%, the weight of Population is 41.784%, the weight of Nighttime Lighting is 26.61%, and the weight of Baidu heat value is 1.663%, as shown in **Table 10**. Finally, the value of urban vitality is calculated according to the entropy weight method.

Table 10 Entropy Weighting

Term	Information entropy value e	Information utility valued	Weight (%)
NDVI	0.989	0.011	3.243
GDP	0.909	0.091	26.699
Population	0.858	0.142	41.784
Nighttime Lighting	0.909	0.091	26.61
Baidu heat value	0.994	0.006	1.663

In this paper, we use the difference between the average heat value on weekends and weekdays to represent the distribution of people flow density. The results from the distribution of Baidu heat map show in **Figure 19**(b)(c)(d):

From the spatial distribution, the flow of people is mainly concentrated in the center of Xing Qing District, Jinfeng District and Xi Xia District, and there is an obvious trend of high frequency and high-density distribution. On weekdays, at 08:00, the flow of people is mainly concentrated in the center of the city where office buildings are concentrated and reaches its peak at 10:00 and 16:00. And after 18:00, it starts to gather in the residential area. On weekends, the flow of people is mainly concentrated in the urban area at 8:00 p.m. At 10:00 p.m., the flow of people starts to flow out of the center of the urban area and is distributed in all areas.

According to the analysis of population overflow, compared with weekdays, it is obvious that on weekends, the flow of people starts to evacuate outside the center of the city. Between 12:00 and 18:00, the flow of people is mainly concentrated in the center of the city where there is a commercial area and the surrounding rural areas with scenic spots. And after 18:00, the flow of people from the center of the city is dispersed to various areas.

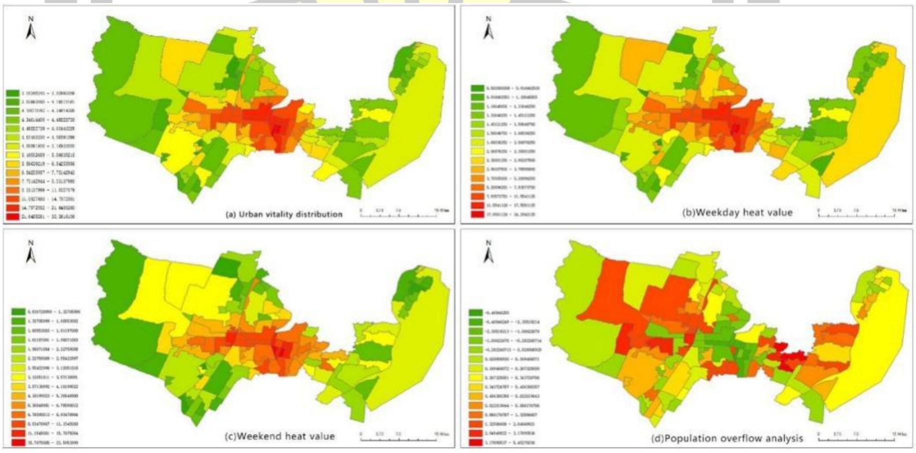

Figure 19 Urban Vitality Distribution

The Urban Vitality Distribution map in **Figure 19** (a) indicates a concentration of vitality in the central districts, with the highest levels in Xing Qing District, particularly in central areas like Yu Huang Ge North Street and Zhongshan South Street. Jinfeng District follows, with its vitality centered around West Shanghai Road and Middle Beijing Road. Xi Xia District exhibits the least urban vitality. The prominence of Xing Qing District as the historical city center and its status as the most economically developed area supports the correlation between urban vitality and economic development, as outlined in the studies by Yue et al. (2021). This underscores the tendency of economic activity to enhance urban liveliness and social interaction within city centers.

4.3 Independent Variable Results and Analysis

The independent variables primarily include diversity, design, distance, and destination, totaling 16 variables.

4.3.1 Diversity

Poi data underwent kernel density analysis and partition statistical analysis using Arc GIS 10.7 software. Six aspects, namely public service, shopping service, transport, food, hotel, and landscape, were analyzed. As shown in **Figure 20**, Food is primarily concentrated in the old city area of Xing Qing District, particularly in Yu Huang Ge North Street, Zhongshan South Street, Wen Hua Street, Xinhua Street, Qianjin Street, Jie Fang West Street, Fu Ning Street, and Feng Huang North Street. In Jinfeng District, it mainly clusters around Man Cheng North Street. Hotel, public service, shopping, mainly concentrate in the street offices of Yu Huang Ge North Street, Zhongshan South Street, Wen Hua Street, Xinhua Street, Qianjin Street, Jie Fang West Street, Fu Ning Street, and Feng Huang North Street in Xing Qing District. Next are the street offices of Shanghai West Road, Beijing Middle Road, Man Cheng North Street in Jinfeng District, and Xi Hua Yuan, Beijing West Road in Xi Xia District. Landscape is primarily distributed in the central urban area, with significant presence in the rural areas of Xing Qing District and Xi Xia District. Transport is mainly distributed in the central urban areas of Xing Qing District, Jinfeng District, and Xi Xia District.

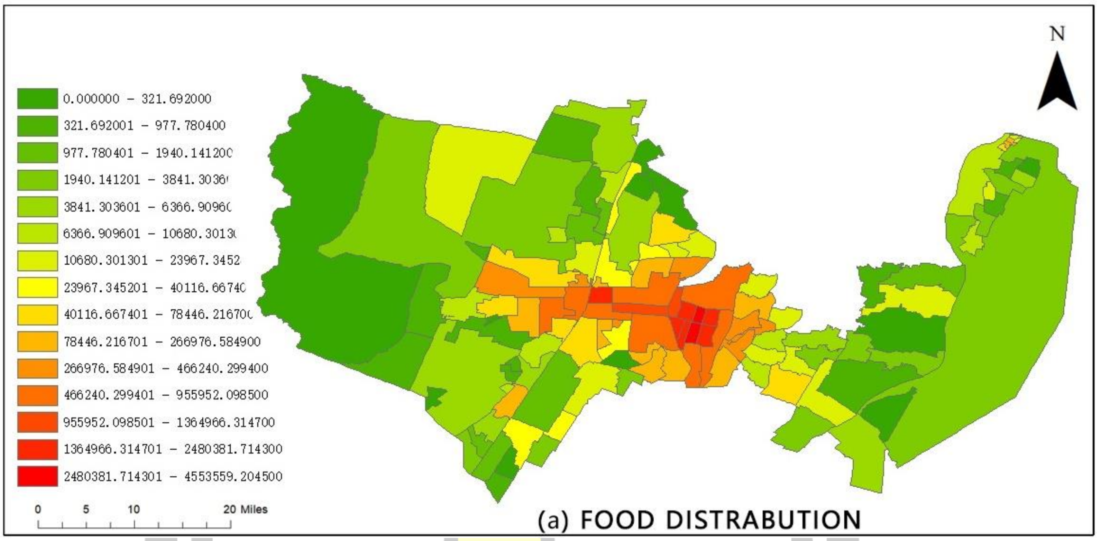

Figure 20 Food Distribution

Public service (Figure 21), Shopping service(Figure 23), Traffic(Figure 25), and Hotel (Figure 22) are mainly concentrated in the central urban area, while other regions are more dispersed. This forms a distribution pattern where the central urban area is clustered, and other areas are scattered. It can be observed that streets with strong urban vitality are distributed in all three districts, with the highest concentration in Xing Qing District, followed by Jinfeng District, and the least in Xi Xia District. The areas with the strongest urban vitality are primarily located in Xing Qing District. Xing Qing District, being the old urban area of Yinchuan City, boasts numerous public facilities and commercial areas. However, with urban development, Yinchuan City has transitioned from a single center in Xing Qing District to multi-center development. Jinfeng District has Jinfeng Wanda as its commercial center, and Xi Xia District has Huai Yuan Night Market as its commercial center. Therefore, in urban planning, more consideration should be given to the balanced development of urban functions.

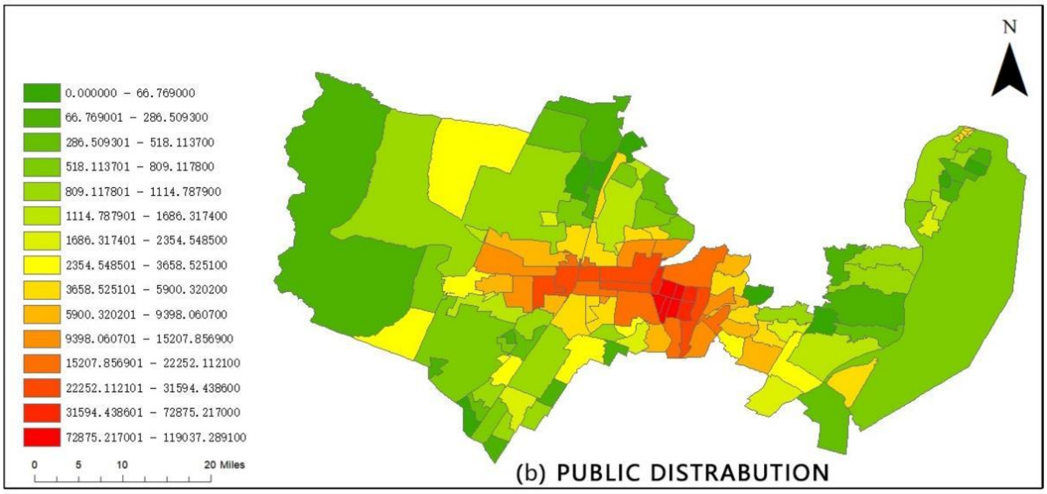

Figure 21 Public Distribution

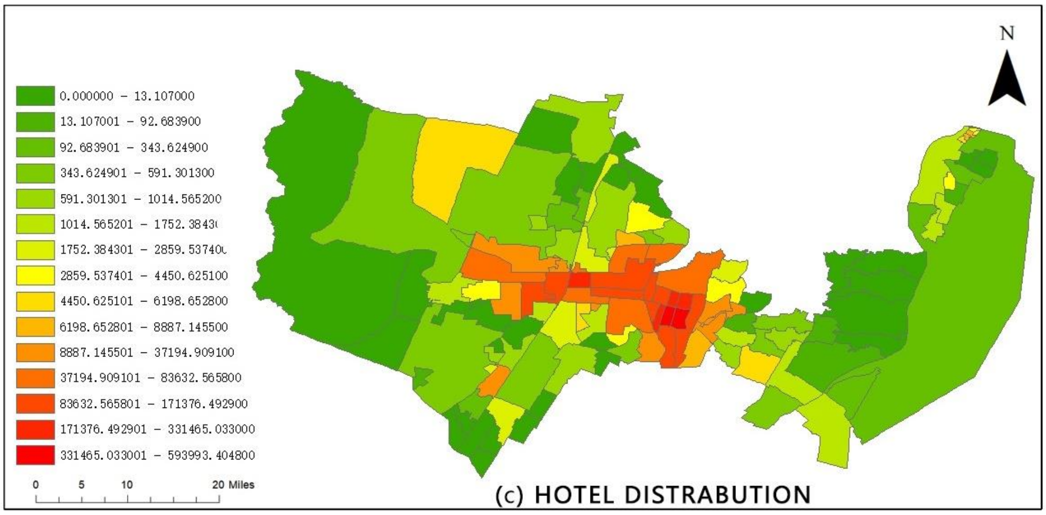

Figure 22 Hotel Distribution

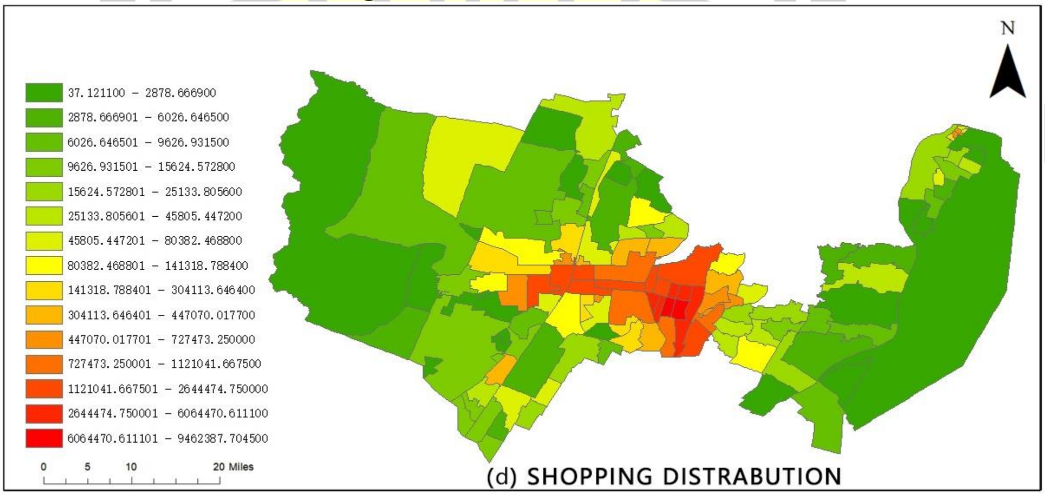

Figure 23 Shopping Distribution

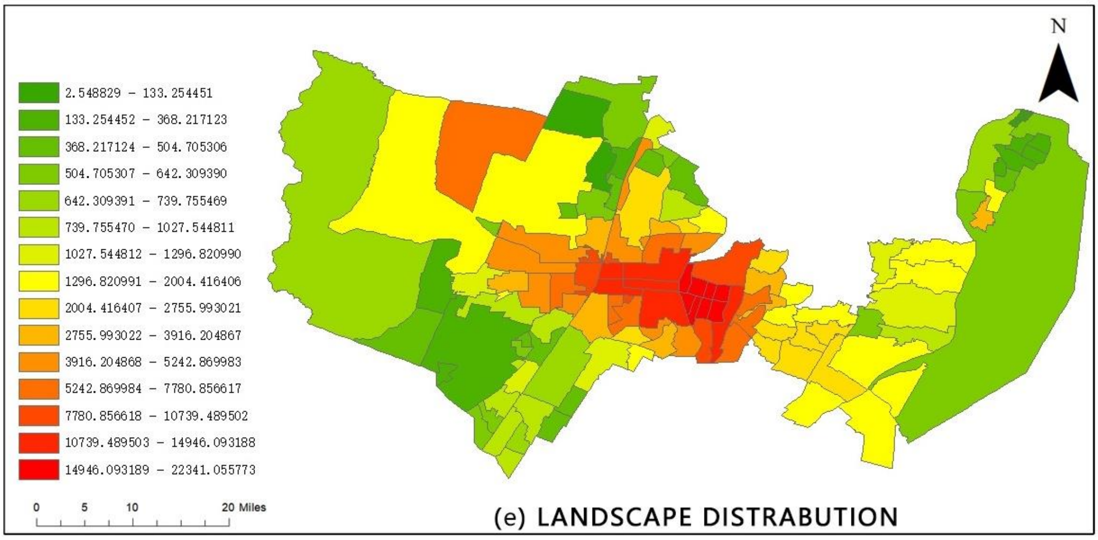

Figure 24 Landscape Distribution

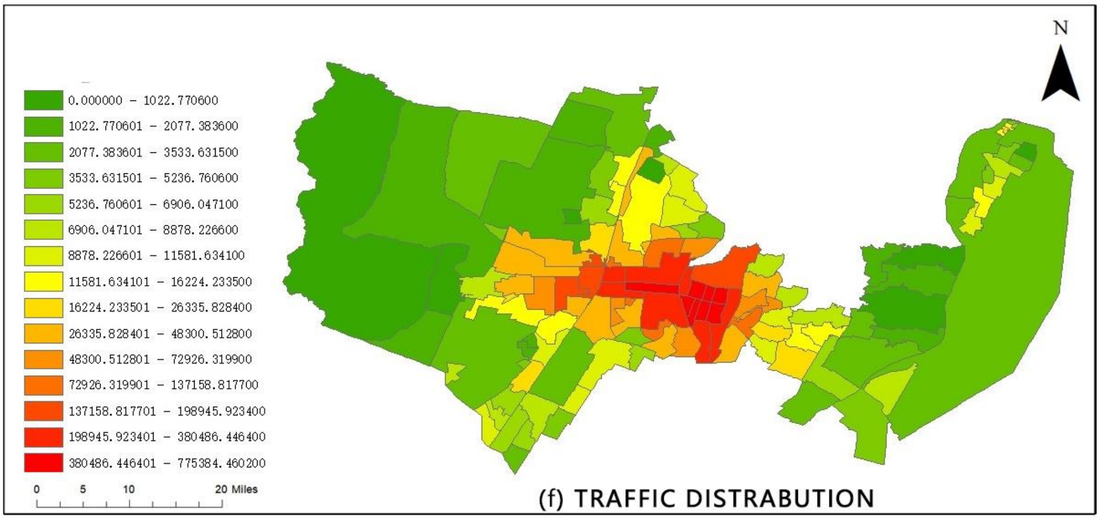

Figure 25 Traffic Distribution

4.3.2 Design

This study extracted five design indicators based on previous research, including Openness, Greenness, Enclosure, Walkability, and Imageability.

As shown in **Figure 26**,areas with higher Openness are mainly located outside the city center, including Tong Nan Village Committee, Jian Fu Qiao Village Committee, Zhen He Village Committee, Daxin Village Committee, Yu Huang Ge North Street, Xinhua Street, and Qianjin Street in Xing Qing District; Wu Li Tai

Village and Zhuan Qu Village in Jinfeng District; and Xi Xia King Mausoleum, Helan Mountain Nature Reserve, Beijing West Road, and Jinghua Village in Xi Xia District.

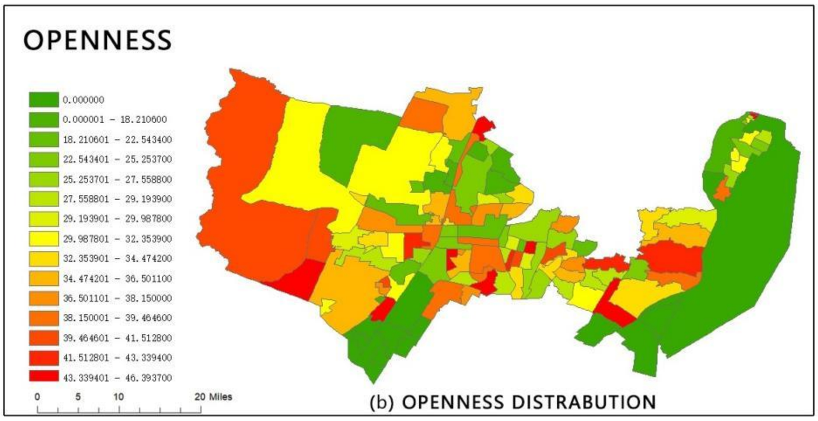

Figure 26 Openness Distribution

As shown in **Figure 27**,Enclosure is predominantly found in areas such as Yue Ya Lake, Mao Sheng Village, Xin Shui Qiao Village, Ta Qiao Village, Wen Hua Street, and Feng Huang North Street in Xing Qing District; Man Cheng North Street, Yong Feng Village, Yue Hai Community, Lian Feng Village, Shanghai West Road, Yellow River East Road, and Wei Jia Qiao in Jinfeng District; and Helan Mountain West Road, Shi Li Pu Village, Rubber Factory, Sanzha Village, Lu Hua Village, and Shuang Qu Kou Village in Xi Xia District. The highest concentration is observed in Jinfeng District, while Xing Qing District and Xi Xia District exhibit lower levels.

