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# Evolutionary Characteristics of Urban Public Space Accessibility for Vulnerable Groups from a Perspective of Temporal–Spatial Change: Evidence from Nanjing Old City, China

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**Abstract:** Social equity/inequity and equal/unequal rights to the city extend beyond the distribution of urban parks and green spaces, necessitating research on equitable accessibility to encompass a broader range of public spaces. However, previous research has predominantly focused on green spaces, neglecting other types of public spaces. To address this gap, the present study takes the public space pattern of Nanjing Old City as the research object, employing the minimum distance method, the gravity potential method, and bivariate local Moran's I to evaluate the matching relationship between the demand of socially vulnerable groups and the supply of public spaces, as well as its temporal–spatial evolution from 2010 to 2020. The results reveal spatial heterogeneity in the accessibility of public spaces for vulnerable groups at the block level, with 28.1% of the total number of blocks and 22.1% of the total area of blocks experiencing a supply–demand imbalance in 2010. From 2010 to 2020, under the rapid urban development, construction of public spaces, and the general decline in population density and proportion of vulnerable populations, the supply–demand imbalance has exacerbated the distribution of public spaces at both individual and aggregate levels. This imbalance is reflected in the deteriorated accessibility of public spaces for vulnerable groups. This study reveals the mismatches between development, population movement, and public space construction in the old city of Nanjing over the past decade, providing decision-making suggestions and foundations for the future optimization of public spaces, thereby offering an effective tool for assessing and improving the accessibility and equitable distribution of public spaces based on the needs of vulnerable groups.

**Keywords:** urban public space; spatial equity; vulnerable groups; temporal–spatial change

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## 1. Introduction

In the context of persistent population expansion, an increasing number of individuals are migrating to urban areas in pursuit of enhanced living and employment prospects. In this process, cities must prioritize not only the enhancement of economic and social standards but also the development of a conducive living environment for their inhabitants [1]. Research has shown that a rational layout of urban public space is a key factor in improving the quality of life of residents and that it plays an irreplaceable role in promoting community interaction and enhancing the attractiveness of cities [2]. The term urban public spaces refers to areas accessible to the general public, which are primarily used for citizens' daily life and social activities [3]. The essence of public space lies in its publicness; thus, it should be shared equally by everyone.

In the contemporary era of challenges in the ecological environment and urban expansion, the recognized value of green spaces in improving urban ecological systems and environmental quality [4] has led to the recent focus on evaluating the accessibility and equity of these green spaces [5–8]. The accessibility of urban public green spaces has been extensively explored, with distance being considered a primary indicator of measuring

this accessibility. The frequency of green space usage tends to decrease as the distance increases [9], and proximity is identified as a crucial determinant of usage [10,11]. Fan developed a green accessibility index based on a weighted calculation of accessibility vs. quality and assessed the accessibility of various levels of urban parks in Shanghai from 2000 to 2010 [12]. Some studies focus on the relationship between urban green space accessibility and human health, devising more evidence-based accessibility metrics [13,14]. The equity of green space accessibility is increasingly recognized as an environmental justice issue. Research primarily focuses on fairness analyses of parks and green space based on primary social fairness, analyses of park and green space fairness for vulnerable groups, and the relationship between parks, green spaces, and health [15]. It is found that the existing layout of parks and green spaces is unfair, with lower accessibility for the elderly, children, immigrants, and minority groups [16]. Areas with higher property prices tend to have greater accessibility to parks and green spaces [17], and urban parks in city centers are more accessible than those in suburban areas [18]. After the concept of equity evolved from mere equality towards justice, the demands of vulnerable groups, including low-income individuals, migrant workers, and physiologically vulnerable groups, including children, the elderly, and women, have garnered particular attention. Studies indicate that residents with lower socioeconomic status spend more time in parks and green spaces [19]. Therefore, identifying the needs of different groups and providing them with more targeted services has become a focus of research.

