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The Identification and Dynamics of Urban Shadow Areas from the Perspective of People Flows—A Case Study of Nanjing

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Abstract: Urban shadow areas, formed by long-term unbalanced and inadequate development during the rapid process of urbanization, are of great significance to a city's overall development. However, relatively little attention has been paid to identifying and characterizing urban shadow areas. Drawing upon a dataset on urban morphology and cellular signaling, and taking Nanjing as a case study, this paper proposes a method to identify urban shadow areas from the perspective of people flows. The empirical results show that there are 19 urban shadow areas within the downtown areas of Nanjing, 11 of which are distributed in the old downtown areas and the rest are relatively scattered in the periphery. As for morphological characteristics, these urban shadow areas differ from each other in terms of indicators such as building density and development intensity. Moreover, the empirical results show that these urban shadow areas are not isolated but closely connected with other parts of Nanjing. Based on the different spatio-temporal distribution patterns of their connections, the 19 urban shadow areas are divided into four types, and the characteristics of each type have been investigated by analyzing a representative shadow area. It is suggested that policies aiming to eliminate the negative effects of urban shadow areas should consider heterogeneity in their spatial distributions within a city, the temporal distribution of their external connections, and their dominant functions.

Keywords: urban shadow area; people flow; cellular signaling data; urban morphology; Nanjing

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1. Introduction

The "dark-under-the-lights" areas caused by the long-term unbalanced and inadequate development of urban space have always been sources of pain and difficulty in urban renewal. So far, scholars have mainly used the concept of "shadow areas" to discuss the issue of "darkness under the lamp", but existing research has mainly focused on the "shadow area" phenomenon on a regional scale [1–3], while relatively little attention has been paid to the phenomenon of "shadow areas" on an intra-urban scale [4–6]. However, since reforming and opening up, many Chinese cities have been faced with the prominent problems of unbalanced and even polarized development due to the rapid urbanization process. Such unbalanced development has been specifically manifested by the emergence of urban shadow areas, which are usually close to the urban central areas of a city but are characterized by "low-density buildings, low-end business types, and low-end functions". For instance, some studies have found that there are urban shadow areas of a certain scale within about 500–800 m around a city's central areas, such as those found in Zhujiang New Town and Guangzhou Beijing Road in Guangzhou, Yan'an Road in Hangzhou, Xinjiekou in Nanjing, etc. [5].

In an era of stock planning, urban shadow areas are typical "high-value, low-price" areas which usually include shantytowns, old communities, industrial relics, and other spatial types [7]. In terms of spatial characteristics, such as development intensity, building density, and building height, there is a huge gap between these urban shadow areas and the surrounding urban central areas, which, to a certain extent, affects the happiness and well-being of people living and working in these shadow areas. At the same time, while these shadow areas promote the formation of the core structure of urban central areas, they also exacerbate the unbalanced and inadequate spatial development of the urban central areas. With the in-depth implementation of urban renewal policies in many Chinese cities, how to further deepen the scientific understanding of the spatial development laws of urban shadow areas has become an important issue that urgently requires more academic attention [8].

Existing research on urban shadow areas has mainly analyzed their spatial morphological characteristics such as development intensity and building density [5,6]. Some studies have also focused on how to detect urban shadow areas in remote sensing images by developing some identification algorithms [9–11]. However, studies merely based on urban morphology data may not fully reflect the spatial development patterns of urban shadow areas, which does not help us understand the dynamic mechanisms of the formation of urban shadow areas. In fact, due to advantages in location and cost, urban shadow areas are the primary place for the spillover of non-central functions from their surrounding central areas, such as residences, restaurants, express delivery, retail, and other functions that provide citizens with security and convenient services. This results in significant flows of different types of elements, such as people, logistics, and information, creating a dynamic connection between urban shadow areas and their surrounding central areas. Among the many types of element flows, people's daily activities most directly reflect the needs of different groups of people in urban shadow areas, and the interaction between daily activities and urban morphology is also the most significant [12]. Therefore, the impact of daily activities needs to be considered in the definition and identification of urban shadow areas. At the same time, it is necessary to further explore the connection rules between urban shadow areas and other parts of a city by analyzing the patterns of people flows, which helps provide a theoretical basis for promoting the renewal of urban shadow areas from a humanistic perspective.

Against this backdrop, this paper takes Nanjing as an example, develops a method to identify urban shadow areas, and analyzes how urban shadow areas are dynamically connected with other parts of the city by drawing upon data on urban morphology and people flows. In addition, policy implications concerning how to eliminate the negative effects of urban shadow areas are also put forward based on the empirical findings. In doing so, we aim to contribute to the existing literature by identifying and characterizing urban shadow areas from both static and dynamic perspectives.

The remainder of this paper is structured as follows. Section 2 reviews the existing literature on the definition, identification, and evolution mechanisms of urban shadow areas. Section 3 describes the data and methodologies used in this study. Section 4 presents the identification results of urban shadow areas in Nanjing. Section 5 analyzes how urban shadow areas have been connected with the other parts of Nanjing from a dynamic perspective. Section 6 discusses the empirical findings and puts forward some policy implications and Section 7 concludes the study.

2. Literature Review

Academic research on the "shadow area" phenomenon can be traced back to the discussion of the "agglomeration shadow" effect in the new economic geography theory [13–15]. It is generally believed that small cities which are close to big cities suffer from many restrictions in economic and social development because the competition effect is greater than the "borrowed size" effect [1,16,17]. Recently, scholars have paid increasing attention to the phenomenon of "shadow areas" mainly from three aspects, that is, the definition, identification, and evolution of "shadow areas".

2.1. The Definition and Characteristics of Shadow Areas

As for the definition of "shadow area", scholars have rarely used the concept of "shadow area", but usually other concepts such as "agglomeration shadow" [14–16] and "interplaces between cities" [18,19], to explore the phenomenon of "shadow areas" on a regional scale. Some scholars have used terms such as "distressed inner-city neighborhoods" [4] and "inner-city suburbanization" [20,21], to explore the phenomenon of "shadow areas" on in intra-urban scale. In addition to the different concepts used in the literature, existing studies have different views on whether the development of "shadow areas" will necessarily be negatively affected by surrounding large cities or surrounding urban central areas. Some studies believe that small- and medium-sized cities can achieve better development through "borrowed size" [16], whereas other studies believe that the development of "distressed inner-city neighborhoods" is restricted by the central area of the inner city [4].

In the Chinese context, Zhang and Zhuang have paid attention to the "shadow area" phenomenon at the regional scale and proposed the concept of a "metropolitan shadow area" [22]. Recently, some scholars have also proposed concepts such as "development shadow areas" [23] and "metropolitan multiple shadow areas" [24], while some scholars have followed the concept of "agglomeration shadows" [25,26]. As the problem of the unbalanced and inadequate development of urban space becomes increasingly prominent, the phenomenon of "shadow areas" on an intra-urban scale has gradually attracted academic attention, resulting in the emergence of concepts such as "city center shadow area" and "city shadow area" [5–7]. Although there are differences in the use of multiple concepts, scholars have generally believed that shadow areas have the following four characteristics. The first one is a development gap phenomenon formed due to different combinations of agglomeration and radiation in central cities and their surrounding areas [27]. Also, they believe that shadow areas are scattered spaces that are located in the urban central area of a city and that exhibit the characteristics of low-end service functions, old building forms, and a sharp decline in the density and height index of public facilities [5]. The last two consensual characteristics constitute a phenomenon in which a central city has a negative effect on the development of its surrounding areas [28], as well as on areas maintaining weak spatial connections with the central city's industries [29].