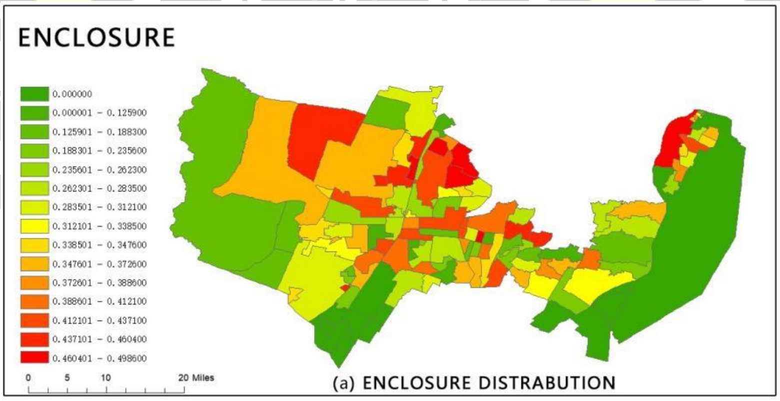

Figure 27 Enclosure Distribution

As shown in **Figure 28**, Greenness is concentrated in areas such as Yue Ya Lake, Si Jia Qiao, Qiang Jia Miao, Wali, Ta Qiao Village Committee, Li Jing Street, Wen Hua Street, and Feng Huang North Street in Xing Qing District; Shanghai West Road, Yellow River East Road, Wei Jia Qiao, Xi Xin Village, and Xin Lian Village in Jinfeng District; and Helan Mountain West Road, Shi Li Pu Village, Huanghua Village, Helan Mountain Farm, and Lu Hua Village in Xi Xia District.

The highest concentration is observed in Xi Xia District, while Xing Qing District and Jinfeng District exhibit lower levels.

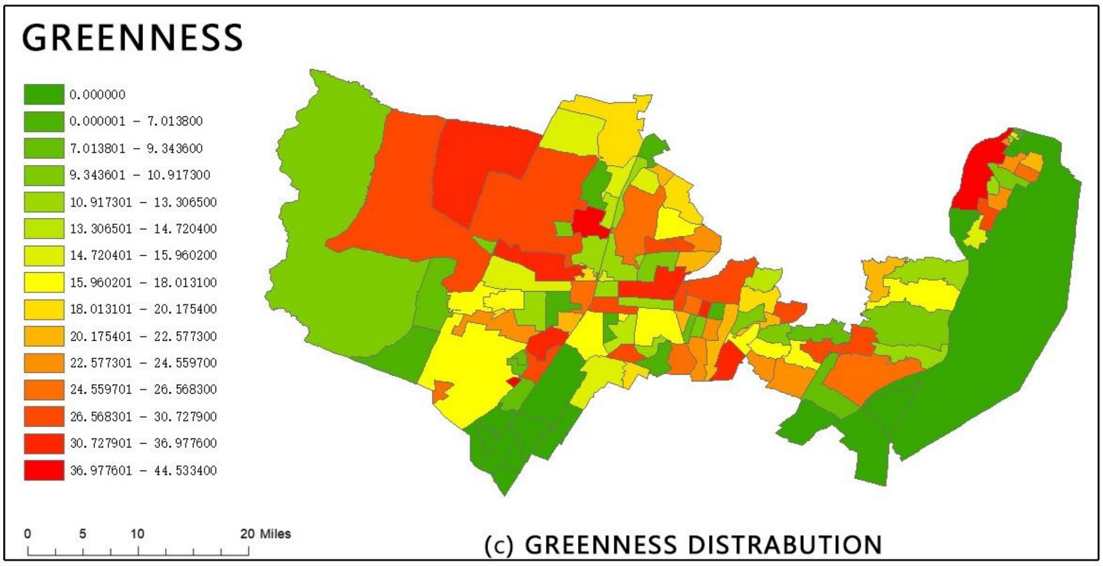

Figure 28 Greenness Distribution

As shown in Figure 29, Walkability is mainly concentrated in Helan Mountain Farm and Helan Mountain Nature Reserve in Xi Xia District.

Imageability is primarily distributed away from the central urban area, with the highest concentration in Xing Qing District, followed by Jinfeng District and Xi Xia District.

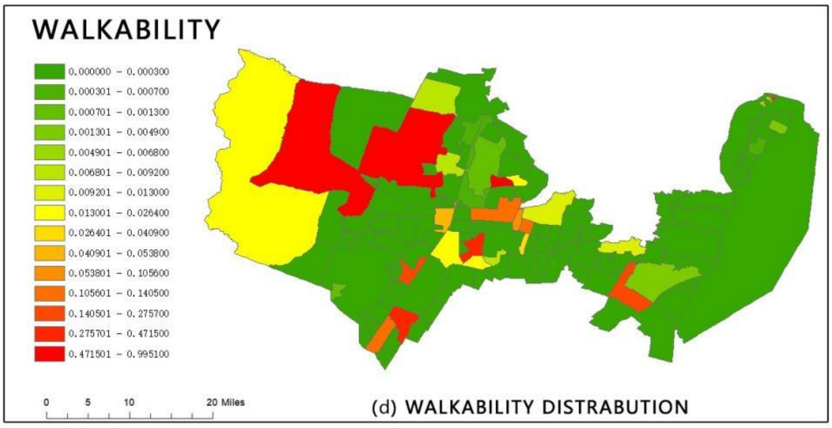

Figure 29 Walkability Distribution

Areas with higher Openness are primarily located outside the city center, mainly due to the higher building density and height in the central urban area, resulting in lower openness and fewer places with a view of the sky. Greenness is mainly lacking in greenery on major streets but is more prevalent in green spaces and suburban areas. Enclosure is mainly found on secondary streets, where the main streets are enclosed by buildings, resulting in lower levels of enclosure on secondary streets. Both Walkability and Imageability exhibit a trend of being lower in the central urban area and higher in the suburbs. This trend may be related to the data collection method, as lane angles may not reflect the walkability from the perspective of pedestrians, as shown in Figure 30.

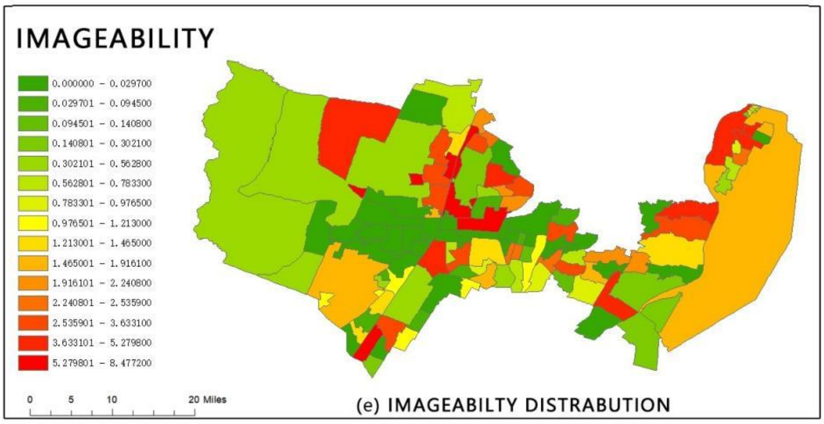

Figure 30 Imageability Distribution

4.3.3 Distance to Transit

According to the literature, we utilized the density of bus stations and road density to measure the "Distance to Transit" variable. In this study, a total of 172 express roads, 248 main roads, 667 secondary roads, 584 branch roads, and 520 streets and alleys were identified as the sample road network data for urban vitality research in three urban districts. The accessibility of public transit was measured by the number of bus stations, totaling 356 bus stations. The bus stations are primarily concentrated in the central urban areas of Xing Qing District, Jinfeng District, and Xi Xia District. The road network is mainly concentrated in the central areas of Xing Qing District and Xi Xia District.

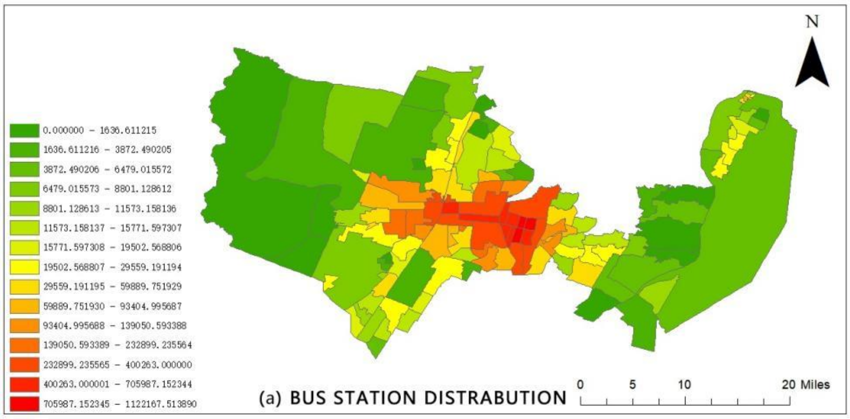

Figure 31 Bus Station Distribution

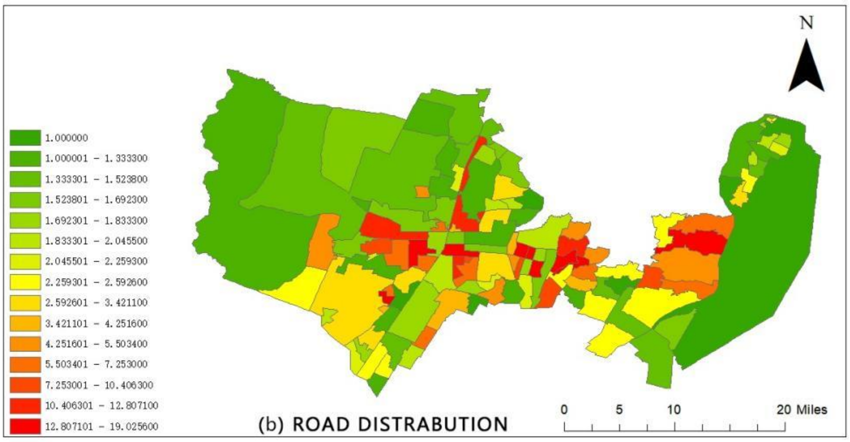

Figure 32 Road Distribution

4.3.4 Destination Accessibility

As shown in Figure 33,Figure 34,Figure 35 and Figure 36,the SDNA analysis reveals the following:

i. Traffic Network Aspects

Using a radius of 500 meters, the main roads with high closeness and centrality are Yin Gu Road, Yu Huang Ge North Street, and Jie Fang West Street in Xing Qing District; Beijing Middle Road, Great Wall Middle Road, Shanghai West Road, Yue Hai Community, and Man Cheng North Street in Jinfeng District; and Helan Mountain West Road in Xi Xia District. With a radius of 1200 meters, the roads with high closeness are Yin Gu Road, Yu Huang Ge North Street, and Jie Fang West Street in Xing Qing District; Beijing Middle Road, Great Wall Middle Road, Shanghai West Road, Yue Hai Community, and Man Cheng North Street in Jinfeng District. At a radius of 1200 meters, centrality is distributed higher while closeness is lower, particularly on Yin Gu Road, Yu Huang Ge North Street, Wen Hua Street, Qianjin Street, Jie Fang West Street, Li Jing Street, and Feng Huang North Street in Xing Qing District. This indicates an increase in accessibility along the east-west roads of Cultural Street, Qianjin Street, and Jie Fang West Street in Xing Qing District. In Jinfeng District, the highlighted roads include Beijing Middle Road, Great Wall Middle Road, Shanghai West Road, Yue Hai Community, Man Cheng North Street, Zhengyuan Street, Ning An Street, and Bao Hu Middle Road. In Xi Xia District, the highlighted roads include Helan Mountain West Road, Shuo Fang Road, Tong Xin Road, and Huai Yuan Road. Centrality reveals the main traffic arteries in the urban area, such as Beijing Middle Road, Great Wall Middle Road, Shanghai West Road, Zhengyuan Street, Ning An Street, and Bao Hu Middle Road, indicating the maximum potential for north-south traffic flow.

ii. Spatial Structure Aspects

The analysis shows that Xing Qing District and Jinfeng District form a continuous and accessible network, with the old town area of Xing Qing District exhibiting significant pedestrian traffic potential. Other **areas** show fragmented distribution, and the industrial areas in Jinfeng District and Xi Xia District have a lower degree of radiation. This reveals a development pattern characterized by the diffusion of concentric circles, centered around Xing Qing District. This aligns with Xing Qing District's role as the public service and commercial center of Yinchuan City.

These research findings contribute to a comprehensive understanding of the urban dynamics in Yinchuan City, providing a foundation for informed decision-making in urban planning and development.

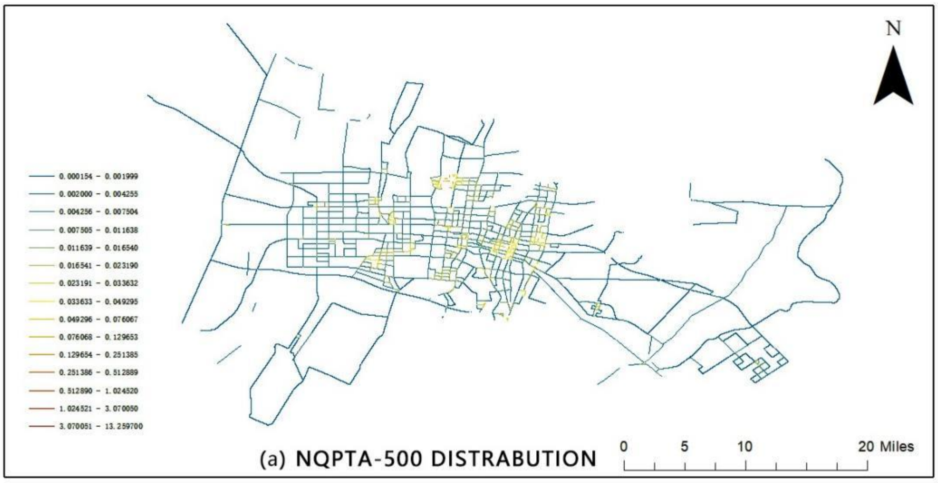

Figure 33 NQPDA-500 Distribution

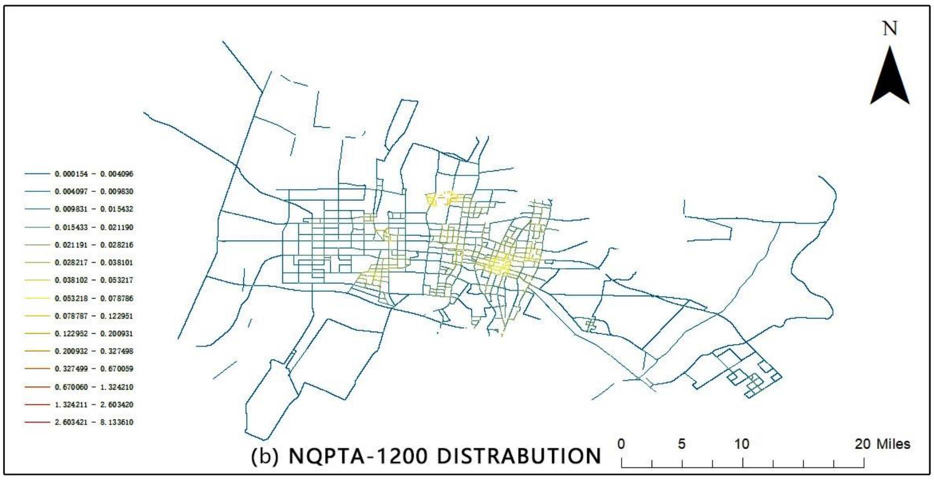

Figure 34 NQPDA-1200 Distribution

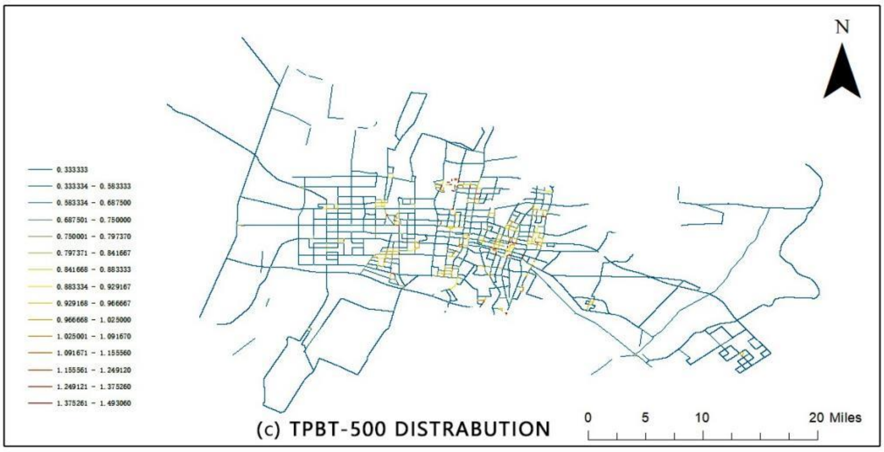

Figure 35 TPBT-500 Distribution

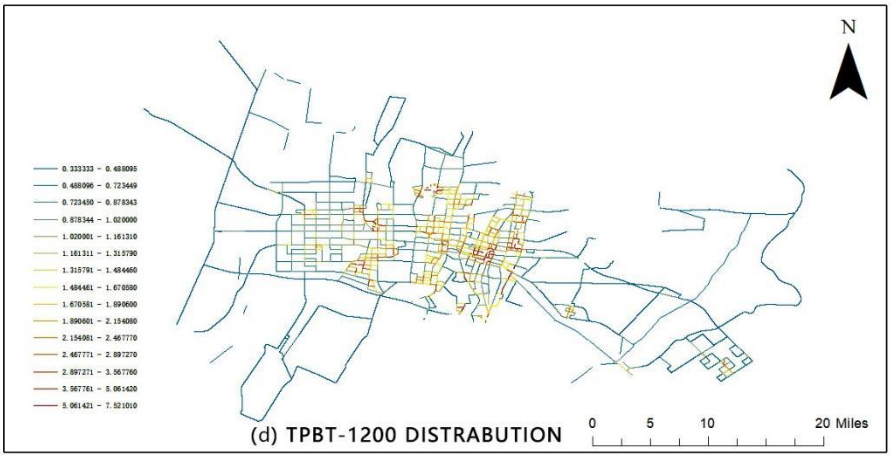

Figure 36 TPBT-1200 Distribution

4.4 Regression Model Results

4.4.1 Regression Model of Weekday and Weekend Urban Vitality

This paper uses (OLS) linear regression, as shown in **Table 11**. The independent variables are built environment variables (Diversity, Design, Distance to transit, Destination accessibility) and the dependent variables are weekday Urban vitality and weekend urban vitality. Dependent and independent variables were regressed stepwise and a total of eight linear regression models were obtained. The Public variable had a VIF greater than 7.5 and was excluded. The VIF of all other variables is less than 7. Table 4 results show that the regression results indicate that the Landscape POI, Public POI, Hotel POI, Shopping POI, Openness, Greenness, Imageability, Road, Bus station, TPBT -500, NQPTA-500, and TPBT-1200 variables are significant for urban vitality. Landscape POI, Public POI, Hotel POI, Shopping POI, Openness, Greenness, Imageability, Road, Bus station, NQPTA-500, TPBT-1200 variables on weekends are significant for urban vitality.