Overall, the aforementioned studies primarily focus on public green spaces. However, public green spaces constitute only a small portion of urban public spaces. A significant portion of citizens' daily lives occurs in public spaces such as squares and streets. Regrettably, these spaces have seldom been quantitatively explored from the perspective of equitable accessibility, and the composition and quantification methods of large-scale urban public spaces remain an unexplored area. The relationship between urban green space distribution and residential layout primarily revolves around people and their activities, emphasizing the recreational value [9] and health benefits [20], which are also widely present in public spaces like squares and streets. Similar to urban green spaces, the distribution of urban public spaces is directly related to the distribution of public welfare, and urban public spaces have played a more critical role in promoting social interaction [21], supporting public life [22], and maintaining urban vitality [23]. Research confirms that well-designed and attractive urban public spaces have an equivalent impact on relieving stress and boosting mood as attractive natural environments [24]. Hard-surfaced public spaces such as streets and squares can offer citizens more accessible and utilizable spaces for both active and passive engagement that feature diversity, acceptance, and understanding. Therefore, urban hard-surfaced public spaces are equally important public goods and resources as green spaces, and their equitable provision has significantly influenced the quality of citizens' lives. Moreover, the location of natural space is often closely related to the innate natural geographical conditions of the city, while the construction of public spaces such as streets and squares has reflected significantly more artificial planning, which rightfully serves as a key indicator for assessing the equity of urban space distribution. Furthermore, urban public spaces, represented by squares and streets, often incorporate plant greening. Squares, streets, urban green spaces, and waterfront areas collectively form a public space continuum that is inseparable from both spatial and behavioral perspectives. The intended purpose of these spaces is primarily for amenity or recreation, making it essential to include them holistically in research perspectives. To a certain extent, especially in densely populated cities like those in China, the presence of streets, squares, and other public spaces can compensate for the inadequacy of public green spaces. This is because urban public spaces provide venues for social interaction and recreational activities, which are crucial for the well-being of urban residents. Studies have shown that when green spaces are limited, the quality of urban life can be improved by providing highly accessible public spaces [25]. The multifunctionality of streets and squares can alleviate the pressure on existing green spaces by incorporating recreational and social functions into urban spaces [3]. Solely focusing

on public green spaces might underestimate the actual recreational and health benefits people derive. This could also lead to inaccurate assessments of the fairness of benefits to individuals. Hence, we argue that studies on equitable accessibility in urban open spaces should encompass a broader range of public spaces beyond just parks and green areas.

With this in mind, this study expands the scope to include the diverse and composite category of urban public spaces. On the one hand, the structural scarcity of green spaces and public spaces in high-density areas makes the issue of equity important in the study of livable environments. Exploring equitable accessibility in urban public spaces based on the perspective of vulnerable groups, rather than solely focusing on public green spaces, has become a crucial research gap that has been largely overlooked in the past. On the other hand, in rapidly developing cities, the physical structure and accessibility of public spaces change along with the urban layout. These changes are reflected in the spatial distribution and physical characteristics of urban public spaces. Through analyzing the evolutionary characteristics of public space accessibility and its influencing factors in different stages of urban development, this study aims to reveal how urban processes affect accessibility to public spaces for vulnerable groups and how the equity of public space distribution changes over time. Due to the relatively fuzzy boundaries of urban public space, there is no public space land use type in the urban land use classification, so the scope of public space needs to be combined with a large number of on-site surveys and research in order to be determined, which is difficult at the urban scale and ultimately leads to the fact that the layout of urban public space is seldom quantitatively explored at this scale. This is one of the gaps addressed in this study.

This study extends the perspective of spatial justice and explores the spatial matching relationship and its temporal–spatial evolution between vulnerable groups' needs and the supply of public spaces using accessibility assessment methods. Our research questions are as follows:

- How can the accessibility of individual and general public spaces be measured separately?
- How well does public space provision match the needs of disadvantaged groups?
- In continually evolving cities, what are the characteristics of spatial and temporal changes in the alignment between public space provision and the demands of vulnerable groups?