2.2. The Identification of Shadow Areas

Shadow areas at the regional scale have been mainly identified based on the scope of influence of urban functions with a particular focus on small- and medium-sized cities located between large cities [14]. Some studies have mainly drawn upon relevant theories in the fields of regional economics and urban geography, focusing on analysis at the economic and social development level. Commonly used indicators and methods include sensitivity and influence coefficients [23], break points and comprehensive connection strength [24,28], Huff model and spatial autocorrelation analysis [27], etc. In contrast, the identification of shadow areas on an intra-urban scale has been mainly based on economic and social development indicators such as housing prices, crime rates, and employment rates [4,21]. Meanwhile, recent studies have explored how to use spatial morphological indicators such as development intensity and building density to identify shadow areas on an intra-urban scale [5]. With the use of multi-source big data in urban morphology and cellular signaling, some studies have expanded their research focus from the urban central area to the whole city. For instance, Yang and Ma have identified the spatial scope of urban shadow areas in Shanghai and analyzed their morphological patterns [6]. Sun et al. have used POI data to study the impact of Shanghai on the distribution of shadow areas of service functions in small towns in a southern Jiangsu province [29].

2.3. The Formation and Evolution Mechanisms of Shadow Areas

According to agglomeration–diffusion theory, the formation and evolution of urban shadow areas are essentially affected by the non-equilibrium aggregation and diffusion of elements in space, and the forces driving the aggregation and diffusion of spatial elements have diversified characteristics. Some studies have discussed the effects of specific factors, such as the residential preferences of middle-class families [20], the location and accessibility of the shadow area [14,30], government planning policies [4], and urban spatial structure [21,31]. The formation and evolution mechanisms of urban shadow areas in the Chinese context have mainly been discussed via qualitative analysis. Such discussions have mainly drawn upon theories such as Friedman's "Core-edge" theory, Myrdal's "diffusion-echo" theory, etc., which usually focus on spatial agglomeration–diffusion interactions. In terms of specific influencing factors, studies differ from each other. Some studies have emphasized the policy constraints on the development of shadow areas from core cities [22,29] and the functional division of labor between the shadow area as well as its immediately adjacent core city or core area [7]. Meanwhile, other studies put industrial structures [29], the characteristics of people's daily activities [6], regional integration strategies [15], and network externalities [32,33] as the key points.

3. Materials and Methods

3.1. The Study Area

The study area of this paper is the downtown area of Nanjing, the capital city of Jiangsu Province, China. As the core urbanization area in Nanjing's future development process, it is also the main area for Nanjing to shoulder the function as a regional central city. The downtown area of Nanjing consists of 4 administrative zoning districts, including Jiangbei, Xianlin, Dongshan, and the main city, covering a total area of 846 km^2 and with a population of about 6.7 million (Figure 1). Although it only accounts for 12.8% of the administrative area, this area contains 63.2% of the city's total population.

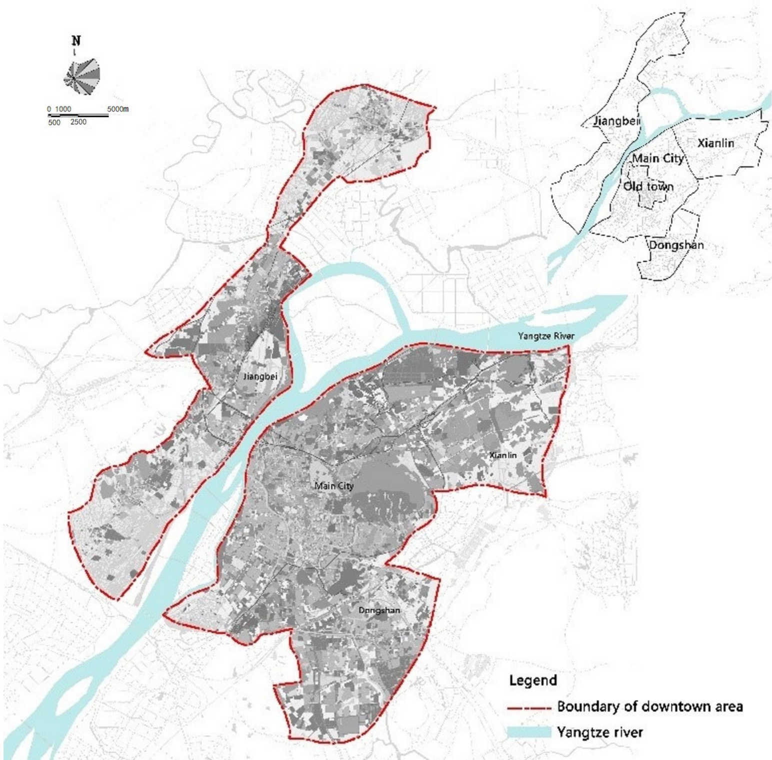


Figure 1. The downtown area of Nanjing.

3.2. Data Source and Processing

The data used for this paper include Nanjing urban morphology data and cellular signaling data. The urban morphology dataset is constructed based on the complete and accurate vector topographic map of Nanjing's downtown area, which is calibrated, corrected, and updated after a field survey carried out by the author's research group. The urban morphology data contain detailed information on buildings, land plots, blocks, roads, and the natural landscape environment (Figure 2). In the ArcGIS 10.3 platform, all the above information is uniformly projected into the WGS_1984 coordinate system, which is used to calculate the key indicators of urban morphology.

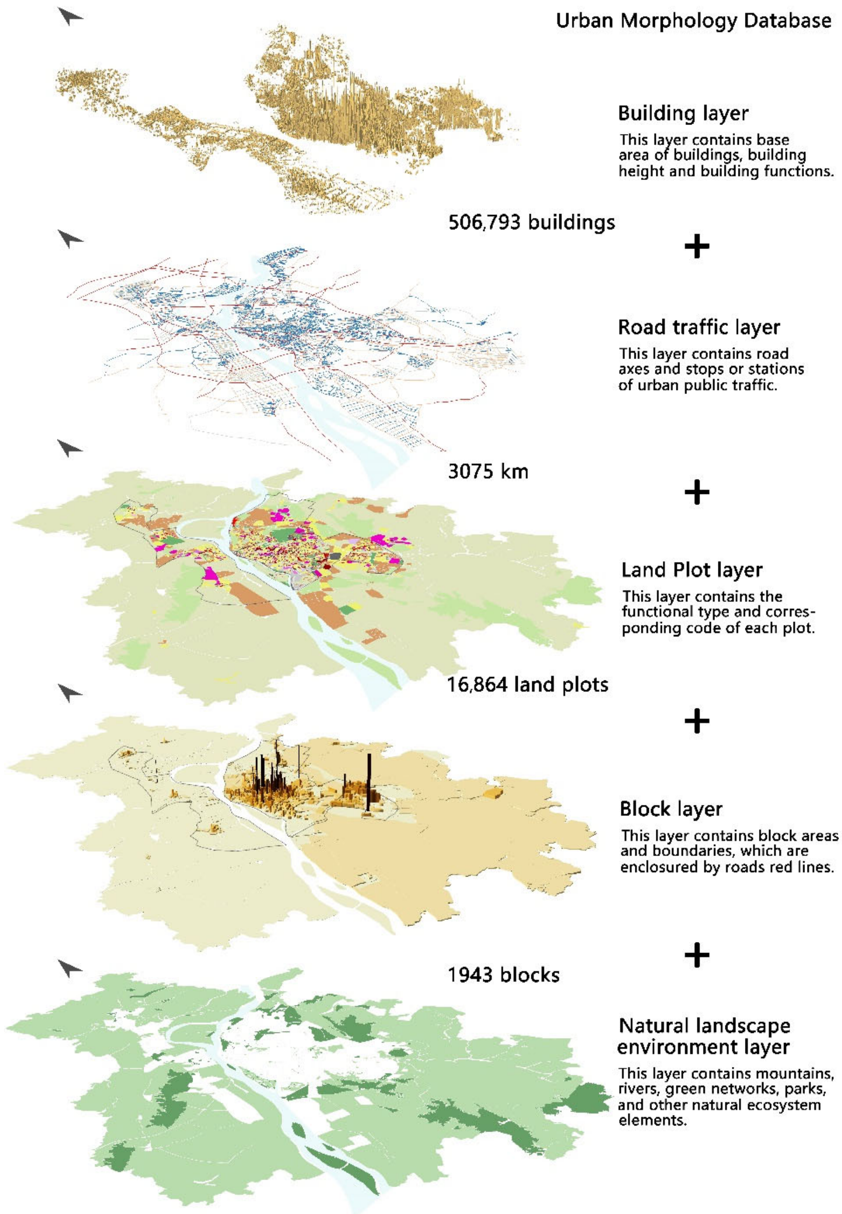


Figure 2. The urban morphology data of the study area.