Table 11 Regression Model of Built Environment and Urban Vitality

Variable	**Variable name**	**Weekday Urban vitality**						**Weekend Urban vitality**					
		standard error	**t**	**P**	**VIF**	**R^2**	**Adjust R^2**	**standard error**	**t**	**P**	**VIF**	**R^2**	**Adjust R^2**
Diversity	Landscape POI	0.073	6.546	0.000	1.988	0.69	0.674	0.062	9.919	0.000	1.988	0.708	0.693
	Food POI	0.159	-0.364	0.716	6.404			0.136	-1.184	0.239	6.404		
	Public POI	0.235	-1.968	0.052	9.077			0.202	-1.982	0.050	9.077		
	Hotel POI	0.092	5.442	0.000	2.753			0.079	5.523	0.000	2.753		
	Shopping POI	0.099	2.989	0.003	2.291			0.085	2.205	0.029	2.291		
	Traffic POI	0.138	1.528	0.129	4.55			0.118	0.777	0.439	4.55		
Design	Openness	0.07	1.873	0.064	1.037	0.19	0.155	0.062	2.845	0.005	1.037	0.202	0.168
	Enclosure	0.123	0.927	0.356	3.436			0.108	0.98	0.329	3.436		
	Walkability	0.148	0.247	0.806	3.306			0.13	-0.002	0.998	3.306		
	Greenness	0.089	-2.987	0.003	1.154			0.078	-2.76	0.007	1.154		
	Imageability	0.114	3.539	0.001	1.098			0.1	3.503	0.001	1.098		
Distance	Road	0.059	3.827	0.000	1	0.556	0.549	0.041	5.866	0.000	1	0.726	0.722
	Bus station	0.061	11.574	0.000	1			0.043	16.726	0.000	1		
Destination	TPBT-500	0.113	-2.452	0.016	5.443	0.607	0.594	0.097	-1.45	0.150	5.443	0.63	0.617
	NQPTA-500	0.099	-2.281	0.024	2.55			0.085	-2.96	0.004	2.55		
	NQPTA-1200	0.118	0.023	0.982	2.983			0.102	0.46	0.646	2.983		
	TPBT-1200	0.131	7.935	0.000	6.73			0.113	7.467	0.000	6.73		

Note: *, **, *** represent 1%, 5%, and 10% significance levels, respectively.

4.4.2 Regression Model of Urban Vitality

Linear regression is used to study the linear relationship between independent variables and dependent variables. The independent variables are Diversity, Design, Distance to transit, Destination accessibility, which includes 17 independent variables. The dependent variable is Urban vitality. The dependent and independent variables are regressed stepwise and there are four models. The first model was a linear regression of the dependent variable and the Diversity variable. The second model is a linear regression of the dependent variable and the Design variable. The third model is a linear regression of the dependent variable and is Distance to transit. The fourth model is a linear regression of the dependent variable and the Destination accessibility variable.

As shown in **Table 12**, it shows the detailed results of the linear regression. The Public variable had a VIF greater than 7.5 and was excluded. All other variables have VIF less than 7. The adjusted R^2 for the 4D variables are 0.64, 0.15, 0.514, 0.52. The linear regression results show that Landscape, Hotel, Shopping, Openness, Greenness, Imageability, Road, Bus station, TPBT-500, NQPTE-500, and TPBT-1200 have a total of 11 independent variables have a significant effect on urban vitality.

4.5 Weekday and Weekend Spatial Autocorrelation Results

In this paper, Arc GIS was used to calculate Moran's I index for each variable. The Walkability, Greenness, Imageability, and NQPDA-500 variables have p-values > 0. 001.Therefore, these four variables need to be excluded in the next analysis. All other independent variables had Moran's I index, Z-scores, and p-values greater than zero and p-values less than 0.05. This indicates that the variables are more spatially clustered and qualify for a GWR model. The Moran's I value for weekday July 19, 2023, is 0.742. the Moran's I value for weekend is 0. 721.Therefore, Moran's I for weekdays and weekends are positively correlated with clustered distribution. It indicates that there is a spatial relationship between urban vitality in the built environment. The Moran's I value for most of the variables ranged from

0.,063 ~ 0.828, indicating a positive spatial autocorrelation at the p = 0.01 level of significance.

Table 12 Regression Model of Built Environment and Urban Vitality

Variable	**Variable name**	**B**	**standard error**	**Beta**	**t**	**P**	**VIF**	**R^2**	**Adjust R^2**	**F**
Diversity	Landscape	0.354	0.067	0.399	5.258	0.000	1.951	0.654	0.64	F=44.323 P=0.000
	Food	-0.176	0.122	-0.163	-1.441	0.152	4.332			
	Hotel	0.464	0.086	0.486	5.388	0.000	2.75			
	Shopping	0.215	0.091	0.192	2.366	0.020	2.223			
	Traffic	0.054	0.107	0.049	0.503	0.616	3.167			
Design	Openness	0.107	0.063	0.144	1.695	0.093	1.037	0.185	0.15	F=5.319 P=0.000
	Enclosure	0.107	0.11	0.151	0.978	0.330	3.436			
	Walkability	0.035	0.132	0.04	0.263	0.793	3.306			
	Greenness	-0.24	0.08	-0.269	-3	0.003	1.154			
	Imageability	0.35	0.102	0.301	3.441	0.001	1.098			
Distance	Road	0.19	0.054	0.22	3.486	0.001	1	0.522	0.514	F=65.519 P=0.000
	Bus station	0.614	0.057	0.684	10.83	0.000	1			
Destination	TPBT-500	-0.223	0.109	-0.298	-2.038	0.044	5.443	0.536	0.52	F=34.021 P=0.000
	NQPTA-500	-0.227	0.096	-0.236	-2.359	0.020	2.55			
	NQPTA-1200	0	0.115	0	0.001	0.999	2.983			
	TPBT-1200	0.88	0.127	1.127	6.923	0.000	6.73			
Dependent variable：Urban vitality										
Note: *, **, *** represent 1%, 5%, and 10% significance levels, respectively.										

4.6 Spatial Autocorrelation Results

In this paper, we use the "Moran's I" tool in Arc GIS software to calculate the Moran's I index of each variable. As shown in **Table 13**, the Moran's I index of Walkability variable is -0.023, and the Z score is -0.577, and the P-value is more than 0.5. Therefore, this variable should be removed from the GWR model. The Moran's I index, Z score, and P value of all other independent variables are greater than zero, and P is less than 0.05, indicating that the variables are more spatially clustered and qualify for the GWR model. The Moran's I value for most of the variables ranged from 0. 063 ~ 0.828, indicating positive spatial autocorrelation at the p = 0.01 level of significance.

This study employs Geoda software to delve into the local spatial autocorrelation of urban vitality distribution, producing a LISA cluster map to visualize the data. According to Luc (2010), the LISA cluster map is instrumental in pinpointing clusters of various values, such as high-high, low-low, high-low, and low-high value clusters.

The analysis reveals that the local Moran's I for urban vitality stands at 0.880, indicating a strong degree of local spatial correlation. As illustrated in **Figure 37** , high-high value clusters predominantly occupy the central urban areas of Xing Qing, Jinfeng, and Xi Xia Districts, while low-low value clusters are generally found in rural locales.

During weekdays, the local Moran's I for average heat value is 0.786, with high-high value clusters concentrated in the central urban zones of the districts. On rest days, this value slightly decreases to 0.733, yet high-high value clusters remain prevalent in both the central urban and rural areas of Xi Xia District, along with central Xing Qing and Jinfeng Districts.

Overall, the central urban region harbors most high-value agglomerations, displaying significant polarization and a marked contrast with surrounding areas. Despite this, the overall radiating impact on adjacent regions remains relatively unclear.

Table 13 Global Moran's I Index

Variables	**Variables Name**	**Global Moran's I Index**	**z-value**	**p-value**
Distance	Road	0.149833	5.226676	0<0.001
	Bus station	0.644252	22.057471	0<0.001
Diversity	Landscape	0.794562	26.59994	0<0.001
	Food	0.567847	20.116474	0<0.001
	Public	0.631761	21.873806	0<0.001
	Hotel	0.474115	16.986665	0<0.001
	Shopping	0.546094	19.629339	0<0.001
	Traffic	0.67476	23.062783	0<0.001
Design	Openness	0.236753	8.029853	0<0.001
	Enclosure	0.188987	6.44013	0<0.001
	Greenness	0.102764	3.625915	0.000288
	Imageability	0.057753	2.178916	0.029338
	Walkability	-0.023684	-0.577112	0.563864
Destination	NQPDA-500	0.081663	3.36813	0.000757
	TPBT-500	0.796895	26.295905	0<0.001
	NQPDA-1200	0.175974	6.499889	0<0.001
	TPBT-1200	0.827791	27.333419	0<0.001

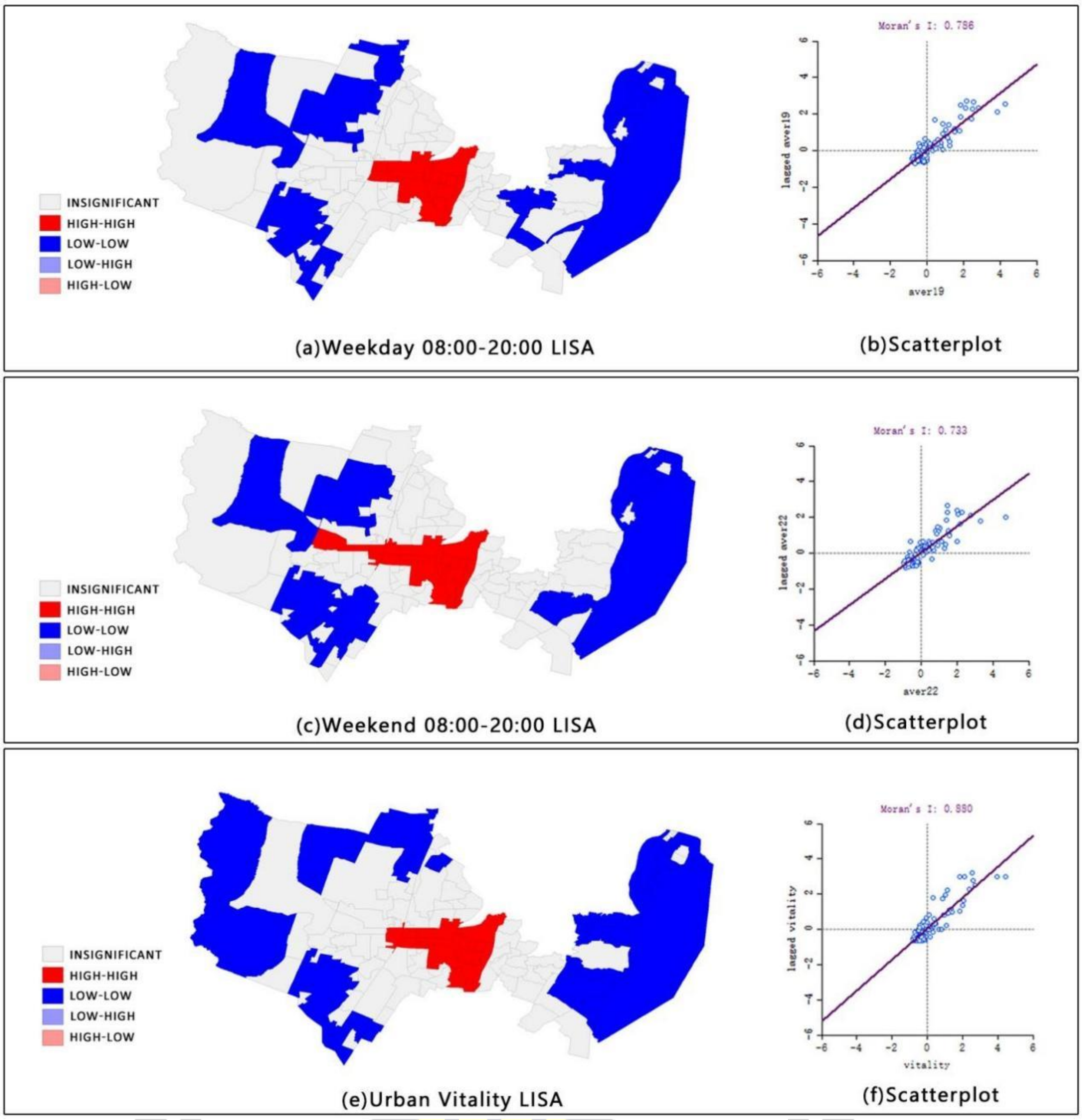

Figure 37 LISA clustering Distribution Map

4.7 GWR Results

4.7.1 Weekday and Weekend GWR Results

According to Moran 's I statistics, most of the dependent and independent variables have significant strong positive spatial autocorrelation. Variables significantly correlated with urban vitality were selected to determine spatial heterogeneity using geographically weighted regression (GWR). The results show that the GWR model has significant improvement compared to OLS regression. Spatial distribution of regression coefficients of influencing factors of GWR model ().

The analysis of the GWR model reveals that Weekday's 'Road' variable is positively correlated in the central part of Xing Qing District, Jinfeng District, and Xi Xia District, such as Sheng Li Street and Jie Fang Xi Street, as shown in Figure 38. It is negatively correlated in most of the eastern part of Xing Qing District, the north and south of Jinfeng District, and the north and south of Xi Xia District. As shown in Figure 39,Weekend's 'Road' variable is negatively correlated in the more scenic countryside or the outskirts of the city. In other words, the stronger the road density in the central city, the stronger the impact on urban vitality. For the outside of the central city, the stronger the road density, the weaker the urban vitality.

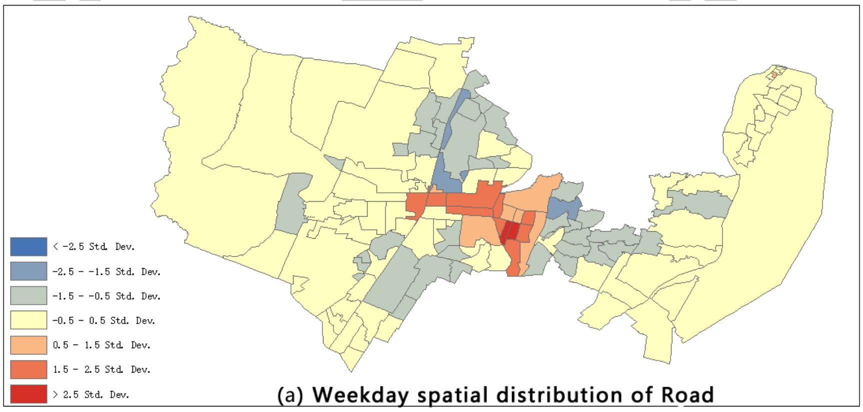

Figure 38 Weekday Spatial Distribution of Road

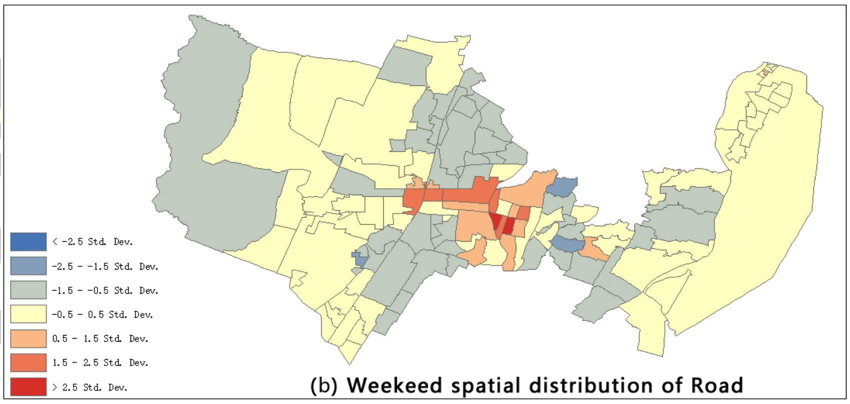

Figure 39 Weekend Spatial Distribution of Road

As shown in Figure 40, weekday's 'Bus station' variable is mostly positively correlated in Xing Qing District, Jinfeng District, and Xi Xia District central city. It is negatively correlated in the center of Xing Qing District, the north of Jinfeng District, and the concentric road of Xi Xia District. As shown in Figure 41,Weekend's 'Bus station' variable is mostly negatively correlated in the central urban areas of Xing Qing District, Jinfeng District, and Xi Xia District. In the overall negative correlation is basically have a more crowded commercial area. This suggests that the greater the density of bus stations, the weaker the urban vitality.

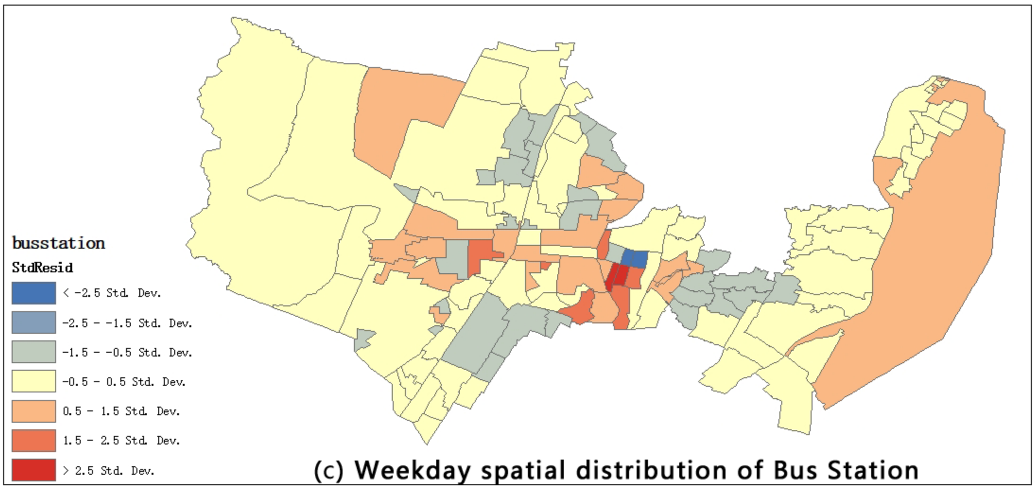

Figure 40 Weekday Spatial Distribution of Bus Station

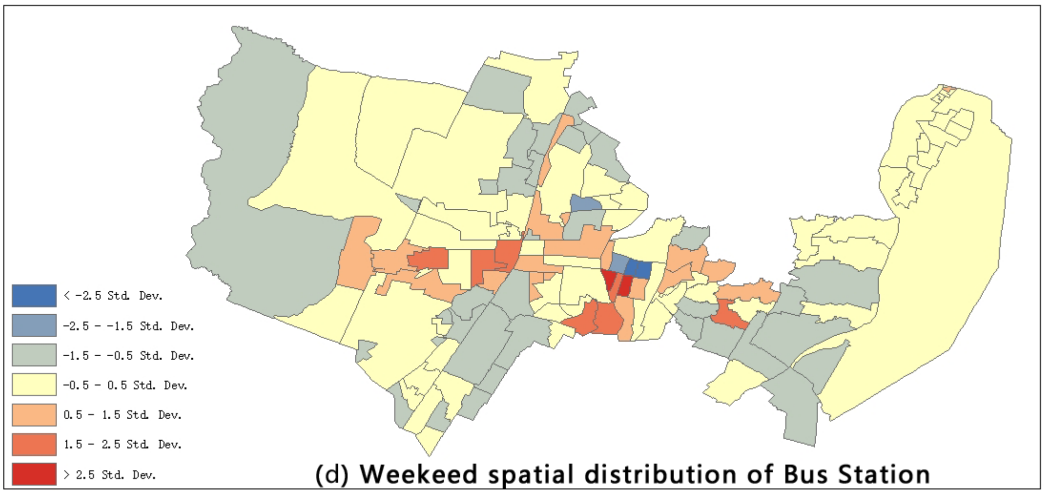

Figure 41 Weekend Spatial Distribution of Bus Station

As shown in Figure 42-Figure 47, 'Food', 'Traffic' and 'Shopping' variables are positively correlated with urban vitality in the central city of Xing Qing, Jinfeng and Xi Xia districts on weekdays. Streets with high pedestrian traffic on weekend show a strong positive correlation, while most areas show a negative correlation. Most of the areas with negative correlations are far away from the center of the city. Traffic congestion caused by too much concentration of food and shopping in the center of the city reduces the vitality of the city.