## 2. Theoretical Framework

### *2.1. Definition and Scope of Public Spaces*

Urban public spaces are defined as areas in the city that are freely and unrestrictedly accessible to the public, regardless of gender, race, age, or social class [26], including centered spaces such as squares and parks [27] and movement corridors such as streets and pavements [28,29]. Carr categorized public spaces into eleven functional types, including public parks, squares and plazas, memorials, markets, streets, playgrounds, community open spaces, greenways and parkways, atria/indoor marketplaces, and everyday spaces [3]. Mehta suggests that public spaces can be defined based on ownership, access, control, and use [30]. The work of Talen and Pasaogullari confirms that the type and location of public space are both measurable and meaningful [31,32]. Elements of public spaces that promote social interaction include parks (such as district parks, neighborhood parks, and vest-pocket parks), squares/plazas (such as central squares and corporate plazas), and streets, particularly the quantity/type of street and the presence or absence of sidewalks [31]. The integration of public spaces should be seamless rather than abrupt.

The characteristics of contemporary public spaces exhibit diverse activities and social mixing. The context of public spaces is becoming increasingly multidimensional, making their categorization progressively more challenging [33,34]. It is advocated that the context of public spaces is understood through local circumstances, space typologies, and their use [26]. In this study, urban public spaces underscore their civic functions, primarily encompassing human-made outdoor environments like urban squares, streets, parks, green spaces, and waterfront areas. These spaces are integral to citizens' daily lives, making

it imperative to prioritize their accessibility and equity to ensure equal benefits for all residents. Playgrounds, community facilities, and commercial/retail spaces also play important roles at the neighborhood level. However, in China, these spaces typically have specific access requirements, and therefore, this study does not include these types of public spaces. Public spaces must be situated within urban development land; therefore, water bodies, agricultural and forestry lands—including garden plots, forests, and pastures—and other non-development areas are not classified as public spaces.

### *2.2. The Theoretical Framework of Accessible Equity Researches and the Focus of This Study*

The research on the accessible equity of public spaces focuses on the relationship between the layout of public spaces and humans. Specifically, it encompasses the subjects and objects of research on the meaning of equity, the intervention of research perspectives, the understanding of access, and the quantification of accessibility, according to which this study establishes a theoretical framework (Figure 1).

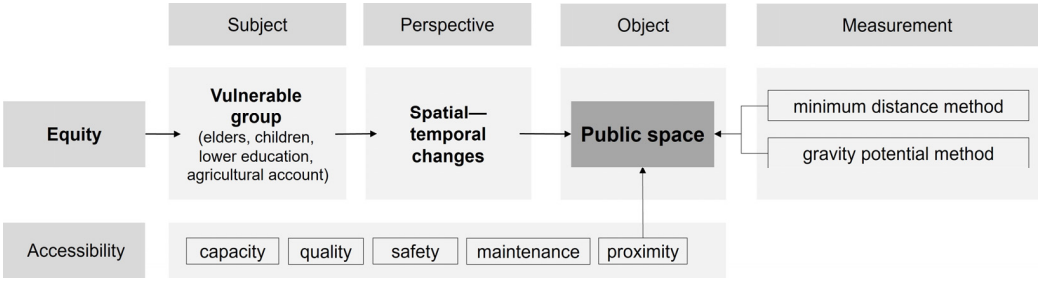



**Figure 1.** The theoretical framework of accessible equity research and the focus of this study.

Firstly, the study explores the cognition of the research subject. Equity distribution implies that the siting of public resources should maximize accessibility for as many different social groups as possible, and urban public spaces should be as accessible as possible for the majority of people, especially those with a high demand for public spaces. Compared with equality-based strategies, true equity takes accessible equity for vulnerable groups into account [35,36].

Secondly, in terms of research objects, there is a considerable need to study the equity/inequity of the social life of cities that public space provides to people in different parts of the city, as it is an important part of the environmental justice movement and the construction of inclusive and shared cities. Compared with the spatial attributes of urban parks or green spaces, the social attributes of urban public spaces are much stronger, and the collective public character brought by public spaces is a key dimension of a good city, critical for the development and maintenance of social connections [37].

Thirdly, on the intervention of research perspectives, previous studies on spatial accessibility mainly focus on analyzing the contradiction between activity requirements and spatial distribution and accessibility of facilities based on the current layout [38,39]. Such analysis is conducted solely according to the existing state, lacking attention to the temporal and spatial evolution of facilities and population. Hence, this research pays more attention to the diachronic perspective, aiming to analyze and reveal the spatial and temporal evolutionary characteristics of accessibility to facilities in the process of rapid urbanization, as well as the evolutionary laws and mechanisms behind them.