For the cellular signaling data, this paper obtains data provided by China Mobile, which covers approximately 70% of the share of the entire mobile phone market in Nanjing. There are 104,247 mobile phone base stations in the downtown area of Nanjing and the dataset covers 14 days in 2015, including 10 working days and 4 weekends. It is worth mentioning that network interruption, transmission delay, external environment interference, system failure, and other undesirable conditions are inevitable during the generation and collection process of the cellular signaling data, which would generate some invalid data. After data cleaning and considering the weather conditions, this paper finally selects the data collected for 11 November (the working day) and 21 November (the weekend), which have a normal distribution. The number of mobile phone users covered by the data is more than 2 million per day.

Specifically, the database contains mobile phone base station data and cellular signaling data. The former records the identification code of each base station and its corresponding geographic coordinate information. For each base station, we can obtain the number of users it records during each two-hour interval. By creating Tyson polygons based on the location of base stations and allocating each base station to a block, we can then obtain the number of people for each block during each two-hour interval. The latter data contain information on people flows. This includes anonymously encrypted mobile phone terminal IDs, signaling type, and the time that signaling occurs when the phone is connected to the base station. In order to simplify the data, this paper randomly projects the user's location to the adjacent block of the corresponding base station, and then maps all the stay points of each user to obtain their movement trajectory on that day (Figure 3).

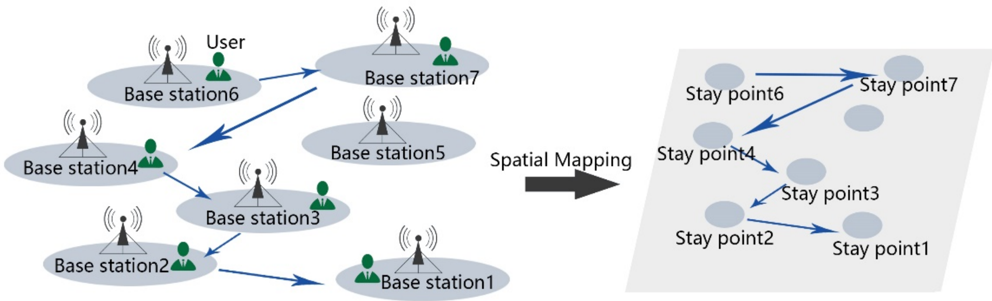


Figure 3. Spatial location mapping and trajectory generation of mobile phone users.

3.3. Methodology

3.3.1. The Basic Unit of Analysis

This paper selects blocks as the basic unit of analysis, mainly for the following two reasons. On the one hand, one might argue that grids can be an alternative choice. However, a grid is only a random division method for urban space, which has no planning significance and thus cannot fully reflect the purpose of this paper. On the other hand, we think blocks are a better choice than land plots. First, blocks are enclosed by roads with clear spatial boundaries and can be regarded as an independent spatial unit in the city. In contrast, some land plots have human influence factors due to the issue of development rights. Second, each block unit is relatively complete in form because of the enclosing of the roads. Meanwhile, a block is, to a certain extent, a basic unit of people's cognition of urban space. Third, compared with blocks, land plots are more likely to have extreme or unbalanced spatial characteristics due to the excessive or low development intensity of local areas, which may lead to biased identification results. Consequently, this paper considers block as an ideal unit of analysis for the identification of urban shadow areas. To this end, the various types of data involved in this study are aggregated to a block level to calculate the relevant indicators.

3.3.2. The Method of Identifying Urban Shadow Areas

In this paper, urban shadow areas are defined as areas that are adjacent to urban central areas but with lower construction intensity, fewer public service facilities, and insufficient population vitality. Based on this definition, this paper holds that three factors should be considered in the identification of its spatial boundary, including construction intensity, the number of public service facilities, and population vitality at the block level. The expression of each indicator is given as follows:

$$Intensity_i = \frac{\sum_{k=1}^{N} floor\_area_{i,k} \times}{block\_area_i} \quad (1)$$

$$Facility_i = \sum_{j=1}^{M} type\_number_{i,j} \quad (2)$$

$$Popu_i = \sum_{l=1}^{S} base\_popu_{i,l} \quad (3)$$

where $Intensity_i$, $Facility_i$, and $Popu_i$ represent the construction intensity, the number of public service facilities, and the population vitality of block i, respectively. $floor\_area_{i,k}$ and $height_{i,k}$ mean the floor area and height of building k in block i. $type\_number_{i,j}$ reflects the number of public service facilities of type j in block i. $base\_popu_{i,l}$ represents the number of mobile phone users recorded by the base station l in block i.

Specifically, considering that the urban shadow area is a relative concept, we identify its spatial boundary through exploratory spatial data analysis, a method that has been commonly adopted in recent studies [34–36]. The technical route of this identification method is described as follows (Figure 4). For each indicator, we detect the local spatial autocorrelation pattern of its distribution by calculating the local Moran's *I* index. Blocks with statistically significant values of local Moran's *I* can be classified into four categories: (1) blocks with high values of the indicator surrounded by those with similar high values (HH); (2) blocks with low values of the indicator surrounded by those with similar low values (LL); (3) blocks with high values of the indicator surrounded by those with low values (HL); and (4) blocks with low values of the indicator surrounded by those with high values (LH).

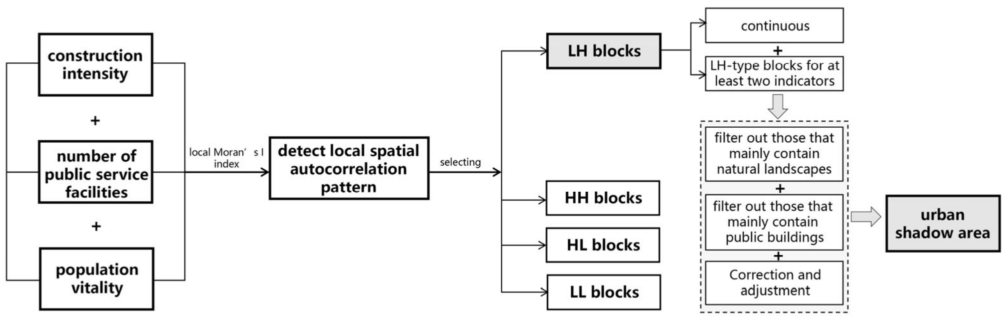


Figure 4. The technical route of the identification method.

Furthermore, blocks that belong to the LH category, at least for two out of the three indicators, can be regarded as part of potential urban shadow areas. On the one hand, LH-type blocks suggest that these blocks have relatively lower values of an indicator but are surrounded by blocks with higher values, which is in line with the definition of urban shadow areas. On the other hand, we set stricter criteria that blocks should be LH-type blocks for at least two indicators, which filters out blocks that only belong to the LH type for just one indicator. This criteria helps to identify blocks that are more close to the definition of urban shadow areas. One might argue for even stricter criteria that a block could only be considered when it belongs to the LH type for all the three indicators. In fact, we tried these criteria but found that they were too strict to identify enough urban shadow areas within the study area, which is not in line with what we have observed in our field survey either. In addition, as an urban shadow area should be a continuous one, the LH-type blocks are further integrated if they are adjacent to each other under the criterion of rook continuity.