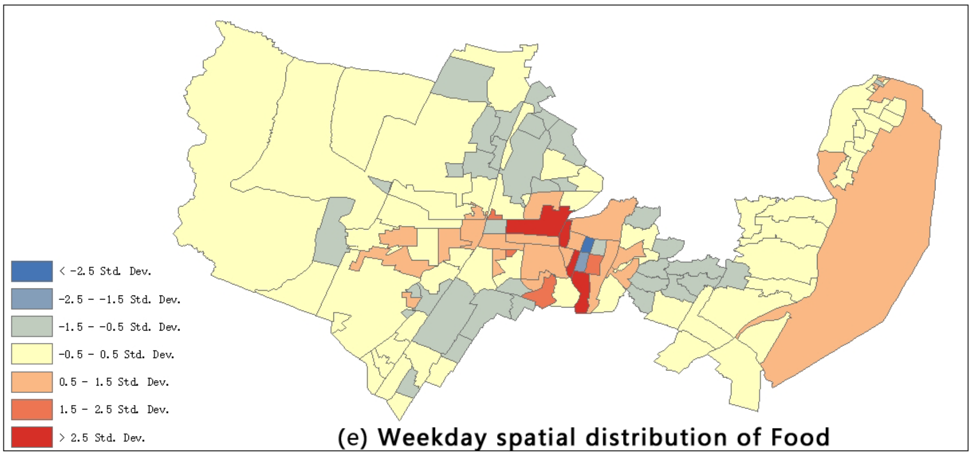

Figure 42 Weekday Spatial Distribution of Food

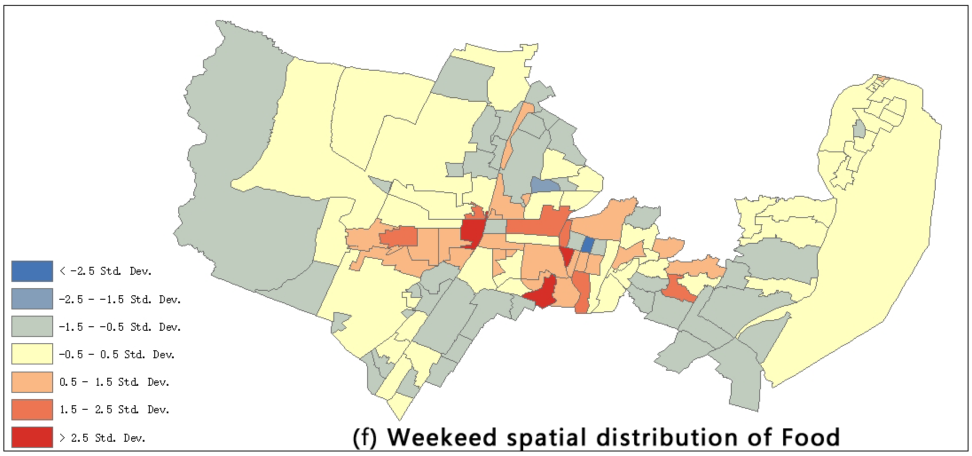

Figure 43 Weekend Spatial Distribution of Food

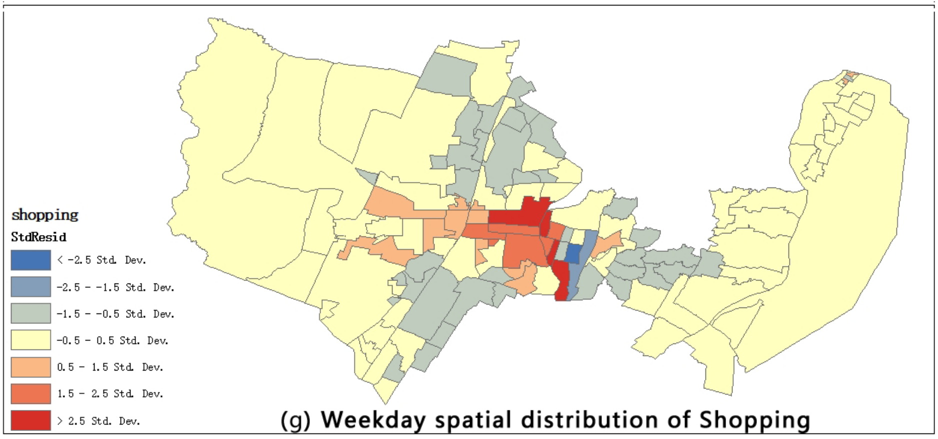

Figure 44 Weekday Spatial Distribution of Shopping

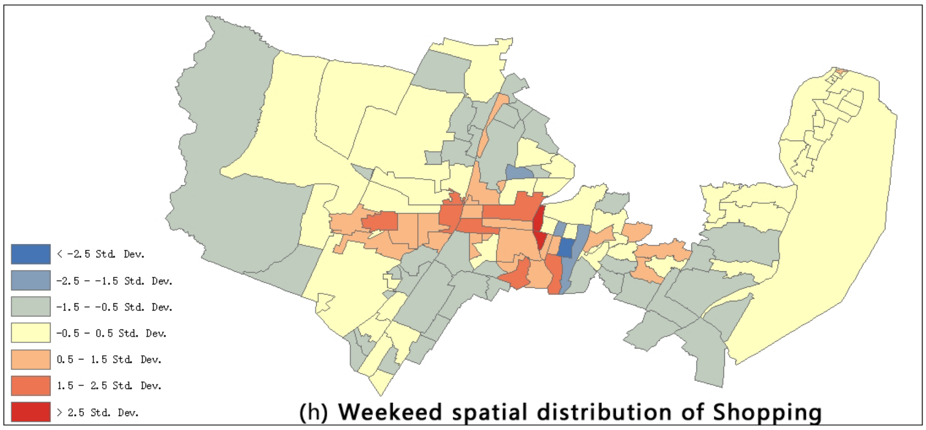

Figure 45 Weekend Spatial Distribution of Shopping

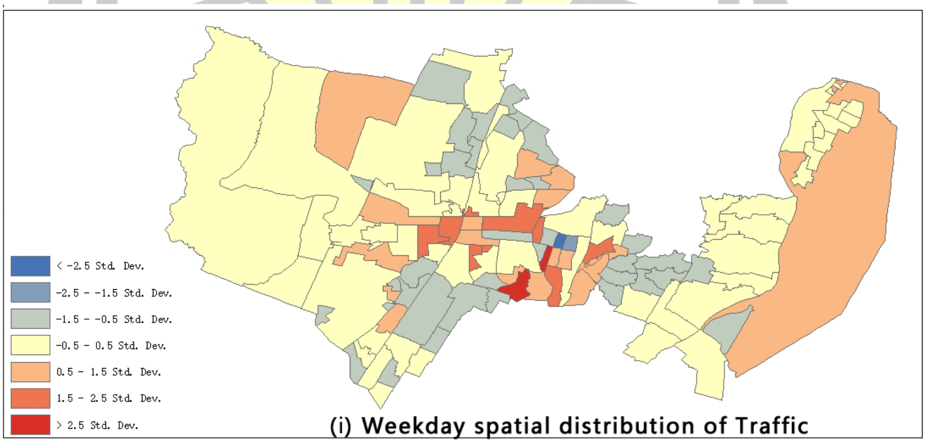

Figure 46 Weekday Spatial Distribution of Traffic

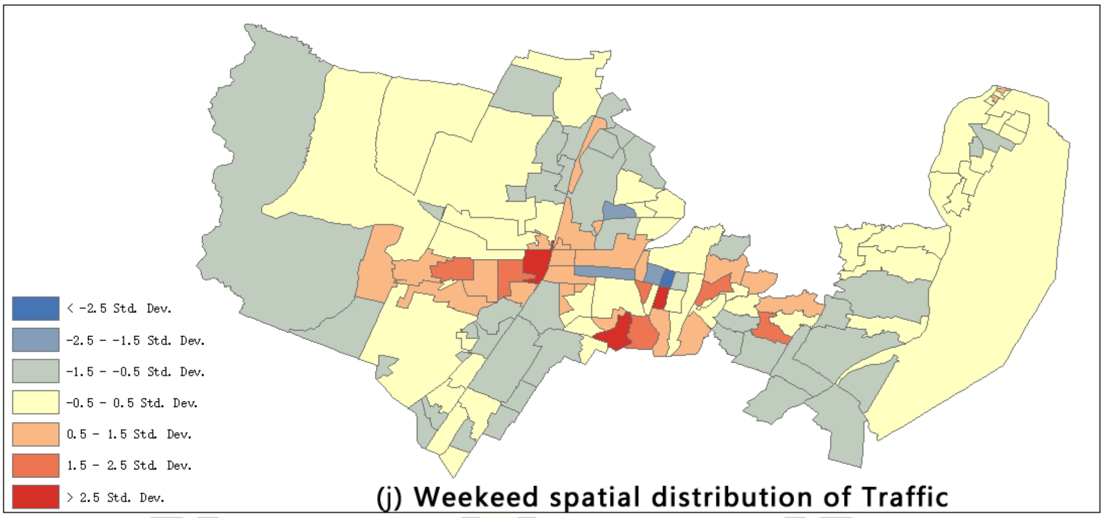

Figure 47 Weekend Spatial Distribution of Traffic

As shown in Figure 48 and Figure 50, 'Openness' and 'Enclosure' on weekdays show a positive correlation in the center of the city and a negative correlation in other areas. Increasing urban open space and enhancing the enclosure of buildings on both sides of the road can increase urban vitality and attract more people. As shown in Figure 49 and Figure 51The 'Openness' and 'Enclosure' on weekends show a negative correlation with most of the suburban areas. This may be because people tend to go to the suburbs on weekends.

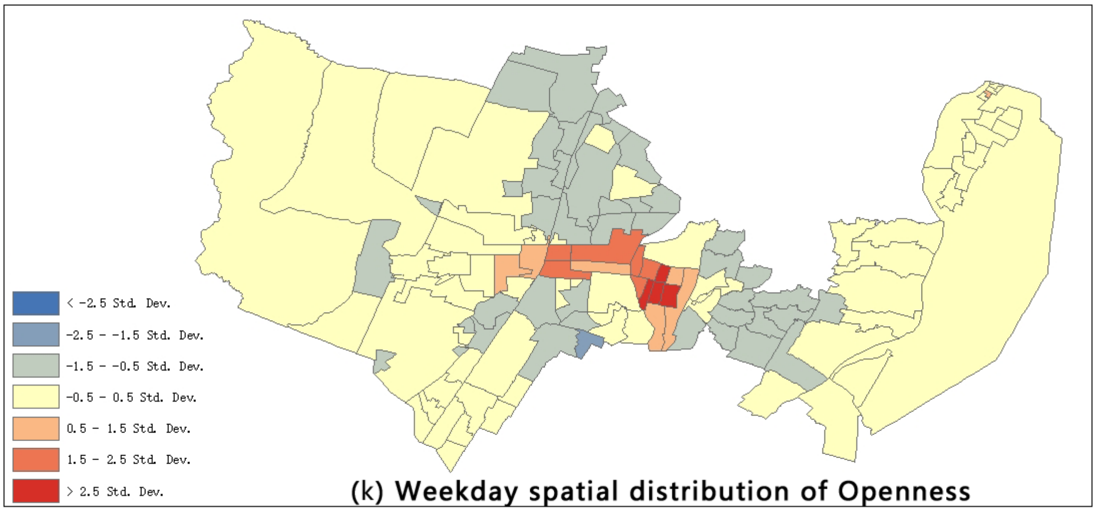

Figure 48 Weekday Spatial Distribution of Openness

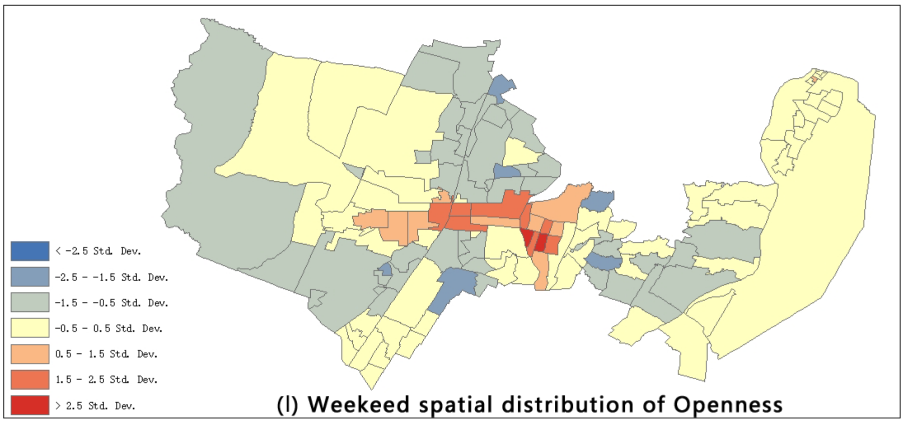

Figure 49 Weekend Spatial Distribution of Openness

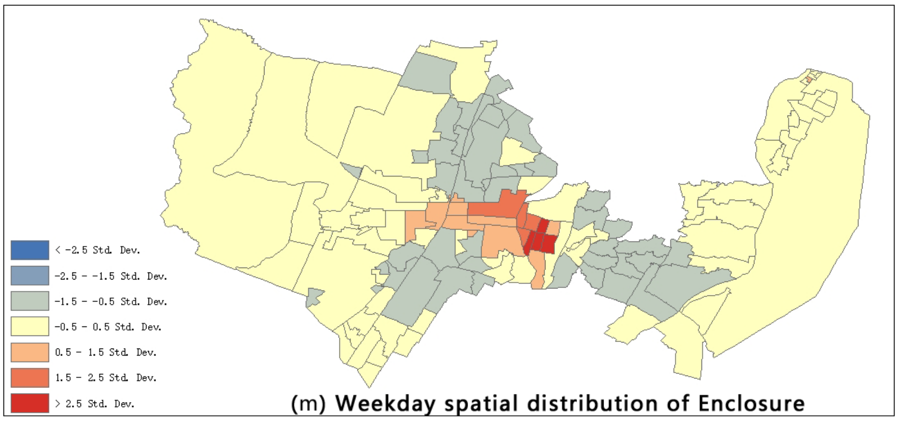

Figure 50 Weekday Spatial Distribution of Enclosure

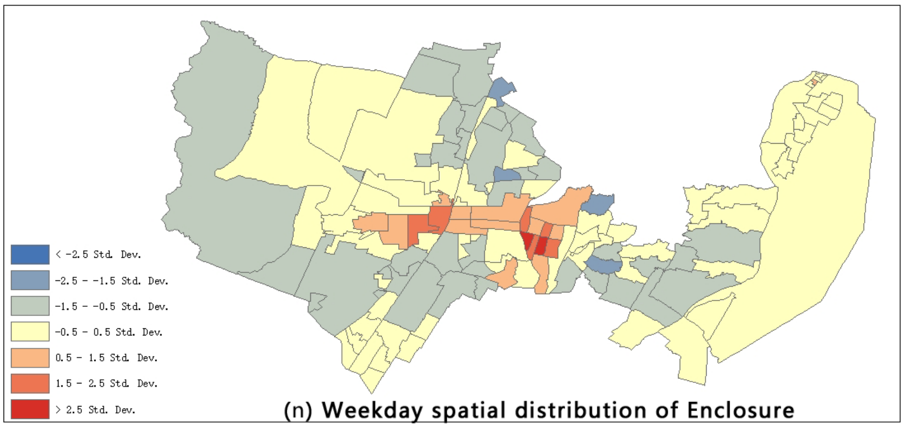

Figure 51 Weekday Spatial Distribution of Enclosure

As shown in Figure 52,Figure 54 and Figure 57, weekday's 'TPBT-500', 'TPBT-1200', 'NQPTA-1200' are positively correlated in the center of the area, and negatively correlated in other areas with high pedestrian flow. As shown in Figure 53,Figure 55 and Figure 57,the weekend's 'TPBT-500', 'TPBT-1200', and 'NQPTA-1200' show a negative correlation in the suburbs of the city. Weekday urban centers attract population clusters mainly because of work demand, and most of the trips to workplaces are dependent on transportation. Therefore, the relationship between transportation and vitality in these areas is positive. But vitality diminishes with increasing distance from the center. The expansion of the areas positively correlated with rest days verifies the tendency of people to evacuate from the center of the city.