Fourthly is the understanding of access. Accessibility encompasses factors that affect access or use, such as proximity, capacity, quality, safety, and maintenance of the spaces [7,40]. Among these, proximity is the most crucial, serving as a necessary condition for measuring accessibility and being closely related to urban patterns and urban planning decisions [39]. The accessibility of short-distance public spaces holds considerable significance to citizens, especially for vulnerable groups with limited mobility.

Finally, this study examines the quantification of geographic access using the minimum distance method and gravity model. The minimum distance method measures the

accessibility by calculating the distance to the closest facility to the district, which is most appliable in scenarios where users tend to use the closest neighboring facility. Considering that residents generally take a proximity approach in their daily routine [41], the minimum distance is suitable for evaluating the proximity accessibility of public space. However, this method overlooks the cumulative accessibility contributed by multiple facilities within reasonable reach, which can be compensated by the gravity potential method. By taking into account the spatial spillover effect of facilities and the distance obstruction effect, the gravity potential method, which takes into account the spatial scale and distance attenuation, can better measure the overall accessibility of public space.

Based on the above analysis, this study locates the research subject in the vulnerable groups, the research object in the urban public space layout, and based on the perspective of spatial and temporal changes, comprehensively applies the minimum distance method and the gravitational position method to analyze the fitting relationship between the supply of public space and the demand of the vulnerable groups, and evaluates the fairness of the allocation of urban public space in the process of rapid urbanization.

## 3. Materials and Methods

### *3.1. Research Methods*

This study focuses on the correlation between public space accessibility and the needs of vulnerable populations. Blocks are used as the basic unit for accessibility calculations because the characteristics of population distribution within blocks tend to be consistent. Due to the weak subjective initiative of vulnerable groups in using public spaces and their lower sensitivity to time and travel costs, in order to consider these two contradictory characteristics of public space use, the study uses the minimum distance method to quantify the accessibility of a single public space, representing the individual attraction and the gravitational method to quantify the accessibility of the overall public space, thus representing comprehensive attractiveness. Residents' needs are centered on socially vulnerable groups, with their population distribution characteristics serving as the demand evaluation factor. By fitting the service level of public spaces with residents' needs using bivariate local Moran's I, the aim of the study is to explore the matching degree and its temporal–spatial change characteristics, evaluate the development and construction effectiveness of public spaces in the research area and provide decision-making suggestions and foundations for the future optimization of public spaces (Figure 2).