So far, we have identified as urban shadow areas those areas that are purely based on statistical calculation, some of which might not fully reflect the spatial reality. Therefore, the identification result needs further correction and adjustment. On the one hand, we filter out the identified urban shadow areas that mainly contain natural landscapes such as mountains, water bodies, farmlands, and protective green space. Though these landscapes have relatively lower levels of construction intensity and a lower density of public service facilities, they are usually not close to urban central areas and thus cannot be regarded as urban shadow areas. On the other hand, we filter out the identified urban shadow areas that mainly contain public buildings such as museums, libraries, and schools. Though these areas usually have relatively low construction intensity, they are often active, vibrant, and full of people. Therefore, these areas cannot be seen as urban shadow areas either.

3.3.3. Indicators Reflecting the Dynamics of Urban Shadow Areas

In this study, we use two indicators to explore the dynamics of urban shadow areas. One is the volatility of people flows and the other is the day–night ratio of people flows. Specifically, the former indicator represents the stability of the overall people flows (both inflow and outflow) of an urban shadow area during 12 time intervals, which can be measured using the standard deviation method. The latter represents the difference in the overall people flows between day and night for a certain urban shadow area. The expressions of the two indicators are given as follows:

$$Volatility_i = \sqrt{\frac{\sum_{t=1}^{12}\left(flow_{i,t} - \overline{flow_i}\right)^2}{12}} \tag{4}$$

$$Ratio_i = \frac{flow\_day_i}{flow\_night_i} \tag{5}$$

where $Volatility_i$ and $Ratio_i$ represent the stability of the overall people flows and the day–night ratio of people flows for each urban shadow area i, respectively. $flow_{i,t}$ reflects the overall people flows at the time interval t, which is the sum of both people inflows to the urban shadow area i and people outflows from the urban shadow area i. $\overline{flow_i}$ means the average people flows of the urban shadow area i over a whole day. $flow\_day_i$ and $flow\_night_i$ represent the overall people flows during the daytime and the nighttime, respectively. The former is measured according to the people flows between 8:00 am and 10:00 am in the morning, while the latter is measured according to the people flows between 2:00 am and 4:00 am at night. The reason for choosing these two periods is that, according to the habits of most people, these are the periods which best reflect and represent these two types of behavior. Data on people flows of a certain urban shadow area and during a certain time interval can be aggregated at the mobile phone base station level.

4. The Distribution of Urban Shadow Areas in Nanjing

Based on the above-mentioned data and method, we finally identify 19 urban shadow areas within the study area, 11 of which are located in the old downtown area of Nanjing. Table 1 describes the basic morphological information of these urban shadow areas, including their areas, the number of blocks that they contain, and their nearby urban central areas. Overall, these urban shadow areas contain 97 blocks, covering an area of about 13.53 square kilometers. Furthermore, these urban shadow areas have a total building floor area of about 7.21 square kilometers, and a total building footprint area of about 2.88 square kilometers. Therefore, the average plot ratio of these urban shadow areas is about 0.53 and the average building density is 0.21. Moreover, we can find that there is remarkable heterogeneity among these urban shadow areas. For instance, their areas range from 4.19 hectares to 323.59 hectares, and the number of blocks they contain range from 1 to 14. Despite this heterogeneity, we can see that all these urban shadow areas are close to at least one urban central area of Nanjing.

Table 1. The basic information of 19 identified urban shadow areas in Nanjing.

Name of Urban Shadow Area	Area (Hectares)	Number of Blocks	Name of Nearby Urban Central Area
Wutang Parcel	323.59	1	Wutang Plaza central area
Qingliangmen Avenue	15.93	1	Hexi central area
Liuhe Parcel	149.28	4	Liuhe central area
Baijiahu Parcel	9.33	5	Baijiahu central area
Andemen Avenue	109.70	6	Confucius Temple central area
Kening Road	162.68	11	Baijiahu central area
Fengtainan Road	289.60	12	Hexi central area
Shengzhou Road	34.35	14	Confucius Temple central area
Huowaxiang Parcel	28.61	5	Xinjiekou central area
Youfuxi Street	18.18	6	Xinjiekou central area
Hunan Road	28.48	3	Hunan Road central area
Pukou Parcel	16.52	3	Jiangbei central area
Xianlin Parcel	69.22	7	Xianlin central area
Yihe Road	24.59	14	Hunan Road central area
Cibeishe Parcel	12.58	2	Xinjiekou central area
Yunnanbei Road	7.79	2	Hunan Road central area
Qingshi Street	7.48	2	Xinjiekou central area
Guyilong Parcel	4.19	1	Xinjiekou central area
Jiankang Road	9.64	1	Confucius Temple central area

Figure 5 depicts the spatial distribution of urban shadow areas in Nanjing. Overall, we can see that the distribution is characterized by internal agglomeration and external dispersion. Specifically, internal agglomeration refers to the relatively dense distribution of multiple urban shadow areas within the old downtown area of Nanjing, such as the Xinjiekou central area, the Hunan Road central area, and the Confucius Temple central area. For instance, urban shadow areas such as Guyilang Parcel, Qingshi Street, Youfuxi Street, Huaihai Road, Huowaxiang Parcel, and Cibeishe Parcel are all around the Xinjiekou central area, while urban shadow areas such as Hunan Road and Yunnanbei Road are close to the Hunan Road central area. In addition, internal agglomeration is reflected by the fact that these urban shadow areas are mainly clustered along the Zhongshanbei Road, Zhongshan Road, and Zhongshandong Road, and along the Zhonghua Road to Zhonghuamen Gate, which is spatially related to the city's historical context. This may also reflect the historical factors that influence the phenomenon of urban shadow areas. In fact, the Gulou District and Qinhuai District within the old downtown area contain the largest number of urban shadow areas, partly because these two administrative districts have a relatively long history of development and are among the earliest developed areas in Nanjing. Therefore, they are more likely to experience unbalanced development.

External dispersion refers to the fact that the number of urban shadow areas is relatively smaller outside the old downtown area. The distribution of the eight urban shadow areas shows a relatively scattered layout, which has occurred in some newly developed areas such as the Hexi central area in the west of Nanjing and the Dongshan central area in the south of Nanjing. Specifically, urban shadow areas such as Qingliangmen Avenue and Fengtainan Road are located in the Hexi central area, while the Dongshan central area mainly contains urban shadow areas such as Baijiahu Parcel and Kening Road. Furthermore, some urban shadow areas are located around the Jiangbei central area and the Xianlin central area, which are further away from the old downtown area of Nanjing.