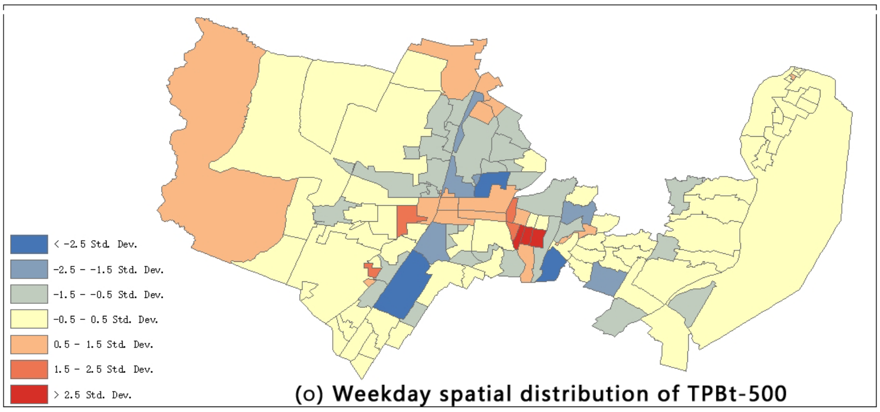

Figure 52 Weekday Spatial Distribution of TPBT-500

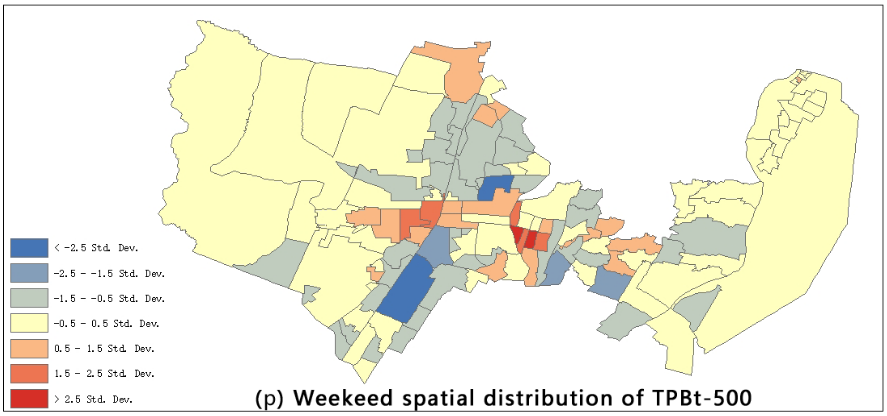

Figure 53 Weekend Spatial Distribution of TPBT-500

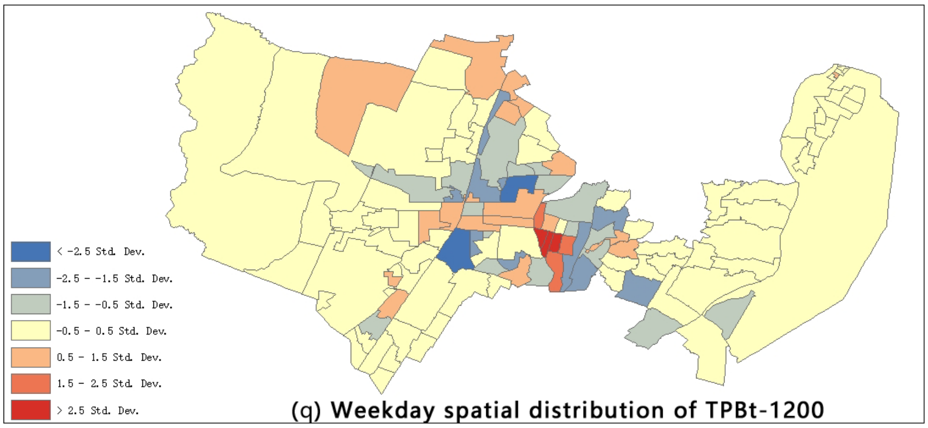

Figure 54 Weekday Spatial Distribution of TPBT-1200

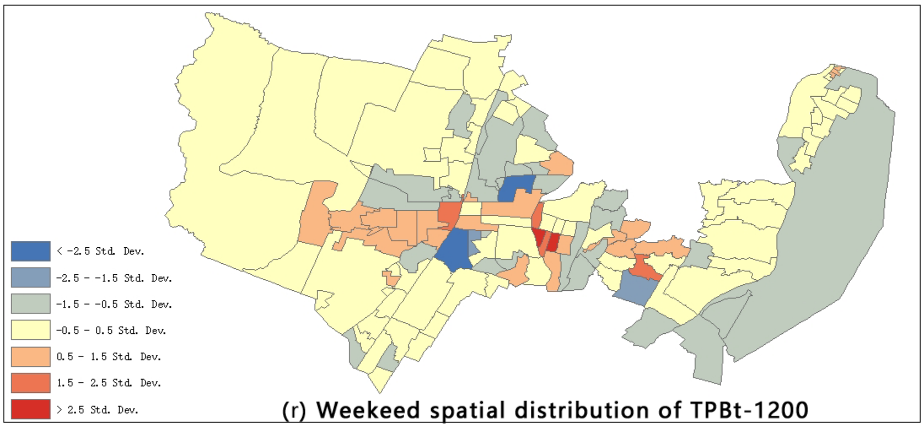

Figure 55Weekend Spatial Distribution of TPBT-1200

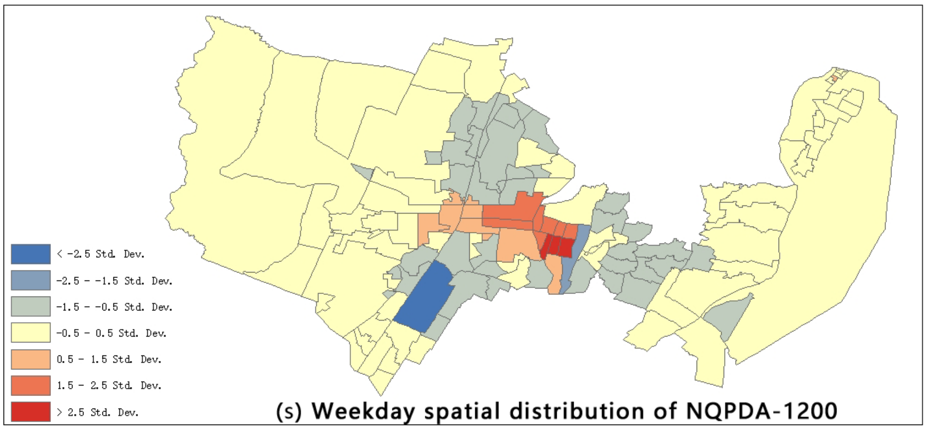

Figure 56Weekday Spatial Distribution of NQPDA-500

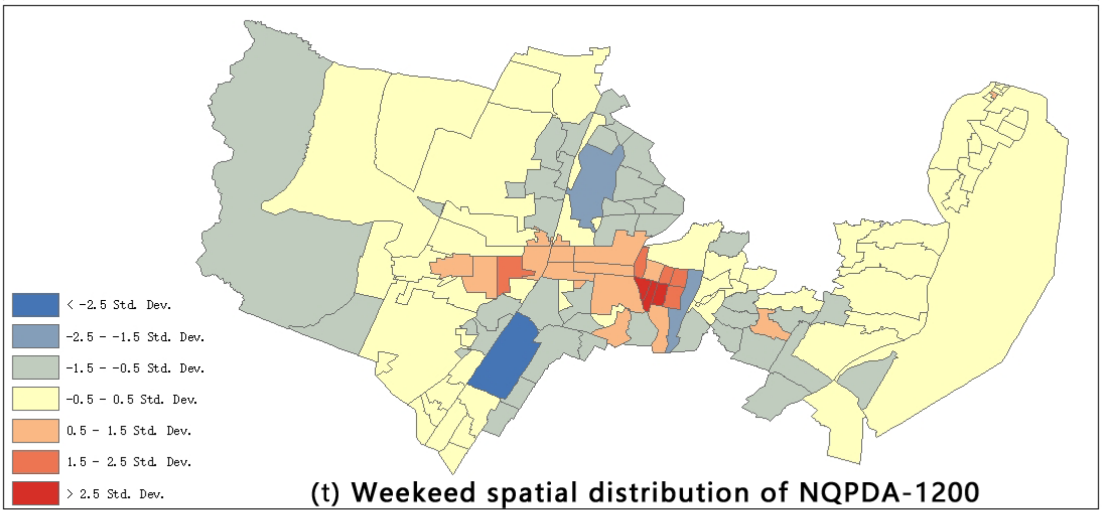

Figure 57 Weekend Spatial Distribution of NQPDA-1200

Overall, according to the GWR analysis, the central area of Xing Qing District in Yinchuan City is the area with higher urban vitality, the central area of Jinfeng District is the second, and the central area of Xi Xia District is the third. The areas with higher urban vitality mainly focus on high quality shopping, living, dining and transportation services, confirming the results of previous studies.

4.7.2 GWR Results

Moran's I statistics indicate that there is a significant and strong positive spatial autocorrelation present among most of the dependent and independent variables in the study. In the process of GWR, variables that had a p-value greater than 0.001 were omitted from the analysis. This exclusion resulted in the removal of four variables, after which the GWR was applied to assess spatial heterogeneity. The findings from the GWR revealed that the adjusted R^2 values for the variables Diversity, Design, Distance, and Destination are 0.909, 0.166, 0.833, and 0.746, respectively. Both R^2 and adjusted R^2 demonstrated a significant increase, suggesting a more robust model fit in comparison to the OLS regression. Moreover, the GWR parameters exhibited notable spatial variations, which are graphically represented in Table 14 , providing a clear distinction from the OLS regression results.

Table 14 GWR model results

Variables	**Variables Name**	**R-squared**	**Adjusted R-squared**	**AICC**
Distance	Road	0.436442	0.378387	701.585664
	Bus station	0.844884	0.830861	541.351076
Diversity	Landscape	0.894852	0.885143	493.392118
	Food	0.853229	0.840503	533.945205
	Hotel	0.805256	0.788293	568.685294
	Shopping	0.794048	0.776474	575.397214
	Traffic	0.898042	0.889075	489.212087
Design	Openness	0.397918	0.320334	714.787681
	Enclosure	0.396193	0.318626	714.961977
	Greenness	0.379944	0.301328	717.809954
	Imageability	0.391957	0.317351	714.674329
	Walkability	0.385473	0.316238	715.187786
Destination	NQPDE-500	0.396083	0.344515	706.975645
	TPBT-500	0.61152	0.572924	655.858794
	NQPDE-1200	0.412496	0.359402	704.410414

	TPBT-1200	0.737362	0.714975	604.876796

The analysis of the GWR model sheds light on the spatial relationship between Road density and urban vitality. Road is positively correlated in the central part of Xing Qing District, Jinfeng District, and Xi Xia District, such as Sheng Li Street, Jie Fang West Street, Shanghai West Road, Beijing Middle Road, Xi Yuan Garden, and Beijing West Street. And it is negatively correlated in most of the eastern part of Xing Qing District, the north and south of Jinfeng District, and the north and south of Xi Xia District. In other words, the stronger the road density in the central city, the stronger the impact on urban vitality. For the outside of the central city, the stronger the road density, the weaker the urban vitality.

Bus station is positively correlated in most of the central city of Xing Qing, Jinfeng, and Xi Xia districts, such as Sheng Li Street, Jie Fang West Street, Shanghai West Road, Beijing Middle Road, Xi Jian Garden, and Beijing West Street. Whereas, negative correlation is presented in Zhongshan Street, Yu Huang Ge North Street, most of the eastern part of the central city of Xing Qing District, the northern part of Jinfeng District's Read Sea Community, Man Cheng North Street in the central city, and Concentric Road in Xi Xia District. Those that show negative correlation basically have commercial areas with denser pedestrian flow. This suggests that the greater the density of bus stations, the weaker the city's vitality. In the central urban areas of Xing Qing, Jinfeng, and Xi Xia Districts, the 'Road' variable demonstrates a positive correlation, implying that higher road density correlates with increased urban vitality. Conversely, this correlation turns negative in most of the eastern parts of Xing Qing District and the northern and southern regions of both Jinfeng and Xi Xia Districts, as depicted in Figure 58. The implication here is that within the heart of the city, robust road networks enhance urban vitality, while on the outskirts, increased road density may not have the same positive effect.

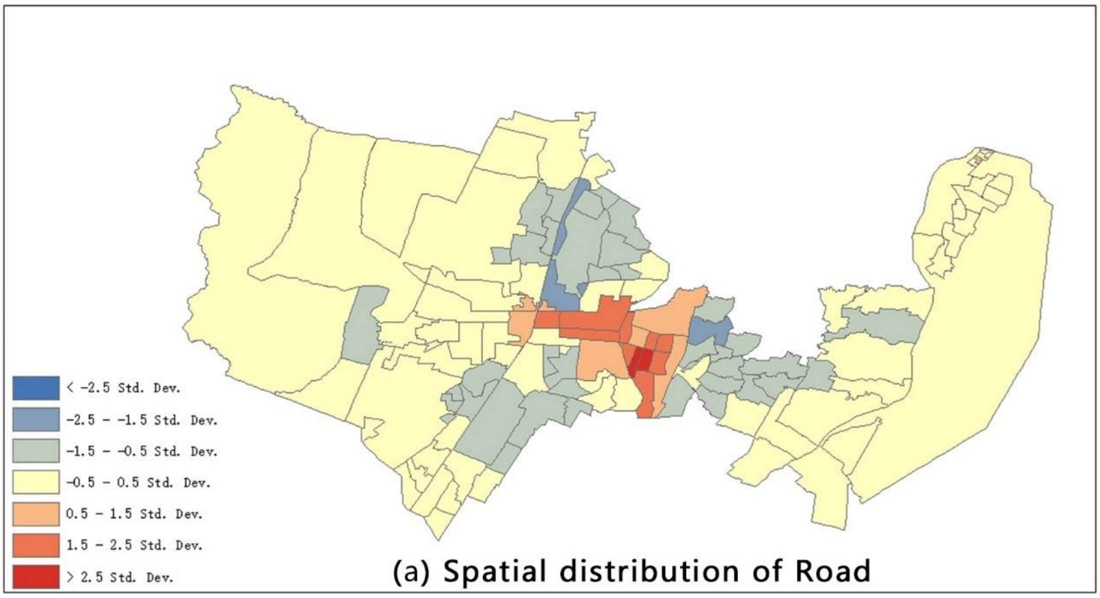

Figure 58 Spatial Distribution of Road

Regarding the 'Bus station' variable, as shown in Figure 59, a positive correlation with urban vitality is observed predominantly in the central areas of Xing Qing, Jinfeng, and Xi Xia. However, areas with a high concentration of bus stations and heavy pedestrian traffic, typically commercial zones, display a negative correlation. This suggests that an over-concentration of bus stations might lead to traffic congestion, which in turn could impede the ease of movement, thereby diminishing urban vitality.

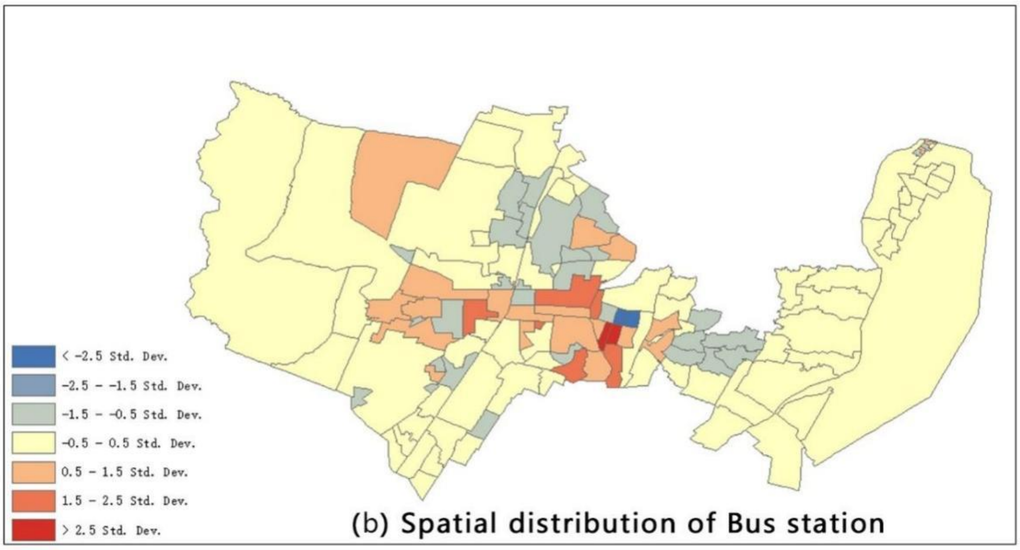

Figure 59 Spatial Distribution of Bus Station

As shown in Figure 60, the Landscape variable is negatively correlated with urban vitality in Xi Xia District as a whole. The Landscape variable in Diversity is positively correlated in Sheng Li Street and Qianjin Street and negatively correlated in Zhongshan North Street, Yu Huang Ge North Street and Jie Fang West Street in Xing Qing District. The central city area shows two different phenomena. Jinfeng District shows positive correlation in Shanghai West Road and Xi Hu Community, and negative correlation in Red Sea Community and Ping Fu Qiao Village. This part is all residential area, and the residence shows high density aggregation. Most of Xi Xia District shows a positive correlation, and West He Lan Shan Road shows a negative correlation. In general, the overall residential density in Xi Xia District is not high. On the other hand, the north side of West Helan Mountain Road is mainly a university town with 10 colleges and universities. So, it shows a negative correlation between landscape and urban vitality. The main reason is that the residential density in this area is not high, and the north side of West He Lan Shan Road is mainly a university town.

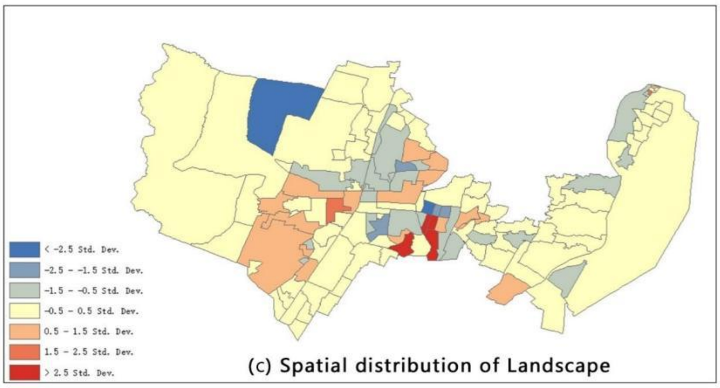

Figure 60 Spatial Distribution of Landscape

As shown in Figure 61 and Figure 62,Food and shopping variables are strongly positively correlated with Sheng Li Street in Xing Qing District, and negatively correlated with Zhongshan North Street and Yu Huang Ge North Street. In Jinfeng District, there is a positive correlation in West Shanghai Road and Middle Beijing Road, and a negative correlation in Yue Hai Community. This area has high residential density. The center of Xi Xia District is positively correlated. The center of Xing Qing and Jinfeng districts show negative correlation in areas where people gather densely. Too much concentration of food and shopping in the center of the city will also reduce the vitality of the city.