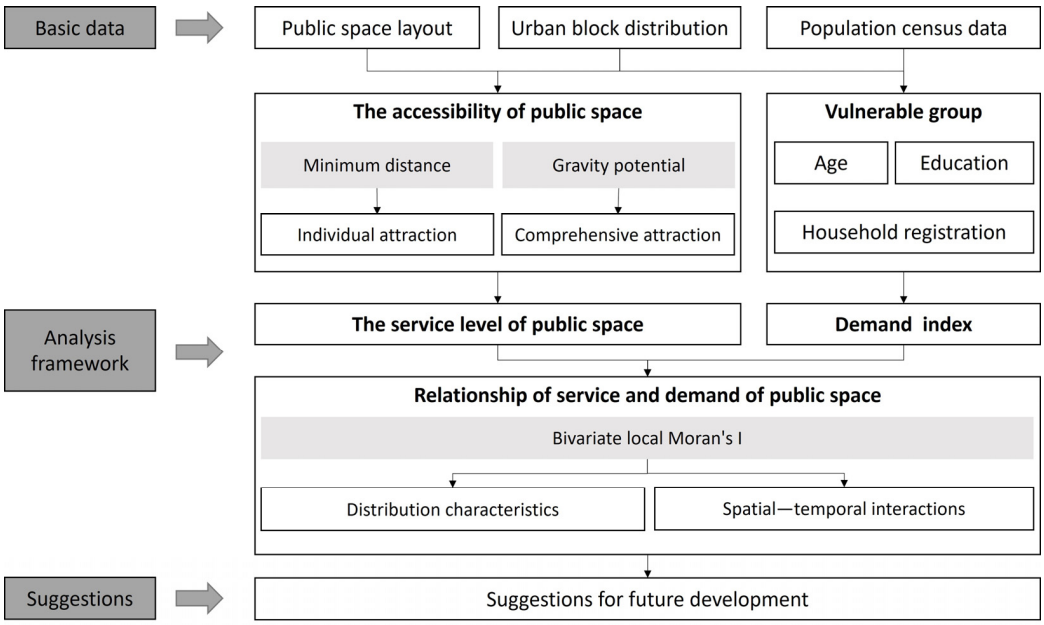



**Figure 2.** Overview of this study.

3.1.1. Accessibility Calculation Method

Algorithms for measuring the walking accessibility of public spaces are all based on the same idea that space accessibility is represented by positioning the relation between the public space layout and population distribution. The combination of the minimum distance method and gravity potential method can synthesize the individual accessibility of public spaces with the overall accessibility of the public space system [42], thus comprehensively revealing the accessibility of urban public space.

1. Minimum distance approach

Considering the urban environment characteristics, the distance that residents need to go through to reach the public space is often greater than the straight-line distance from the starting point to the public space, and the use of cost distance is effective in addressing this issue. The minimum cost distance from each grid point within the research area to the edges of public spaces is calculated with the road areas treated as low-cost grids and non-road areas as high-cost grids. Taking the scale of the research area and the actual size of public spaces into account, 3 m as the grid unit can meet the requirements of evaluation accuracy.

$$Z_i^E = \min\left|d_{ij}\right| \tag{1}$$

where, $Z_i^E$ means the minimum distance analysis index of block $i$; $d_{ij}$ means the distance from block $i$ to the public space $j$.

On the basis of grid evaluation, zonal analysis is used to calculate the average minimum cost distance of the grid in each block as the evaluation result of the overall minimum cost distance of the block, which represents the accessibility to public spaces in the vicinity of each block.

2. Gravity potential approach

In the gravity potential approach, the public space is endowed with weight by varied size and distance decay, and the accessibility value means the potential supply capability of each public space. This approach emphasizes the blocking effect of distance, and it is based on the assumption that the farther away a place is, the less likely users are to go, although they can reach any urban space theoretically. Formally, this index is expressed as:

$$Z_i^G = \sum_j \frac{S_j}{d_{ij}^{\alpha}}, d_{ij} \neq 0 \tag{2}$$

wherein $Z_i^G$ means the gravity analysis index of block $i$, $S_j$ means the size of public space $j$, $d_{ij}^{\alpha}$ reflects the distance decay factor, $d_{ij}$ means the distance from block $i$ to the public space $j$, and $\alpha$ means the friction parameter, which is set to a value of 2, according to the empirical value.

However, the formula may over-estimate the attraction of urban public spaces. Particularly, not all urban public spaces attract residents from any distance to reach by walking, so public spaces have a certain service radius. In this study, the attraction is determined according to the hierarchy system of public spaces. Based on the hierarchy of district level, urban level, and regional level, the public space at the higher level has a stronger attraction. With reference to the guiding standards for open spaces [43,44], the maximum service radii of district-level, urban-level, and regional-level public spaces are set as 0.5 km, 3 km, and whole city, respectively, and the public space gravity beyond such a distance is deemed as 0. The point distance in ArcMap was used to calculate the distance between the center point of public spaces and the center point of districts, and the attractiveness of different levels of public spaces to each district was calculated based on the above distance thresholds and formula. Finally, in order to visually compare the change in overall accessibility between 2010 and 2020, the 2010 accessibility results were divided into five classes using the natural breakpoint method, which maximizes the differences between classes, and the accessibility results of 2020 were separated by the same breakpoints as those of 2010.