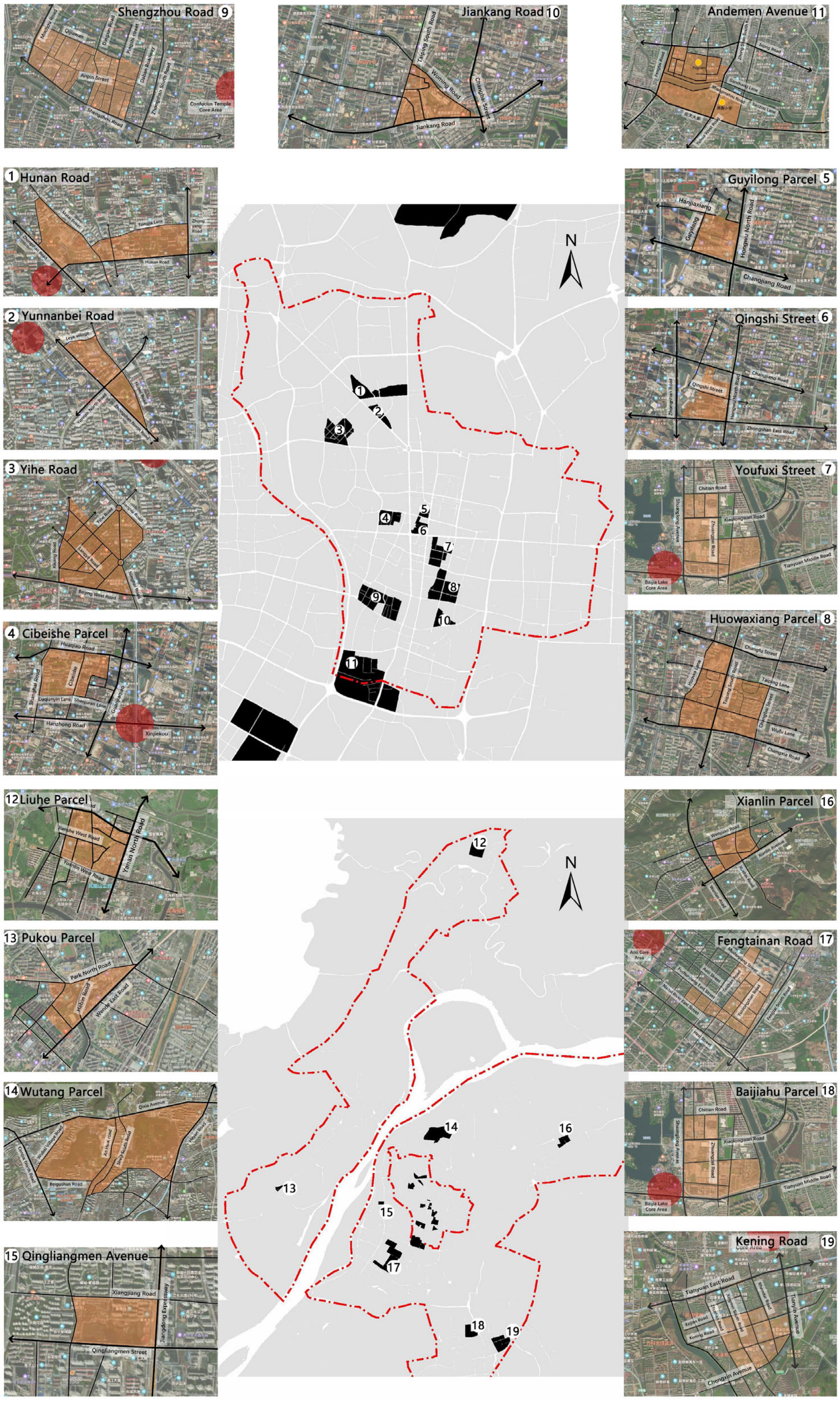


Figure 5. The spatial distribution of the urban shadow areas of Nanjing.

5. The Dynamic Connections between Urban Shadow Areas and Other Parts of Nanjing

Figure 6 shows the calculation results of the two indicators that we have constructed to reflect the dynamic connections of the identified urban shadow areas with other parts of Nanjing. As for the indicator of volatility of people flows, this ranges from 1.80 to 33.86

with an average value of 15.27. Specifically, the Wutang Parcel shadow area has the lowest volatility value, while the Yihe Road shadow area has the highest volatility value. In terms of the indicator of the day–night ratio of people flows, it has an average value of 5.04, with the value of the Xianlin Parcel shadow area being the lowest (2.14) and that of the Jiankang Road shadow area being the largest (9.70).

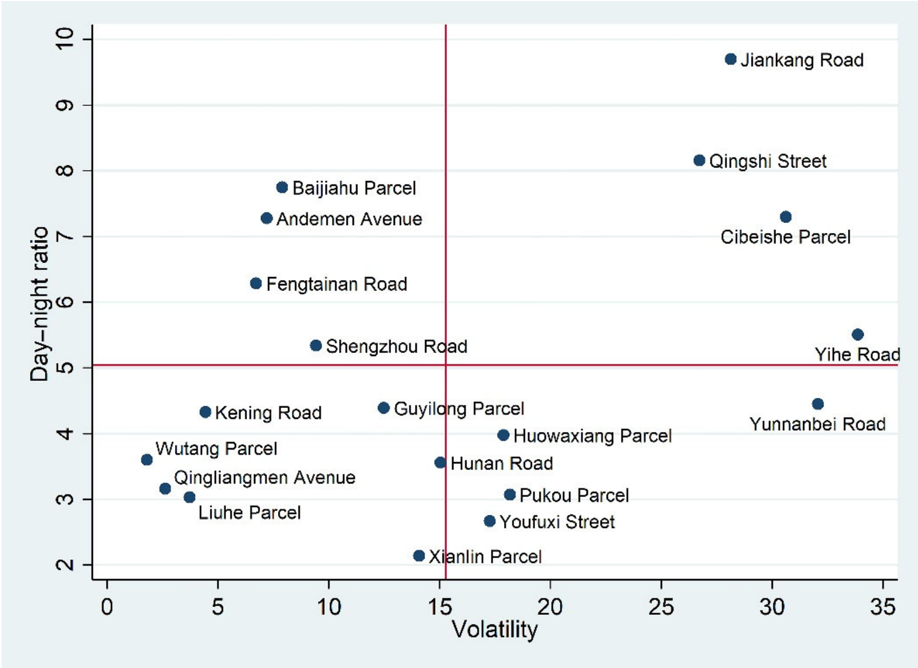


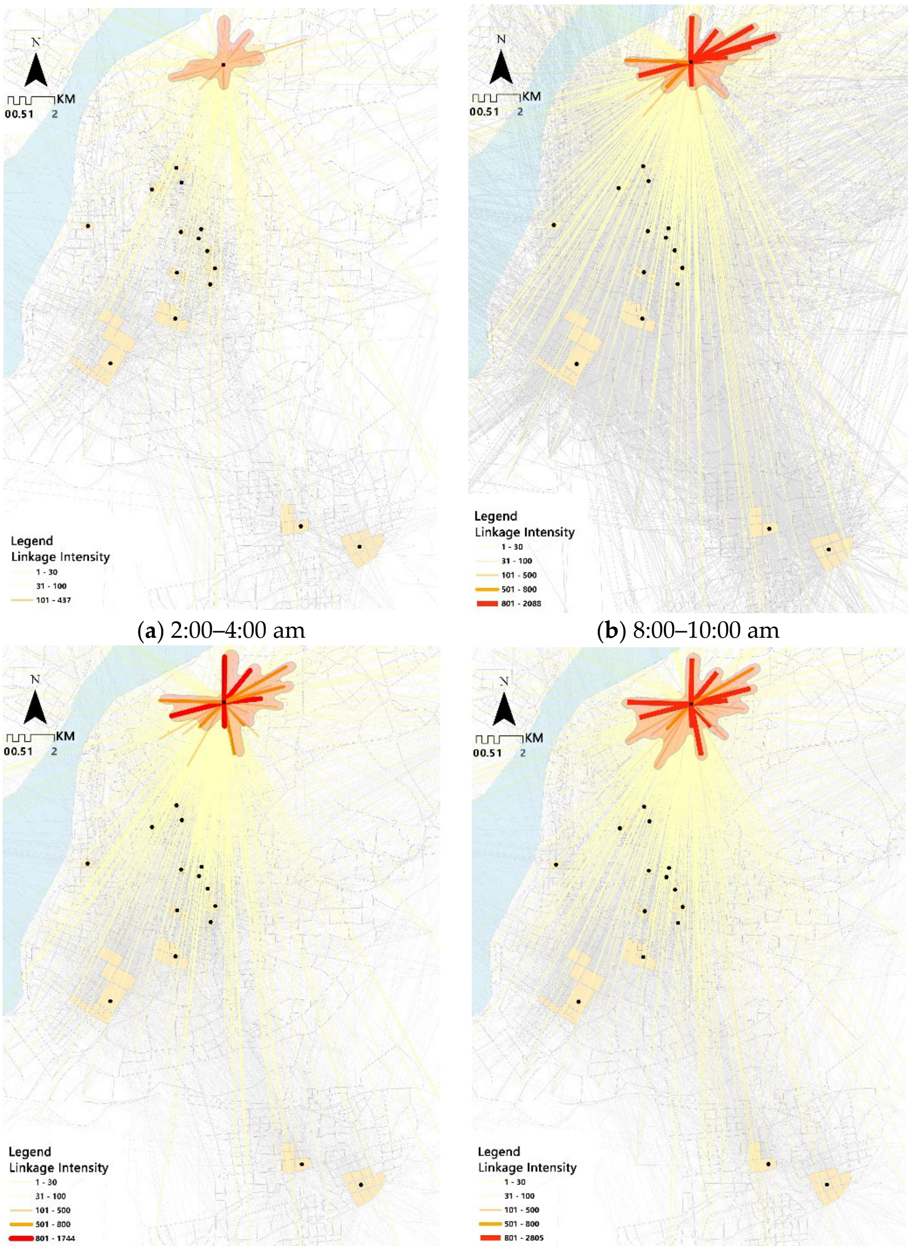
Figure 6. The distribution of two indicators of urban shadow areas.