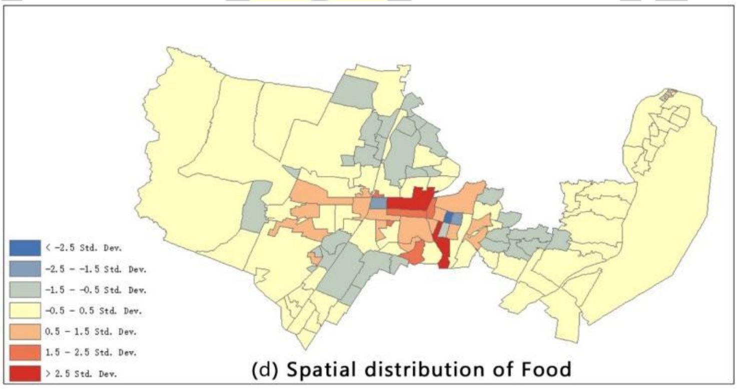

Figure 61 Spatial Distribution of Food

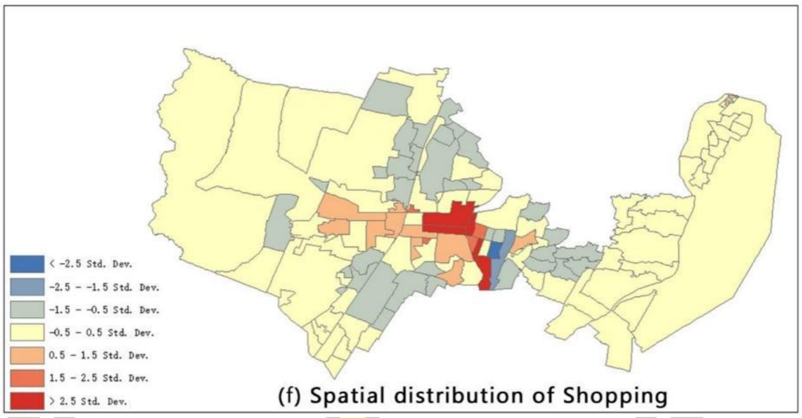

Figure 62 Spatial Distribution of Shopping

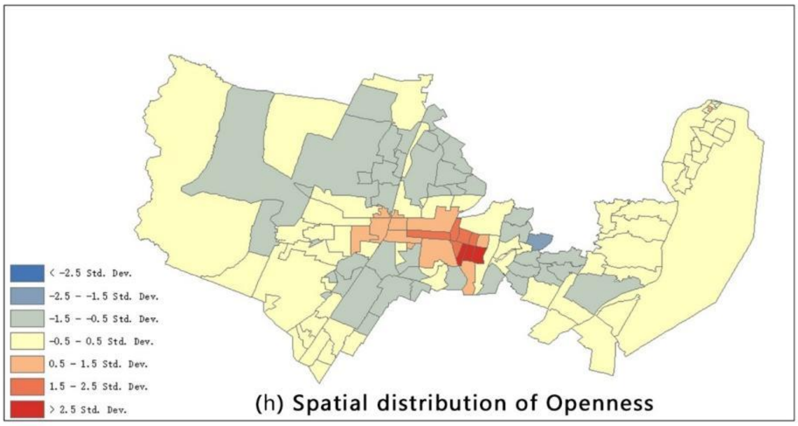

Figure 63 Spatial Distribution of Openness

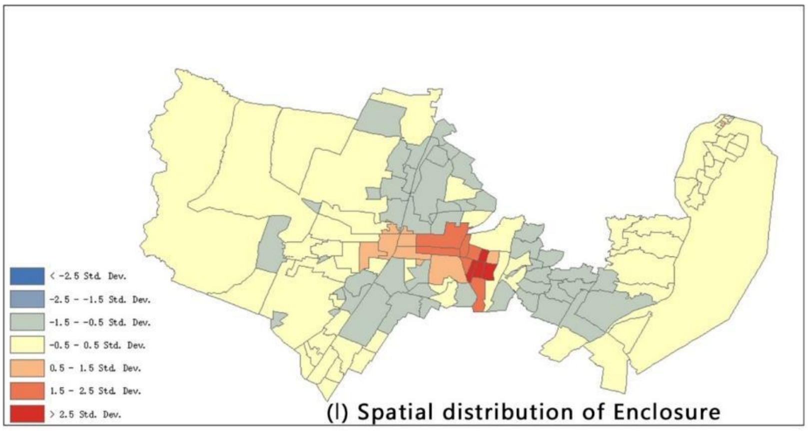

Figure 64 Spatial Distribution of Enclosure

As shown in Figure 63 and Figure 64, illustrates that the indicators of Openness, Greenness, Enclosure, Walkability, and Imageability within Design exhibit a positive correlation in the city's center, whereas this correlation turns negative in the peripheral areas. There is a distinct positive relationship between Design and urban vitality at the city's heart, which diminishes as one moves away from the center. Additionally, the vitality tends to decrease more in larger cities. Enhancing the design elements, particularly Openness and Enclosure, in the central areas significantly influences the city's core vitality and has the potential to draw more individuals. While most design-related research relies on subjective assessments, our method offers objective measurements, providing a distinct advantage by enabling the conversion of perceptual findings into concrete design guidance for the urban planning of the city center.

As shown in Figure 65 and Figure 66,Destination accessibility in TPBT-500, NQPTA-1200 center area is positively correlated, and other areas with high pedestrian traffic are negatively correlated. Helan Mountain Nature Reserve in Xi Xia District is positively correlated, NQPTA-500 in the central area is positively correlated, TPBT-1200 in the central area of Xing Qing District is positively correlated, Yingu Road is negatively correlated, and the community of reading the sea in Jinfeng District is negatively correlated. Negative correlation in Yinchuan Forest Farm, Xi Xia District. Under the calculation radius of 0.5 km and 1.2 km, both NQPDA and TPBT show positive correlation, indicating that the accessibility and centrality of the street network in the central city of Yinchuan are more uniform. However, the areas showing negative correlation are all crowded areas, indicating that transportation accessibility in crowded areas is counterproductive to urban vitality.

It demonstrates that in the central area of Yinchuan City, there is a positive correlation between the TPBT-500 and NQPTA-1200 variables, while areas with high pedestrian density exhibit a negative correlation. This suggests that the street network's accessibility and centrality are more cohesive in the city's center. SDNA analysis indicates that the Xing Qing District not only has strong agglomerative appeal but also possesses robust traffic management capabilities, facilitating ease of movement. Conversely, the Jinfeng and Xi Xia Districts, despite having considerable potential for access, are more remote and less accessible. Overall, there is a central urban cluster pattern encompassing the Xing Qing, Jinfeng, and Xi Xia Districts. The urban vitality across Yinchuan City requires further enhancement. GWR analysis reveals that the Xing Qing District's center serves as the heart of Yinchuan, integrating features of allure, agglomeration, and accessibility. The center of Jinfeng District primarily functions as a conduit for traffic and a hub for central gatherings. Meanwhile, the center of Xi Xia District, despite being readily accessible, falls short in terms of both attraction and agglomeration capabilities.

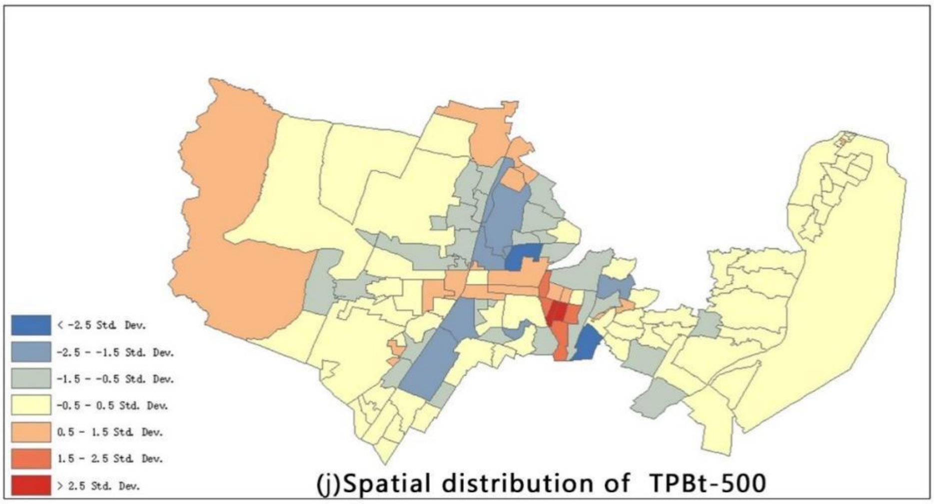

Figure 65 Spatial Distribution of TPBT-500

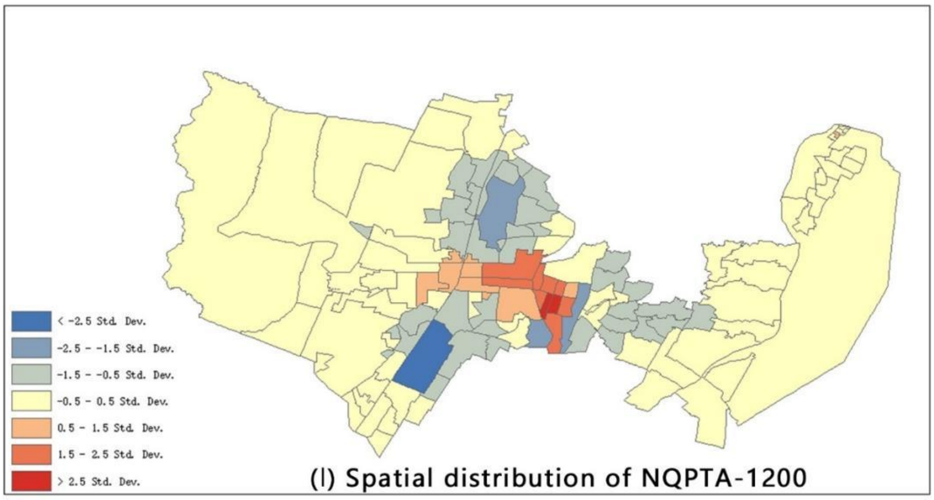

Figure 66 Spatial Distribution of NQPDA-1200

4.8 GBDT Results

4.8.1 Urban Vitality GBDT Results

The findings illustrated in Figure 67 underscore the significance of various factors, as determined by the Gradient Boosting Decision Tree (GBDT) algorithm.

Notably, the top five factors identified through the feature importance analysis are TPBT-1200, Traffic, Imageability, Shopping, and Food. Each of these factors plays a crucial role in influencing the dynamics of urban environments and contributes to the overall vitality of city streets.

The GBDT model, employed to assess predictive effectiveness, demonstrates exceptional performance metrics. With an R^2 value of 1 in the training set and a commendable R^2 of 0.803 in the test set, the model showcases a robust fitting effect.

These metrics attest to the GBDT's ability to capture and predict the intricate relationships among the selected features, thereby providing valuable insights for urban planners and decision-makers.

In practical terms, the outcomes of this study advocate for a strategic approach in urban planning and renewal initiatives. Emphasizing the highly ranked indicators, such as TPBT-1200, Traffic, Imageability, Shopping, and Food, is crucial.

By prioritizing these factors, urban planners can channel resources and efforts towards renovating city streets with notable vitality. This approach aims not only to preserve the original charm of vibrant areas but also to enhance the overall liveliness and appeal of the cityscape.

The research underscores the importance of leveraging advanced data-driven methodologies, like GBDT, in urban planning processes.

By incorporating such insights, city planners can make informed decisions that align with the unique characteristics and preferences of urban residents, fostering sustainable development and an improved quality of life.

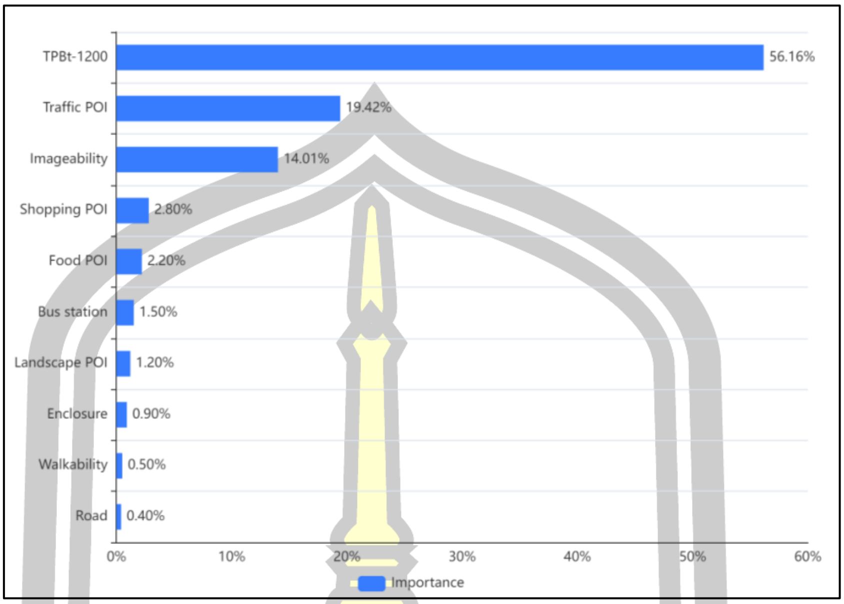

Figure 67 Feature Importance Ranking Results

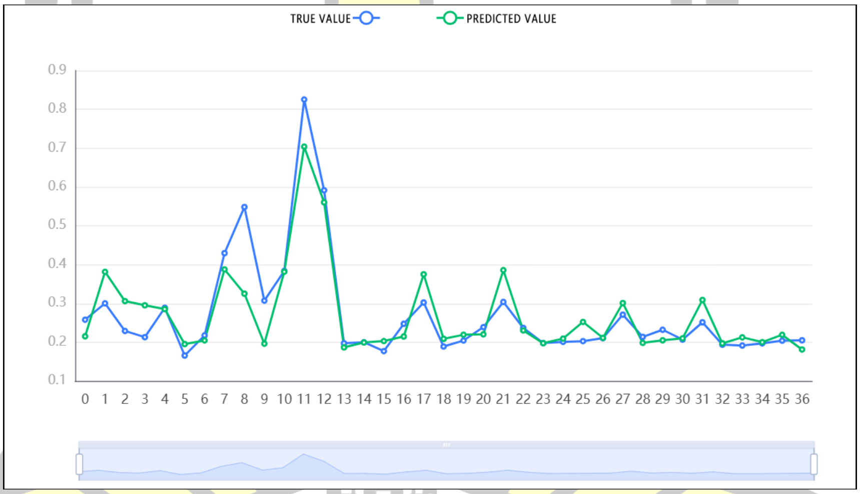

Figure 68 The Curve of the True Value and Predicted Value of GBDT

4.8.2 Weekday and Weekend GBDT Results

4.8.2.1 Weekdays Analysis

As depicted in Figure 69, the weekdays exhibit a distinct pattern of feature importance, providing crucial insights into the dynamics of urban spaces during typical working days. At the forefront of significance is TPBT-1200, commanding a notable 60.6%. This underscores the paramount importance of traffic accessibility during weekdays, reflecting the heightened demand for efficient transportation infrastructure to facilitate daily commutes.

Following closely, Greenness emerges as the second-highest factor, contributing 11.7%. The emphasis on green spaces during weekdays suggests a desire for natural elements in urban environments, likely to provide respite amidst bustling work routines. Imageability and Landscape contribute 8.3% and 4.0%, respectively, indicating the importance of visually appealing and well-designed surroundings. Additionally, the role of Food, with a significance of 3.3%, highlights the significance of culinary amenities in enhancing the weekday urban experience.

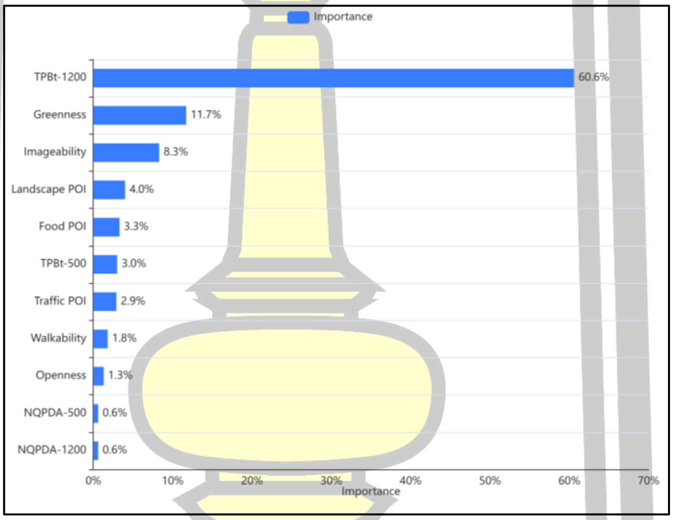

Figure 69 Feature Importance of Weekday’s Ranking Results

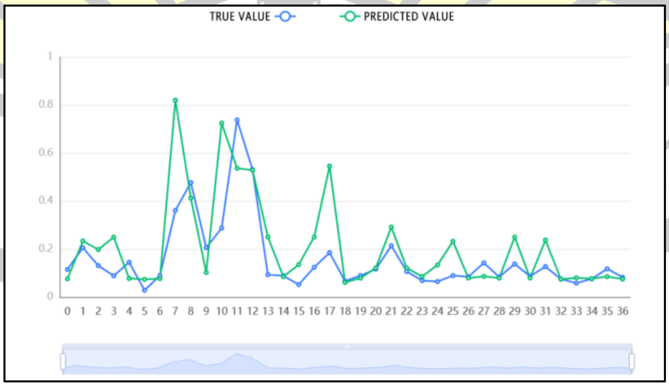

Figure 70 The Curve of the True Value and Predicted Value of GBDT

4.8.2.2 Weekends Analysis

Turning attention to Figure 71, the landscape of feature importance during weekends unfolds a nuanced perspective. Once again, TPBT-1200 commands the top spot with a significance of 61.6%. This consistent priority underscores the year-round importance of traffic accessibility. However, the emergence of Bus Station as the second-highest factor at 13.9% signifies a shift in weekend priorities, emphasizing the role of public transport density during leisure periods.

Imageability and Traffic, contributing 8.0% and 4.1%, respectively, maintain their significance, underlining the continued importance of visually appealing environments and the consideration of traffic even during weekends. Landscape, with 3.1%, reinforces the enduring importance of well-designed urban spaces.

This unique weekend feature importance profile suggests a blend of accessibility and leisure-oriented factors that contribute to the overall attractiveness of urban areas during non-working days.