In Figure 6, the two red lines represent the average values of the volatility and day–night ratio, respectively. With the two average values as the threshold, we can further divide these urban shadow areas into four types: (1) those with relatively low values of both volatility and day–night ratio, including Wutang Parcel, Kening Road, Qingliangmen Avenue, Guyilang Parcel, Hunan Road, Xianlin Parcel, and Liuhe Parcel; (2) those with relatively low values of volatility but high values of day–night ratio, including Baijiahu Parcel, Andemen Avenue, Fengtainan Road, and Shengzhou Road; (3) those with relatively high values of volatility but low values of day–night ratio, including Huowaxiang Parcel, Yunanbei Road, Pukou Parcel, and Youfuxi Street; and (4) those with relatively high values of both volatility and day–night ratio, including Jiankang Road, Qingshi Street, Cibeishe Parcel, and Yihe Road. For each type, we select one representative shadow area to explore in detail the characteristics of its dynamic connections with other parts of Nanjing as well as the underlying mechanisms.

5.1. Low in Both Volatility and Day–Night Ratio: Using Wutang Parcel as an Example

For urban shadow areas that have relatively low values of both volatility and day–night ratio, they generally have weak connections with other parts of Nanjing and these connections are relatively stable over time. These shadow areas are mainly distributed in the peripheral areas of Nanjing, which have been dominated by vacant land and agricultural and forestry land. Therefore, they usually have fragmented spaces and are less attractive for people.

Here, we take the Wutang Parcel shadow area as an example, which is located to the north of the old downtown area of Nanjing (Figure 5). Its connections with other parts of Nanjing at different time intervals is shown in Figure 7. Obviously, this area mainly connects with its nearby areas, with a relatively lower level of connection strength and fluctuation. The spatial morphology of this shadow area has two main characteristics, which partly account for the distribution of its dynamic connections. First, this shadow area is mainly surrounded by district-level urban centers and large residence, while the area itself is dominated by abandoned plants and agricultural and forestry land. Therefore, it lacks sufficient public service facilities and the development intensity of this area is relatively lower than its surrounding areas. Second, the internal traffic network structure of this shadow area is relatively broken, which mainly contains small and narrow roads. Thus, the accessibility of this shadow area is weak, which is not attractive for people either. Taken together, we find that this shadow area can only provide very limited employment opportunities and its public service facilities are not attractive for people to agglomerate. Consequently, it is expected to have low values in both volatility and the day–night ratio of people flows.



(**a**) 2:00–4:00 am (**b**) 8:00–10:00 am
(**c**) 12:00–14:00 pm (**d**) 16:00–18:00 pm

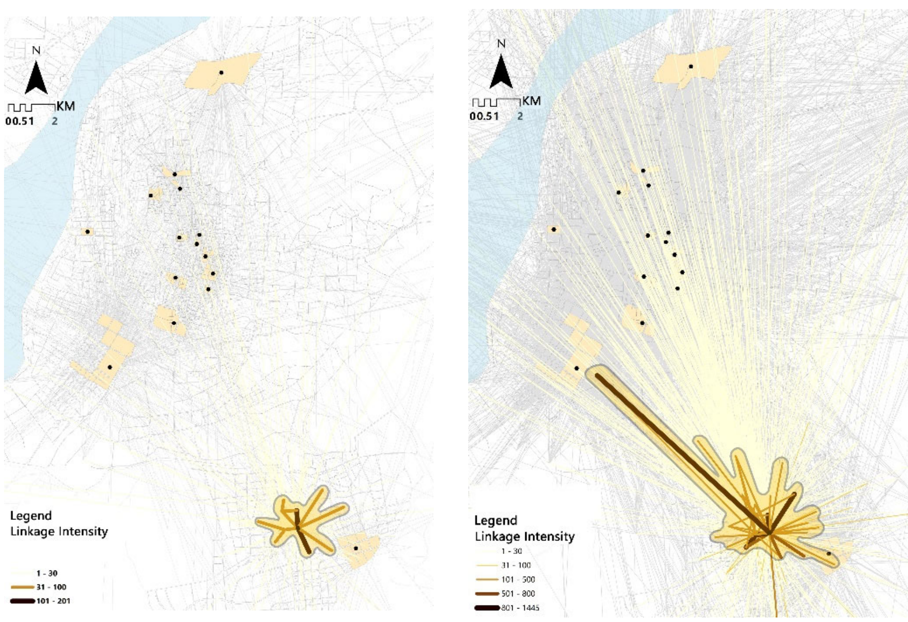
Figure 7. The dynamic connections of the Wutang Parcel at different time intervals.

5.2. Low in Volatility but High in Day–Night Ratio: Using Baijiahu Parcel as an Example

For urban shadow areas with low values of volatility but high values of day–night ratio, their internal spaces are usually homogeneous, most of which are dominated by production and manufacturing functions with a similar architectural texture. However, due to the relatively large number of job opportunities these shadow areas can provide, they usually have more frequent people flows during the daytime and less frequent people flows during the nighttime. Therefore, the day–night ratio of people flows for these shadow areas is remarkable.

This study takes the Baijiahu Parcel as an example to further explore the spatial characteristics of these shadow areas. As shown in Figure 8, there is a remarkable difference in people flows between the daytime (8:00–10:00 am) and nighttime (2:00–4:00 am), suggesting a relatively high value of day–night ratio. Specifically, the spatial characteristics of the Baijiahu Parcel shadow area can be discussed from the following aspects. First, since the shadow area is within the Jiangning Development Zone of Nanjing, it has been dominated by industrial land. Moreover, this shadow area has attracted many high-tech industries such as green and intelligent automobile manufacturing, life science, artificial intelligence, and future networks. Such industries have enjoyed rapid development, which helps this area provide relatively stable employment opportunities. Second, this shadow area has good traffic conditions. It is adjacent to the Baijiahu central area of Nanjing, the Nanjing South Station, and Nanjing Lukou International Airport, which ensures that the area has good accessibility. From the perspective of urban morphology, however, the buildings of this shadow area are relatively small in scale, being mainly low factory buildings with one–three floors. Furthermore, there is a large proportion of vacant land due to the requirements of production protection. In contrast, its surrounding areas contain many commercial complexes and high-rise residential buildings.

Influenced by the above-mentioned characteristics, the population type and the pattern of their daily activities are relatively unitary. Employees working in these manufacturing factories account for the majority population in this area, leading to a small residential population base and a relatively low fluctuation rate. In addition, most of the employees are residents living in nearby areas, which results in regular commuting behaviors. Taken together, we can expect that the people flows of this shadow area are less fluctuating but have a relatively high value of day–night ratio.