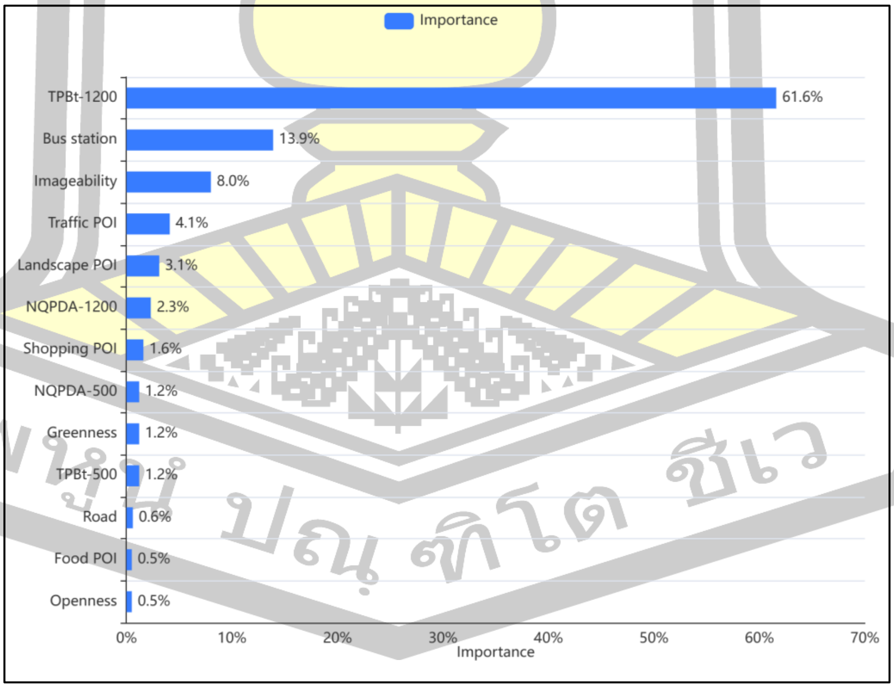

Figure 71 Feature Importance of Weekend’s Ranking Results

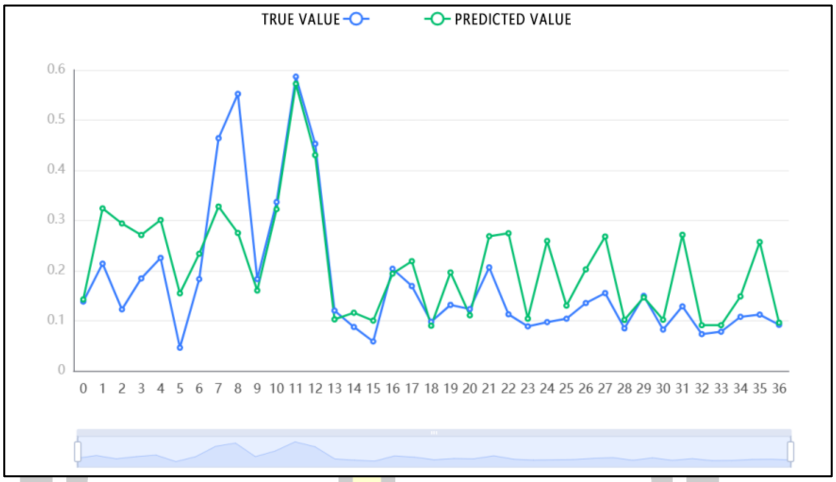

Figure 72 The Curve of the True Value and Predicted Value of GBDT

The nuanced differentiation between weekdays and weekends in feature importance underscores the importance of tailoring urban planning strategies to temporal patterns. During weekdays, a focus on enhancing traffic accessibility and integrating green spaces aligns with the demands of the typical workweek. On weekends, the emphasis shifts towards optimizing public transport and preserving a visually appealing urban landscape, catering to the recreational needs of residents. By prioritizing these highly ranked indicators in a context-specific manner, urban planners can effectively contribute to the creation of resilient, dynamic, and people-centric urban environments.

Chapter5 Discussion

5.1 Spatial-temporal Dynamics of Population Density in Yinchuan City

The study reveals the dynamic changes in population density across different regions of Yinchuan City over time. The central urban area experienced the most significant fluctuations, followed by the urban periphery. A unique spatial-temporal pattern emerged, indicating an influx of population towards the central urban area during the day and a trend of moving away from the central urban area during the night. Population density also exhibited variations during weekdays and weekends.

On weekdays, population density in each region showed more pronounced fluctuations during specific time intervals: 7:00-9:00, 11:00-13:00, 15:00-16:00, and 17:00-22:00. On weekends, population density fluctuations were more intense during the time intervals of 9:00-14:00 and 19:00-23:00.

Population density activities differed between weekdays and weekends. On weekdays, population density in various regions exhibited intensified fluctuations during specific time intervals, highlighting the importance of factors such as traffic accessibility (TPBT-1200) and green visibility. In comparison to weekdays, weekend activities were delayed, and the nature of activities varied.

On weekdays, activities mainly included rest and work-related activities, while on weekends, activity times changed, and the nature of activities became more diverse and random, focusing on social visits, shopping, and leisure activities in suburban or rural areas.

5.1.1 Differences in the Spatial Distribution of Urban vitality between Weekdays and Weekends

In this study, the distribution characteristics of urban vitality on weekdays and weekends in Yinchuan City are analyzed, and it is found that the spatial distribution of urban vitality on weekdays and weekends is different. This is because different areas of the city have different activities and functions during working hours and non-working hours. The following is a detailed analysis of the spatial distribution of weekday urban vitality and weekend urban vitality in Yinchuan City.

5.1.1.1 Spatial Distribution of Weekday Urban Vitality

The distribution of weekday urban vitality shows obvious Morning and Evening peak characteristics. Weekday urban vitality is mainly concentrated in commercial areas, office areas and transportation hubs in the central urban areas of Xing Qing District, Jinfeng District and Xi Xia District. The vitality of these areas' peaks during 8:00-12:00 and 14:00-18:00 when people from residential areas commute to commercial and office areas. While at 12:00-14:00 and 18:00-20:00, people return from commercial and office areas to residential areas, and the vitality of these areas will decrease, as identified in the research by Zhang (2019) and Qing (2018).These districts are the commercial, cultural, and administrative centers of Yinchuan, concentrating many commercial facilities such as shopping malls, supermarkets, restaurants and cafes, as well as offices such as government agencies, banks and law offices. These facilities attract people to come to work and live in the area, making this area a high level of urban vitality. The main commercial areas in Yinchuan include areas such as Xinhua Street, Gulou Street, and Nan Men Square. These areas have numerous stores, restaurants, entertainment facilities, etc., which attract many consumers and tourists to come to shop, dine and play. These activities further enhance the urban vitality of these areas.

5.1.1.2 Spatial Distribution of Urban Vitality on Weekends

During weekends, the spatial distribution of urban vitality is more diversified and decentralized, as mentioned in the research by A. Diyanah Inani and K. Hafiza Abdul (2012). Moreover, the distribution of urban vitality on weekends is more balanced than on weekdays, as mentioned in the research by G. Xin (2012). People are no longer constrained by the need to commute and are free to organize their activities. As a result, urban vitality may be more decentralized, including a wide range of activities such as shopping, tourism, and entertainment. Some public places, such as parks, shopping malls and museums, may become busier on weekends as more people have time to visit them. In addition, some leisure and entertainment venues and tourist attractions may become hotspots of urban vitality.

Weekend urban vitality is concentrated in areas such as parks, tourist attractions and shopping centers. These areas include Zhongshan Park, Hai Bao Park and Nan Feng Park. These parks and squares are good places for people to relax and have fun, especially on weekends, where people engage in a variety of outdoor activities, such as walking, running, playing ball games, singing, dancing, etc., which makes urban vitality higher in these areas. Yinchuan is a city full of history and culture, with many tourist attractions, such as the Mausoleum of the Xi Xia Kings, the rock paintings on Helan Mountain, and the Zhen Bei Bao Movie Town. On weekends, these attractions attract many tourists to visit and learn from them, further enhancing the urban vitality of these areas. There are many shopping centers in Yinchuan, such as Wanda Plaza, Century Golden Flower Shopping Center and Xinbai supermarket. These shopping centers attract many consumers to shop and dine on weekends, making the urban vitality of these areas higher.

In general, the spatial distribution of weekday urban vitality and weekend urban vitality in Yinchuan is different. On weekdays, areas with high urban vitality are mainly concentrated in the city center and major business districts. On weekends, areas with high urban vitality are mainly concentrated in parks, squares, tourist attractions and shopping centers. This difference reflects the different functions and activities of the city at different times of the day and further influences the development and planning of the city.

5.2 Impact of the Built Environment on Urban Vitality

The 5D variables of the built environment, including land use diversity, design, traffic distance, and traffic accessibility, have a significant impact on urban vitality in Yinchuan City. Variables such as Landscape, Hotel, Shopping, Openness, Greenness, Imageability, Road, Bus station, TPBT-500, NQPTE-500, and TPBT-1200 show a positive correlation with urban vitality. This emphasizes the importance of well-designed urban spaces, convenient transportation, and vibrant commercial areas. Among these, shopping, living, and dining services constitute fundamental land uses, and streets with high road density and well-developed public transportation exhibit higher urban vitality.

5.2.1 Spatial Analysis of Accessibility and Centralization

The study conducted accessibility analysis using radii of 0.5 kilometers and 1.2 kilometers, revealing a positive correlation between NQPDA, TPBT, and centralization. Despite a unified central area with high accessibility, the study emphasizes the need to enhance overall urban accessibility. At the pedestrian scale, areas with high accessibility exhibit a scattered distribution, indicating smaller activity ranges for urban residents in areas with less convenient transportation or lower activity preferences.

At both 0.5 km and 1.2 km radii, NQPDA and TPBT show positive correlations, indicating relatively consistent accessibility and centrality of the street network in the central urban area of Yinchuan. The central area of Yinchuan exhibits lower centrality when reaching various regions, gradually increasing with distance from the center. The overall spatial accessibility of the city still needs improvement. At the pedestrian scale, areas with high accessibility within the city exhibit a scattered distribution with numerous small, high-accessibility points. Regions with lower accessibility are more extensive, indicating smaller activity ranges for urban residents in areas with less convenient transportation or lower willingness to travel. While Xing Qing District possesses good concentration and attractiveness with strong transportation capacity and relief, making it easily accessible, districts like Jinfeng and Xi Xia exhibit strong traffic potential but are "distant" and less accessible. From a local perspective, Xing Qing District serves as the core, encompassing attributes of attraction, concentration, and traversing functions, while Jinfeng District primarily performs transportation and central gathering functions, and Xi Xia District, though easily accessible, lacks attractiveness and concentration.

5.2.2 Geographic Distribution and Urban Vitality

High-high agglomeration areas are mainly located in central regions such as Xing Qing, Jinfeng, and Xi Xia, signifying regions with higher urban vitality. The study emphasizes the interconnectedness between these regions, forming mutually supportive agglomeration areas. Conversely, low-low agglomeration areas are distributed around the periphery, representing regions with lower and slower-growing urban vitality levels.

5.2.3 Spatial Variations in the impact of the Built Environment on Urban Vitality

Geographically Weighted Regression (GWR) reveals spatial variations in the impact of the built environment on urban vitality, indicating subtle relationships between socio-economic factors, environmental context, and observed spatial variations in different regions of Yinchuan. This aligns with previous research emphasizing the influence of socio-economic and environmental factors on regional dynamics.

i. Urban Traffic and Road Improvement

In 2021, Yinchuan City launched the "Three-Year Action Plan for Urban Renewal (2021-2023)," followed by the implementation of the "6+N" traffic congestion relief project in 2022. This initiative involved constructing new main roads, opening dead-end streets, and establishing slow-moving green pathways. Yinchuan City underwent a rapid transformation of key segments such as He Lan Shan Road, Zhengyuan Street, and Bao hu Road to create an urban expressway network. Projects like the extension of Wenchang Street and Feng Huang Street to the north, and the extension of Yue Hai Road and Harbin Road to the east were undertaken. Additionally, plans for 38 urban primary and secondary arteries, including Yanqing Street, were outlined to enhance road traffic efficiency. Thirty-four dead-end streets, including Xinhua Road and Liu Pan Shan Road, were opened, ensuring smooth traffic flow throughout the city. The urban road network achieved seamless and rapid transportation in the main network within the city, with secondary roads interconnected.

ii. Green City Development and Cultural Feature Construction

Since 2022, Yinchuan City has not only worked on clearing and diverting major roads but has also continuously improved micro-circulation in urban roads. Hard landscaping upgrades have enhanced the safety of pedestrians and non-motorized vehicles, while green pathways along lakes have encouraged participation in green commuting. The construction of green pathways enriches diverse green travel choices under the "Bus + Slow Travel" concept, forming a commuting system highly integrated with "Commuting circles," "Living circles," and "Business Circles." The implementation of the Lakeside Greenway project has connected surrounding landscapes, forming a park chain and comprehensive landscape complex. Jinfeng District promotes the development of a healthy greenway system, combined with waterside squares and recreational stations, enhancing the urban impression, and improving the living environment.

iii. Commercial District Transformation and Urban Renewal

In June 2023, Xing Qing District initiated the transformation of five characteristic commercial demonstration streets and the construction of a large-scale smart business district. Yinchuan City's Gulou South Street is a bustling commercial street that initiated a protection and renewal plan for the core area of the historical city center, enhancing the image of the commercial street district. The transformation of Xinhua Street business district includes infrastructure improvement, municipal integration, building facades, and lighting planning, optimizing the city's functional layout, and elevating urban management standards. Xing Qing District is driving the transformation of the Gulou to Yu Huang Pavilion historical and cultural block, refurbishing street facades to create a modern urban style with a historical and cultural atmosphere. Xing Qing District's Jing De Night Market cultural and tourism-themed commercial street leverages its strong commercial foundation by showcasing tourist attractions, old streets, and culinary delights through lighting and art displays. Jinfeng District is creating the "Most Beautiful Way Home" by renovating Snowflake Alley and Xiang An Alley, elevating the quality and vitality of the commercial area.

5.2.4 Differences in Social Activity Patterns

The study identifies significant differences in social activity patterns in Yinchuan City between weekdays and weekends. On weekdays, residents primarily engage in rest and work activities, highlighting the need for a balance between life and career. On weekends, social activities become more diverse and random, reflecting residents' tendency to choose a variety of entertainment and leisure activities when afforded more free time.

Through an analysis of accessibility radii of 0.5 kilometers and 1.2 kilometers, the study explores behavioral patterns of urban residents. Results show that in areas with high accessibility, the activity range of urban residents appears more scattered, indicating a preference for broader activities in areas with convenient transportation. Conversely, in areas with low accessibility, the activity range of urban residents is smaller, possibly constrained by inconvenient transportation or lower willingness to travel.

By analyzing the relationship between the built environment and urban centrality, it is found that at radii of 0.5 kilometers and 1.2 kilometers, NQPDA and TPBT exhibit a positive correlation. This indicates a relatively consistent accessibility and centrality of the street network in the central urban area of Yinchuan. However, there is still a need to enhance overall spatial accessibility to better meet the diverse needs of residents.

These research findings not only provide in-depth insights for urban planning and development in Yinchuan City but also offer valuable lessons for sustainable development studies in other cities. In future urban planning, factors such as population activity patterns, built environment characteristics, and accessibility should be thoroughly considered to create a more vibrant, livable, and sustainable urban space.

Chapter6 Strategies to Enhance Urban Vitality

6.1 Strategies to Enhance Urban Vitality on Weekdays and Weekends

By analyzing the built environment factors and weekday and weekend urban vitality in Yinchuan, we found that Density, Diversity, Design, Distance to transport, and Destination accessibility have a significant impact on urban vitality. In terms of enhancing weekday and weekend urban vitality, we can develop strategies based on the 5D variables of the built environment. Some specific strategies are suggested below.

6.1.1 Strategies for Enhancing Urban Vitality from Density

In Yinchuan City, the distribution of urban density has a significant impact on urban vitality. Through reasonable planning of urban density, it is possible to promote urban economic development and enhance people's quality of life. In core commercial and office areas, building density is appropriately increased to promote intensive use of commercial and office space. This can be achieved by optimizing land use, increasing the number of floors, or encouraging vertical development. This will provide convenient commuting conditions for office workers during the weekday, while enhancing the prosperity and vitality of the commercial districts. In residential areas, a reasonable building density is maintained while focusing on the design and utilization of public space[110, 117]. This creates more places for social interaction and activities, enhancing community interaction and vitality.

On weekends, residents can fully utilize these public spaces for leisure activities such as walking, fitness, and children's games, thus boosting community cohesion and vitality. At the urban fringe, the layout of public transportation systems and service facilities is optimized to guide urban development towards the periphery, forming a multi-center urban structure. This approach reduces pressure on the central city and promotes overall balanced city development. On weekends, these peripheral areas become destinations for people's leisure and tourism activities, such as excursions, camping, and agricultural adventures, all of which increase the attractiveness of the city.

6.1.2 Strategies for Enhancing Urban Vitality from Diversity

Increasing the diversity of the city can attract more people to come to work and visit. During weekdays, we can encourage the development of different types of commercial and office space, such as technology, finance, arts, etc., to attract talents and businesses from different sectors. On weekends, we can increase the diversity of entertainment and recreational facilities in the city, such as cinemas, museums, and parks. In addition, we can increase the diversity and attractiveness of the city by organizing various cultural activities and festivals, such as music festivals, art exhibitions and food festivals.

6.1.3 Strategies for Enhancing Urban Vitality from Design

Good urban design can enhance the charm and vitality of a city. In the design process, the creation and utilization of public spaces must be given attention. Parks, squares, and streets are some examples of public spaces that are not only a place for people to rest and unwind but also a significant symbol and attraction of the city. By designing unique and distinctive parks, squares, and streets, the image and attractiveness of the city can be further enhanced. During weekdays, these public spaces provide a place for office workers to relax and rejuvenate; during weekends, they become a destination for individuals to relax and have fun, engaging in activities such as walking, exercising, and gathering. Furthermore, we can improve the environmental quality of the city by increasing the greenery and beautification of the city. For instance, flowers, plants, and trees can be planted on both sides of the streets, or artworks like fountains and sculptures can be installed in public spaces. In conclusion, thoughtful urban design can significantly contribute to enhancing the charm and vitality of a city.

6.1.4 Strategies for Enhancing Urban Vitality from Distance to Transit

Transit stations are one of the important infrastructures of a city, which can facilitate people's travel and promote the development of the city. On weekdays, we can optimize the public transport network and increase the number and frequency of bus stops and metro stations to facilitate people's commuting and travel. At the same time, we can encourage people to use low carbon means of transportation such as bicycles or walking. On weekends, we can increase the accessibility of urban tourist attractions, such as setting up special tourist lines or free buses around the attractions. In addition, we can encourage travelers to use free travel modes such as bike sharing or car rental.

6.1.5 Strategies for Enhancing Urban Vitality from Destination Accessibility

Improving the accessibility of destinations can significantly enhance the attractiveness and vitality of a city. On weekdays, the accessibility of commercial and office areas can be optimized by installing clear signs or providing map navigation services. This will enable people to effortlessly reach their destinations and locate suitable parking spaces. On weekends, we can further improve the accessibility to the city's entertainment and recreational facilities. For instance, we can establish special tour routes or sightseeing buses that connect various attractions and activity venues. Additionally, we can provide convenient services such as free Wi-Fi and charging facilities to enhance the overall visitor experience. By implementing these measures, we can ensure that everyone, regardless of their mode of transportation, can easily access the city's various attractions, thus promoting a lively and vibrant urban environment.

In summary, through the implementation of measures such as rational planning of urban density, increasing urban diversity, optimizing urban design, and improving accessibility to transportation stations and destinations, we can effectively enhance urban vitality on weekdays and weekends. These measures need to be coordinated and supported to maximize the combined benefits and ultimately achieve a comprehensive increase in urban vitality.

6.2 Strategies to enhance Urban Vitality through the Built Environment

Enhancing urban vitality is a comprehensive goal that requires addressing various aspects of the built environment. The 5D variables of the built environment (density, diversity, design, distance to transit stations, and destination accessibility) are crucial factors influencing urban vitality. Therefore, a series of strategies can be formulated to optimize these aspects and promote sustainable development and improved quality of life for residents in Yinchuan city. Here are some specific strategy recommendations.