(**a**) 2:00–4:00 am (**b**) 8:00–10:00 am

Figure 8. *Cont.*

(**c**) 12:00–14:00 pm (**d**) 16:00–18:00 pm

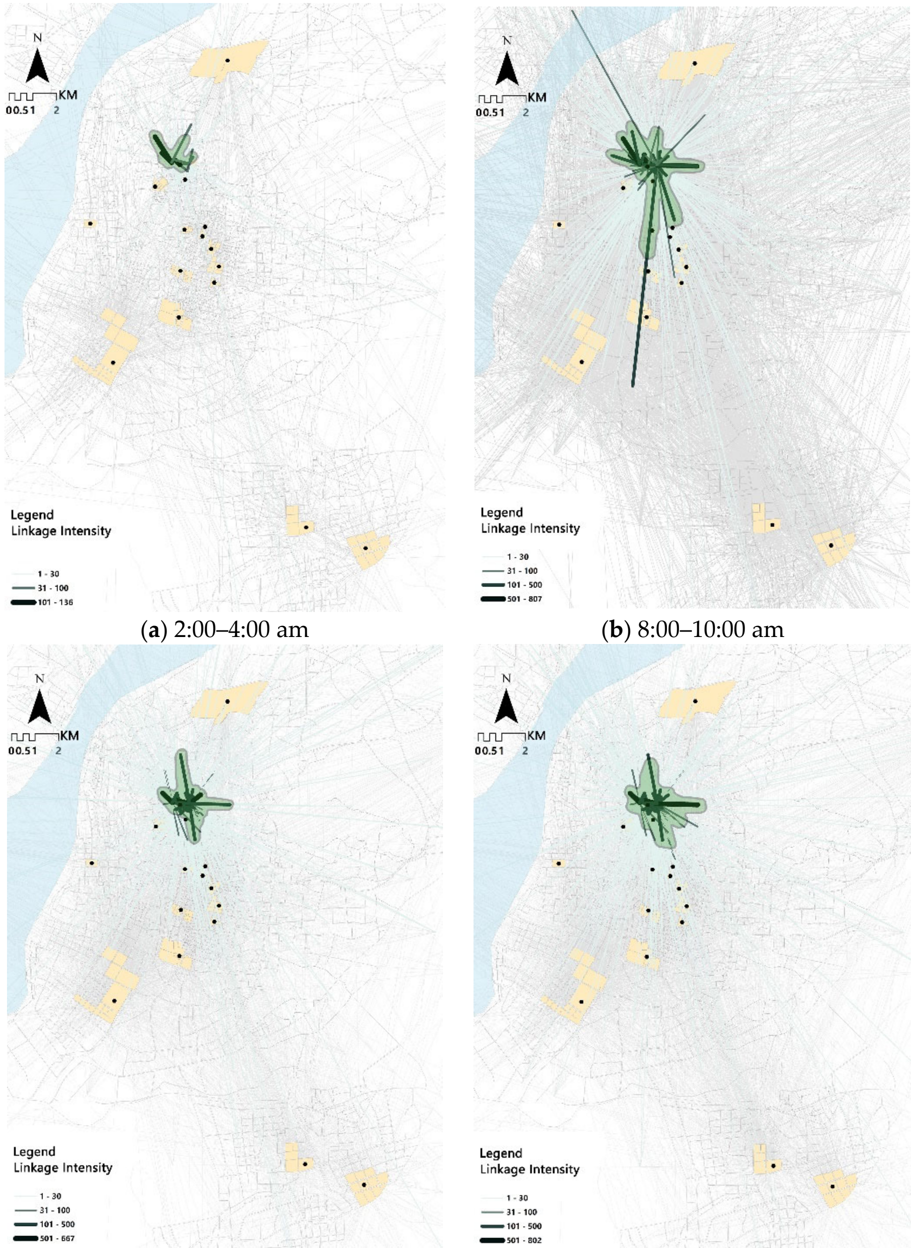
Figure 8. The dynamic connections of the Baijiahu Parcel shadow area at different time intervals.

5.3. High in Volatility but Low in Day–Night Ratio: Using Hunan Road as an Example

For urban shadow areas with high values of volatility and low values of day–night ratio, the most typical feature is the complexity of their land use. It not only contains some dilapidated open space or land under construction, but also a certain amount of commercial facilities. The latter helps attract and gather people, resulting in relatively rich types of people activities. However, due to the relatively weak functions in terms of residences and employment, there is no significant difference in people flows during the daytime and nighttime, which usually means a relatively low day–night ratio.

We select the Hunan Road shadow area as a typical representative of this type of shadow area (Figure 9). This area used to be an important node of the network of people flows in Nanjing. It was very attractive for people and consumers to visit because it is close to the Xuanwu Lake and surrounded by many big commercial complexes. However, with the continuous upgrading of urban development and the increasing of people's living demands, the attractiveness of this area is gradually declining and its renewal is thus imminent. Under this background, this area has entered the stage of demolition and reconstruction, leading to large-scale open spaces under construction. Furthermore, influenced by the decline of its nearby commercial centers, the building density and development intensity of this shadow area have gradually decreased, making this area become increasingly less attractive for people to visit.

Overall, on the one hand, the Hunan Road shadow area has some scattered commercial, residential, and public service facilities. On the other hand, its development is affected by neighboring commercial complexes, universities, parks, and hospitals. Influenced by these two factors, this area has formed a moderate population base. However, the huge difference between this area and its neighboring areas has led to a high level of volatility in terms of people flows. In addition, due to the relatively few employment opportunities it can provide, the differences in people flows of this area during the daytime and nighttime is thus not remarkable, leading to a relatively low value of day–night ratio.



(**a**) 2:00–4:00 am (**b**) 8:00–10:00 am

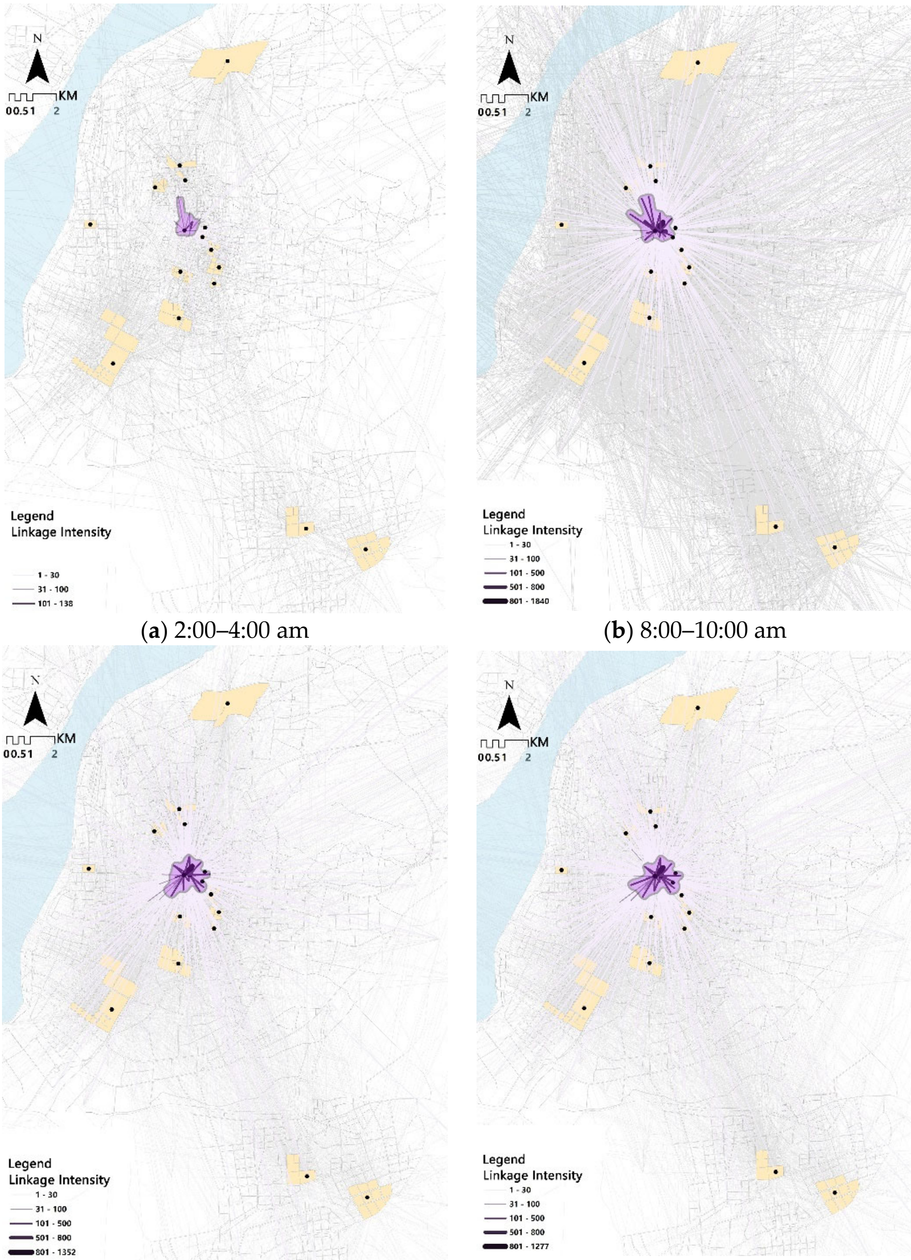
(**c**) 12:00–14:00 pm (**d**) 16:00–18:00 pm

Figure 9. The dynamic connections of the Hunan Road shadow area at different time intervals.

5.4. High in Both Volatility and Day-Night Ratio: Using Cibeishe Parcel as an Example

The majority of the urban shadow areas with high values of volatility and day–night ratio are within the range of the Xinjiekou central area of Nanjing. They are often dominated by old residences and related public service facilities. Though possessing the advantages of relatively dense public service facilities and rich job opportunities, these areas are faced with the disadvantage of relatively high land price and living costs, which leads to a significant tidal phenomenon of people flows.

In this paper, the Cibeishe Parcel is selected as a typical representative of this type of shadow area (Figure 10). This area is adjacent to the Xinjiekou central area and within walking distance of commercial complexes such as Deji Square and the Jinlun International Plaza. Therefore, it has an advantageous location and is surrounded by abundant commercial and public service facilities. In terms of urban morphology, this area has many old communities and historical relics. Therefore, the building height and development intensity in this area is not so high. In fact, most buildings in this area are less than six floors. Furthermore, the internal road network structure of this area is mainly for residential use and daily commuting. However, due to its closeness to the Xinjiekou central area, this area can provide necessary services for daily life, such as logistics delivery, catering, and leisure. In addition, residents living in this area are also potential employees providing services for the surrounding areas and even the whole city, which results in a relatively high level of fluctuation of people flows. Meanwhile, because this area is dominated by residential land, the employment opportunities it can provide are rather limited, which could also lead to a relatively high value of day–night ratio in terms of people flows.



(**a**) 2:00–4:00 am (**b**) 8:00–10:00 am

(**c**) 12:00–14:00 pm (**d**) 16:00–18:00 pm

Figure 10. The dynamic connections of the Cibeishe Parcel shadow area at different time intervals.

6. Discussions

In this paper, the existence of urban shadow areas, as well as their dynamic connections with other areas, have been clearly demonstrated in the case of Nanjing. The empirical results of this study suggest that urban shadow areas do exist in cities, which is in line with other studies that have focused on shadow areas on an intra-urban scale [5–7]. However, these urban shadow areas are not isolated but have dynamic connections with their neighboring central areas and other parts of the city. Therefore, merely considering urban shadow areas as isolated and negative spaces may not fully capture the significance of urban shadow areas to the overall development of a city. In fact, with the rapid development of digitization and globalization, flows of people, logistics, capital, and information have been substantially enhanced, which has also promoted the evolution of urban spatial structures from a hierarchy to a network [31,33]. In this sense, urban shadow areas cannot be simply regarded as isolated and negative spaces of a city. Instead, they actually maintain dynamic connections with other parts of a city and are important nodes of a city's network structure [7].

The empirical results have some policy implications for the planning and design of urban shadow areas in a city. For policy makers, they should bear it in mind that urban shadow areas exist at different development stages of a city. In other words, though these areas may generate negative effects on their surrounding areas, these negative effects cannot be permanently eliminated through urban planning and design due to the existence of unbalanced development. The government should actively refine and activate the characteristic resources of historical relics. Using a series of spatial organization methods, such as public space and activity tour line, these resources are re-utilized and "darned" into the overall cultural context of the city, so as to effectively locate or integrate them into the characteristic space system of the city [6]. In brief, we suggest that policies aiming to improve the development of urban shadow areas could consider the following three aspects.

First, the spatial distribution of urban shadow areas is heterogeneous across different parts of a city. Such heterogeneity should be considered in the relevant policies. Specifically, due to their advantageous locations, urban shadow areas in the old downtown areas of a city usually have frequent people flows. Therefore, it would contribute greatly to the development of these shadow areas if policies could leverage the important role of their neighboring central areas to further enhance the vitality of these shadow areas [8]. For urban shadow areas in the peripheral areas of a city, policies could focus on how to further strengthen the comparative advantages of these areas so that they can integrate into a city's network structure.

Second, the temporal distribution of the external connections of urban shadow areas is also heterogeneous. For a certain urban shadow area, the overall volatility and the strength of people flows are different during different time periods of a day, both of which are influenced by both the shadow area itself and its nearby central areas. Therefore, it is necessary to consider such temporal heterogeneity in the planning and design of urban shadow areas to ensure that they maintain relatively enduring and stable vitality. For instance, promoting the development of night markets might be a good way to utilize the temporal characteristics of urban shadow areas, especially for those in the old downtown areas of a city [23]. This is because these shadow areas are usually less attractive for people during the nighttime. However, they often have large open spaces which can be utilized to develop night markets. In doing so, the night markets can not only bring relatively sustainable people flows to these shadow areas, but also help improve their popularity to a certain extent.

Third, urban shadow areas differ from each other in terms of their dominant functions, which has also resulted in the spatio-temporal heterogeneity of their dynamic connections with other areas. Therefore, such heterogeneity in dominant functions should be considered in policies aiming to eliminate the negative effects of shadow areas on a city's overall development. For instance, for urban shadow areas dominated by residential functions, it would be useful to diversify the building types with multiple functions to gradually promote the formation of a diversified and inclusive community environment. For urban shadow areas dominated by industrial manufacturing functions, promoting the renewal of old and vacant factories and constructing industrial complexes could be an effective way to attract people and facilitate land use mixing.

7. Conclusions

The formation of urban shadow areas is a common phenomenon during the rapid process of urbanization. However, relatively few efforts have been made to delineate and characterize urban shadow areas in a more quantitative way. In this paper, we propose a method to identify urban shadow areas from the perspective of people flows. Taking Nanjing as a case study and drawing upon data on urban morphology and cellular signaling, we have identified and investigated the dynamic connections of 19 urban shadow areas within its downtown areas. The empirical results show that urban shadow areas differ from each other in terms of their morphological characteristics such as building density and development intensity. While 11 urban shadow areas are within the old downtown areas of Nanjing, the distribution of the rest of the 8 shadow areas are relatively scattered in the periphery. Moreover, we find that these urban shadow areas are not isolated but closely connected with other parts of Nanjing, though the spatio-temporal distribution patterns of their connections differ to some extent. The 19 urban shadow areas are further divided into four types by considering their different distribution patterns of connections, each of which is investigated by analyzing a representative shadow area. Based on the empirical results, we suggest that policies aiming to eliminate the negative effects of urban shadow areas should consider heterogeneity in their spatial distributions within a city, the temporal distribution of their external connections, and their dominant functions.

This study has some limitations which could serve as departure points for future research. For instance, due to data constraints, we have only investigated the dynamic connections of urban shadow areas on a given date. Therefore, future studies could consider comparing the connections from an evolutionary perspective. Furthermore, the underlying mechanisms behind the formation of different types of urban shadow areas have only been qualitatively discussed in this paper. Future studies could further explore the mechanisms in a more quantitative way.

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Conflicts of Interest: The authors declare no conflict of interest.

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