6.2.1 Strategies for Enhancing Urban Vitality from Density

i. Smart City Planning

Implement intelligent city planning using advanced technology and data analysis to plan the city's development scientifically and reasonably. Through smart planning, a more accurate assessment of the needs and potential of various regions can be achieved, ensuring the rational distribution of urban density, and coordinated functional layouts.

ii. High-Level Urban Construction

Encourage the implementation of high-level urban construction in the central areas to enhance land utilization efficiency. High-rise structures not only accommodate a larger population but also contribute to a unique city skyline, enhancing the city's image and attracting increased human and resource flow.

iii. Optimized Land Use Mix

Foster mixed land use by integrating commercial, residential, cultural, and recreational zones. Creating a more vibrant and diverse urban environment involves placing commercial facilities around residential areas, enhancing residents' convenience and social interactions.

iv. Increased Density in Central Areas

Focus on elevating the density level in the city center, particularly by introducing more business, cultural, and technological elements. This transforms the city center into a hub for people, information, and resources, thereby increasing urban vitality.

v. Development of Dense Communities

Implement plans for developing dense communities when expanding urban areas. This strategy encourages the concentration of facilities and services within communities, fostering a more prosperous local atmosphere and stimulating social activities among residents.

vi. Guidance of Population Movement

Design and plan to guide population movement, achieving a balanced distribution of daytime work and nighttime leisure. For example, enhancing entertainment and cultural facilities in areas with intensive daytime work can encourage people to engage in activities in surrounding regions, increasing nighttime vibrancy.

vii. Enhancement of Public Transit Accessibility

Density is closely related to public transportation; thus, improving public transit accessibility is an effective means of enhancing urban density. Optimize public transportation networks, provide efficient and convenient transit services, reduce private vehicle usage, and encourage people to rely more on public transportation.

viii. Encouragement of Low-Carbon Travel

Formulate policies to encourage low-carbon travel, supporting green modes of transportation such as walking and cycling. Construct bike lanes, pedestrian streets, and provide shared bike services to reduce traffic congestion and enhance urban environmental quality.

ix. Expansion of Green Spaces

Reasonably allocate green spaces in high-density areas, offering places for urban residents to relax and entertain. Green spaces not only beautify the urban environment but also contribute to increased resident satisfaction and overall livability.

x. Encouragement of Innovative Development

Focus not only on the quantitative growth but also on the qualitative improvement of density. Encourage innovative developments, such as the introduction of green building technologies and intelligent transportation systems, to maintain sustainable development on the foundation of high density.

Through the implementation of these strategies, Yinchuan City's urban vitality can be comprehensively enhanced, achieving optimized urban spaces and sustainable development. Density planning is at the core of urban planning, and through scientifically sound planning and design, cities can become more attractive, dynamic, and competitive.

6.2.2 Strategies for Enhancing Urban Vitality from Diversity

i. Cultural Diversity

Encourage and support the integration of diverse cultural elements to create a culturally diverse urban atmosphere. Establish cultural exchange centers, diverse art exhibition spaces, and host cultural festivals to facilitate communication and collaboration among different cultural groups, enhancing the city's cultural appeal.

ii. Economic Industry Diversity

Support and develop a diversified industrial structure to avoid overreliance on a single industry. Encourage the entry of emerging industries and innovative enterprises, nurture local industries, enhance the city's economic resilience, and provide residents with more employment opportunities.

iii. Commercial and Retail Diversity

Promote diversified business development in commercial areas by introducing various types of retail formats, such as small creative markets, farmers' markets, and specialty shops. Enrich residents' shopping choices and create more vibrant and unique commercial districts.

iv. Architectural and Urban Design Diversity

Adopt diverse architectural styles and urban designs to break away from a singular architectural model. Encourage innovative architectural design concepts to enhance the city's visual appeal. Through flexible urban planning, create distinctive urban zones.

v. Community and Residential Form Diversity

Support various types of communities and residential forms, including shared housing, senior communities, and youth entrepreneurship communities. Encourage people of different ages, incomes, and cultural backgrounds to live together in the same city, fostering a more inclusive and diverse community culture.

vi. Education and Research Field Diversity

Support diverse educational institutions and research centers by introducing higher education institutions, research institutes, and innovation centers from different fields. Promote collaboration between academia, industry, and research to drive technological innovation and the development of the knowledge industry.

vii. Food and Culinary Culture Diversity

Advocate and support restaurants from different cultural backgrounds, offering a diverse range of culinary options. Encourage innovative culinary formats, host food festivals, promote the exchange of local and international culinary cultures, and increase the city's culinary attractiveness.

viii. Health and Leisure Activity Diversity

Develop diverse health and leisure facilities, including parks, sports fields, and leisure squares. Support various types of sports events, cultural performances, and social activities, allowing residents to choose from a rich array of entertainment options.

ix. Institutional and Governance Diversity

Promote diverse governance and management mechanisms, including collaboration between the government and social organizations, community self-governance, etc. Advocate for citizen participation to ensure the voices of different groups are fully expressed, forming a more inclusive and diverse urban governance system.

x. Environmental and Sustainability Diversity

Prioritize urban greening and environmental protection, providing diverse ecological landscapes and public green spaces. Encourage low-carbon and sustainable urban development principles, promote the application of clean energy, making the city more diverse and sustainable across economic, social, and ecological dimensions.

Through these strategies, diverse development in various aspects can be promoted in Yinchuan City, increasing its vibrancy, and making it more attractive, inclusive, and sustainable. Diverse urban development attracts talents and resources from different groups, injecting new vitality into the city's prosperity and innovation.

6.2.3 Strategies for Enhancing Urban Vitality from Design

To enhance the urban vitality of Yinchuan City from a design perspective, the following strategies can be considered.

i. Ecologically Friendly Design

Emphasize ecologically friendly design in urban construction and redevelopment. Utilize green building technologies, construct green roofs, vertical gardens, and other green elements to increase natural features in the city, improve the urban environment, and enhance the quality of life for residents.

ii. Public Space Design

Optimize the design of urban public spaces to create more pleasant environments. This includes planning for squares, pedestrian streets, community parks, etc., providing more leisure and recreational facilities to promote interaction among residents. Design attractive public spaces such as parks, squares, and pedestrian streets to facilitate interaction and socialization. Consider organizing cultural events, art exhibitions, and community gatherings in these spaces to make them the focal points of urban vitality.

iii. Urban Landscape Design

Beautify the urban landscape, including building facades, public spaces, and green belts, to create an appealing cityscape. Use local elements, such as traditional architectural styles or cultural symbols, to give the city a distinctive character.

iv. Green Urban Design

Emphasize green and sustainable urban design, incorporating features like green roofs, urban agriculture, and energy-efficient buildings. This helps improve environmental quality and attracts people to live and work in the city.

v. Creative Industry Parks

Design and develop creative industry parks to attract creative enterprises. This fosters innovation and contributes to the diversified development of the city's economy.

vi. Cultural Preservation and Reuse

Protect and repurpose Yinchuan's historical and cultural heritage by transforming traditional buildings into cultural centers, art studios, or museums, enriching the city's cultural foundation.

vii. Digital City Management

Implement advanced technology in the form of a digital city management system to enhance overall operational efficiency. This includes intelligent traffic management and smart parking systems, raising the city's overall level of intelligence.

viii. Community Design and Engagement

Encourage community residents to participate in urban planning and management through community design. This helps build stronger community relationships and enhances social cohesion in the city.

These design strategies can be integrated into a comprehensive urban development plan to boost the urban vitality of Yinchuan. During implementation, collaboration with local government, residents, and businesses is crucial to ensuring the effectiveness and sustainability of these strategies.

6.2.4 Strategies for Enhancing Urban Vitality from Distance to Transit

Here are some strategies focused on improving urban vitality in Yinchuan City, starting from the aspect of proximity to transportation hubs.

i. Enhance Public Transportation Coverage

Expand and optimize the public transportation network to ensure a more reasonable density and distribution of transportation hubs, meeting the diverse travel needs of residents in different areas. Introduce more public transportation routes, especially those connecting major commercial, residential, and cultural centers, enhancing connectivity within the city.

ii. Improve Transit Facilities

Construct high-quality transfer facilities at transportation hubs and major stations to provide a convenient and efficient transfer experience, reducing travel time. Implement directional signage to guide citizens through seamless transfers, improving the accessibility of the transportation system.

iii. Promote Sustainable Modes of Transportation

Encourage walking and cycling by developing convenient sidewalks and bike lanes, promoting short-distance travel. Advocate for electric modes of transportation, such as e-bikes and e-scooters, to reduce reliance on traditional transportation methods.

iv. Optimize Surroundings of Transportation Hubs

Enhance the urban landscape around transportation hubs, creating a pleasant environment to attract more people to linger. Establish rest areas, cafes, and snack stalls to increase the social and vibrant aspects of transportation hubs.

v. Intelligent Traffic Management System

Introduce an intelligent traffic management system to optimize traffic flow through data analysis, improving efficiency around transportation hubs. Promote real-time information services to provide accurate traffic information, enabling residents to stay informed about travel conditions.

"Smart parking" initiatives assist in traffic flow management. Yinchuan City has studied the construction of parking lots and multi-level parking facilities, setting up on-street parking spaces, utilizing idle land for temporary parking lots, and establishing a "Smart Parking" static traffic management system, completing the upgrade of 103 parking lots.

The system includes features such as parking guidance, reservation of parking spaces, and reverse car location, aiming to meet the parking needs of citizens.

vi. Enhance Accessibility of Transportation Hubs

Establish an adequate number of transportation hubs to cover major urban areas, minimizing the cost for citizens to walk or drive to the stations. Consider multimodal integration to seamlessly connect transportation hubs with other modes of transportation, such as ridesharing, taxis, and bike-sharing.

vii. Support Innovative Transportation Projects

Encourage and support innovative transportation projects, such as autonomous vehicles and aerial transportation, to enhance the city's innovative image. Support sharing economy models, such as ride-sharing services and bike-sharing, to improve the efficiency of transportation resources.

viii. Coordinate with Urban Planning

Harmonize transportation planning with overall urban planning to ensure the organic integration of transportation hubs with residential and commercial areas. Strengthen the regional leading role of transportation hubs to promote the development of surrounding areas.

ix. Green Transportation Measures

Promote green travel by encouraging the use of electric public transportation, reducing the environmental impact of transportation. Establish green parking lots and charging stations to provide eco-friendly parking and charging services.

x. Community Engagement and Feedback Mechanism

Establish a community engagement mechanism for transportation hubs, seeking input and suggestions from residents to enhance the adaptability of transportation planning. Create feedback channels to enable citizens to evaluate transportation hub services, facilitating timely improvements where services may fall short.

By addressing various factors such as public transportation, sustainable transportation, and intelligent traffic management, these strategies, starting from the proximity to transportation hubs, can comprehensively enhance the urban vitality of Yinchuan City, providing residents with a more convenient, comfortable, and sustainable travel environment.

6.2.5 Strategies for Enhancing Urban Vitality from Destination Accessibility

Elevating the urban vitality of Yinchuan City involves optimizing destination accessibility to ensure citizens can conveniently and efficiently reach various destinations. Here are a series of strategies starting from destination accessibility to promote the enhancement of urban vitality.

i. Diversified Transportation Modes

Provide a variety of transportation options, including public transit, bike-sharing, walking, taxis, etc., to meet the diverse travel needs of different demographics. Encourage sustainable travel methods such as walking, cycling, and support the use of electric transportation.

ii. Dense Layout of Public Facilities

Construct densely located public facilities across different city zones, including cultural centers, commercial districts, medical service centers, etc., ensuring citizens can fulfill various needs in their proximity. Integrate public facilities closely with residential areas to reduce the distance citizens need to travel for services.

iii. Smart Urban Planning

Utilize advanced smart urban planning technologies to analyze data, determine destination demands, optimize city layouts, and enhance destination accessibility. Adjust the location and distribution of destinations based on citizens' travel data to accommodate daily needs.

iv. Enhance Attractiveness of Commercial and Cultural Centers

Design and improve the environment of commercial and cultural centers, making them ideal places for citizens for leisure, shopping, and cultural activities. Introduce attractive businesses and cultural events to enhance the appeal of these areas.

v. Convenient Transport Hubs

Build transportation hubs where various modes of transportation converge, improving connectivity across different regions and reducing citizens' time and costs for transportation transfers. Ensure convenient facilities around transport hubs, such as service counters and information centers, to help citizens easily find and reach their destinations.

vi. Guide Urban Development Toward Sustainable Goals

Guide development through urban planning, concentrating major destinations in areas with convenient transportation to reduce the difficulty citizens face in reaching these places. Include destination accessibility in considerations for sustainable urban development, ensuring city sustainability through spatial planning.

vii. Improve Accessibility of Public Facilities

Develop robust transportation infrastructure around public facilities to ensure citizens can easily and quickly reach them. Enhance accessibility features of public facilities to ensure that elderly and disabled individuals can easily reach their destinations.

viii. Promote Digital Services

Drive the digitization of destination services, such as online shopping and telemedicine, to reduce citizens' need to physically visit specific destinations. Provide real-time destination information through digital platforms to help citizens better plan and manage their activities.

ix. Community Engagement and Feedback Mechanism

Incorporate opinions and suggestions from community residents, especially regarding destination accessibility, to better meet citizens' expectations. Establish a feedback mechanism, encouraging citizens to evaluate the quality and accessibility of destination services, facilitating real-time adjustments.

x. Cross-Industry Collaboration

Promote collaboration across different industries, encouraging cooperation between businesses and transportation service providers, cultural institutions, etc., to improve overall accessibility across various sectors. Through collaboration, create a more comprehensive destination accessibility system, providing citizens with more holistic and efficient services.

By comprehensively implementing these strategies focused on destination accessibility, Yinchuan City can effectively enhance urban vitality, creating a more livable, convenient, and attractive urban space.

Chapter7 Conclusion and Future Work

7.1 Conclusion

This study assesses the impact of the built environment on urban energy in Yinchuan City using OLS, Moran's I, GWR, and GBDT models. A comprehensive analysis is conducted on various aspects, including population dynamics, population density activities, built environment, accessibility, and centralization, aiming to gain a profound understanding of the spatial characteristics, and driving factors of urban vitality. The following is a summary of the research:

i. Population Dynamics and Activity Patterns.

The spatiotemporal dynamics of population density in Yinchuan City indicate significant differences in population distribution between the city center and peripheral areas. Population inflow towards the central city is observed during the daytime, exhibiting a centrifugal trend at night. Variances in population activity patterns on weekdays and weekends emphasize the diversity and variability of urban life.

ii. Impact of the Built Environment on Urban Vitality.

Built environment factors across four dimensions significantly contribute to urban vitality. There is a positive correlation between Yinchuan's built environment and its urban liveliness, with high urban vitality concentration primarily found in the central districts of Xing Qing, Jinfeng, and Xi Xia. The correlation between urban vitality and factors such as landscape, hotels, shopping, and greenery underscores the crucial role of urban planning and design in enhancing urban vitality.

iii. Spatial Analysis of Accessibility and Centralization.

Accessibility analysis reveals behavioral pattern differences between the central and peripheral regions. Despite high accessibility in central areas, an overall improvement in citywide accessibility is necessary. High accessibility areas exhibit a scattered distribution, emphasizing smaller activity ranges in areas with inconvenient transportation or lower activity preferences.

iv. Geographical Distribution and Urban Vitality.

Geographical analysis reveals the distribution of high-high aggregation areas of urban vitality, providing valuable insights for urban planning. High-vitality areas form interconnected supporting clusters, while low-vitality areas are dispersed around the periphery, requiring more targeted development strategies.

v. Geographically Weighted Regression (GWR).

The application of the GWR model allows for a detailed understanding of the spatial variation in the impact of the built environment on urban vitality across different regions and times. The subtle relationship between socioeconomic factors and the urban spatial characteristics highlights the diversity of urban development.

vi. Differences in Social Activity Patterns.

Significant differences are found in social activity patterns between weekdays and weekends, emphasizing residents' need for a balance between life and work. On weekends, social activities are more diverse and random, reflecting residents' inclination to choose a variety of entertainment and leisure activities when they have more free time.

vii. Urban Resident Behavior Patterns within Accessibility Radii.

Through accessibility radius analysis, the study explores urban resident behavior patterns. Results show that in high-accessibility areas, residents' activity ranges are more scattered, emphasizing that in areas with convenient transportation, people are more willing to engage in a wider range of activities.

viii. Relationship between the Built Environment and Urban Centrality.

Analyzing the relationship between the built environment and urban centrality reveals a positive correlation between NQPDA and TPBT at different radii. This indicates that the street network in the central city area has relatively consistent accessibility and centrality, but an overall improvement in spatial accessibility is still necessary.

ix. Gradient Boosting Decision Trees (GBDT) Model.

The GBDT model establishes a hierarchy of variable importance, aiding policymakers in focusing on key areas for urban development and providing a framework for future urban planning.

In conclusion, this study provides in-depth insights for the urban planning and development of Yinchuan City and valuable lessons for the sustainable development research of other cities. In future urban planning, factors such as population activity patterns, built environment characteristics, and accessibility should be comprehensively considered to create a more vibrant, livable, and sustainable urban space.

7.2 Limitation and Future Work

7.2.1Limitations

i. Data Limitation

One limitation of this study lies in the availability and quality of data. Discrepancies may exist between different data sources, and certain crucial data may be either unavailable or insufficiently detailed, potentially affecting a comprehensive analysis of factors influencing urban vitality.

ii. Model Simplification

While employing various models, this study simplifies the complexity of capturing urban vitality. Some intricate urban dynamic factors might not be fully considered, thus limiting the precision and applicability of the models.

iii. Spatial Heterogeneity

GWR might be deviations in quantitatively analyzing specific influencing factors of urban vitality due to such spatial variations.

iv. External Factors Not Considered

The study primarily focuses on the internal built environment's impact on urban vitality and does not adequately consider external factors, such as global economic conditions and policy changes, which could also significantly influence urban vitality.

7.2.2Future Work

i. Data Refinement and Updates

Future research efforts can focus on obtaining more detailed and accurate data, particularly concerning specific factors of the built environment, to enhance the accuracy of models. Additionally, regular updates to data can help reflect the latest trends in urban development.

ii. Increased Model Complexity

Further improvement of models could involve introducing more urban dynamic factors, such as socio-cultural variables, policy changes, etc., for a more comprehensive understanding of the mechanisms influencing urban vitality. Methods like complex network analysis can also be employed to better reveal the intrinsic complexity of urban systems.

iii. Multidimensional Research

Future studies could delve into urban vitality from various perspectives, such as the impact on specific industries or demographic groups and explore long-term trends in urban development. In-depth research of this kind can provide more specific guidance for urban planning and policymaking.

iv. Interdisciplinary Research

Cross-disciplinary research can offer a more holistic understanding of the formation mechanisms of urban vitality. Combining methodologies from sociology, economics, human geography, and other disciplines can better capture the multi-layered and multidimensional characteristics of cities.

v. Sustainability and Adaptability Considerations

Future research efforts may pay increased attention to the sustainability and adaptability of urban vitality, considering environmental changes and uncertainties in future urban development. Proposing forward-looking urban planning recommendations is essential.

vi. International Comparisons

Comparing the results of this study with those of other cities internationally can aid in understanding both commonalities and specificities in urban development, providing valuable lessons for other urban areas.

By addressing the limitations and outlining future research directions, a more in-depth understanding of urban vitality in Yinchuan City can be achieved, offering comprehensive and effective support for urban planning and development.

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