3.1.2. Public Space Demand Index for Vulnerable Groups

The travel structure characteristics and behavior patterns of urban residents determine their specific needs for urban public spaces. This study takes the supply equity of public spaces as the evaluation criteria and focuses on the public space needs of socially vulnerable groups. This term commonly refers to groups that are at increased risk of victimization, discrimination, or adverse effects because of factors such as age, economic conditions, and social environments that may restrict their mobility, resulting in lower proactive use of public spaces and fewer opportunities compared with other demographic groups. Vulnerable groups may vary across cultures, and some common examples include children, the elderly, persons with disabilities, ethnic and racial minorities, persons with low levels of education, and persons with low incomes. From the perspective of social needs and support, vulnerable groups are the most in need of outdoor public spaces to meet their daily communication, leisure, and recreation needs. Given the limited mobility of this group, there is an urgent need for public spaces with high accessibility; therefore, calculating the distribution characteristics of the resident population can intuitively reflect the demands of vulnerable group residents for public spaces.

Based on the available urban census statistics, four indices are selected for evaluating vulnerable groups, namely the proportion of the population aged 0–19, the proportion of the population aged 65 and above, the proportion of the population with education below junior high school, and the proportion of the population with agriculture account. The needs of disadvantaged groups are determined not only by age, educational attainment, and household registration but also by low income, disability status, smaller housing areas, the proportion of households living in low-rent housing, and the residential density of the neighborhood among others, which can serve as indicators for measuring the demand indices. A more accurate demand index can also be obtained through interviews. However, the data used in this study come from publicly available data from the Chinese Population Census, and only the aforementioned four indicators meet the requirements. By calculating the population density of vulnerable groups for each block as the resident demand index, this study comprehensively measures the extent of demand from vulnerable groups for public spaces to reflect the spatial distribution characteristics of resident demand from the perspective of equity.

3.1.3. Supply and Demand Fitting Based on Spatial Correlation Analysis

The results of the accessibility assessment of public space and the needs of socially disadvantaged groups are data with spatial attributes, and spatial correlation analysis can intuitively reflect the differences and commonalities in the supply and demand situation in different blocks. The study utilizes GeoDa1.22.0.4 software to calculate the spatial correlation characteristics of the public spaces' supply and demand [45]. The bivariate local Moran's I can reveal the correlation features of different spatial units. Specifically, it calculates the local correlation between the independent variable of Region I and the dependent variable of Region *j* [46]. By calculating the local Moran's I between the minimum distance and the resident demands for each block, as well as between the attractiveness and the resident demands for each block, the spatial distribution characteristics of the supply and demand matching of public spaces can be intuitively reflected. The specific formula is as follows:

$$I = S\sum_{j=i}^{N} W_{ij}D_{ij}$$

where $I$ represents the result of local Moran's $I$. $N$ is the total number of spatial units, $S$ is the supply normalized evaluation results of public spaces, and $D$ is the normalized resident demand index. Since the analysis units are urban blocks, there are no common boundaries or intersections between adjacent units. Additionally, the shapes and sizes of different

analysis units may vary, so a spatial weight matrix is constructed based on the distance, and the specific formula is as follows:

$$W = \begin{bmatrix} 0 & \frac{1}{d_{1,2}} & \cdots & \frac{1}{d_{1,n}} \\ \frac{1}{d_{2,1}} & 0 & \cdots & \frac{1}{d_{2,n}} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{1}{d_{n,1}} & \frac{1}{d_{n,2}} & \cdots & 0 \end{bmatrix}$$

where $d_{i,j}$ is the distance of the $i$th and $j$th spatial units. The distance-based spatial matrix requires setting the threshold distance, within which units are considered to be correlated, while units beyond this distance are considered unrelated. In this study, we assume that vulnerable groups walk to public spaces and set 1000 m as the threshold distance.

### *3.2. Overview of the Study Area*

Nanjing is a crucial central city in the Yangtze River Delta Region of China. It was chosen as a case study area because it has experienced rapid urban growth over the past few decades, reflecting similar physical characteristics to other rapidly developing cities. Nanjing Old City is delineated by the Ming Dynasty's city wall, covering approximately 43.0 $km^2$. As the earliest urbanized area with the highest degree of development in Nanjing, the old city had a permanent population of around 1.376 million at the end of 2010, with a population density of 32,000 people per square kilometer. Due to urban land expansion and the population evacuation policy of the old city, the permanent population decreased to 1.054 million in 2020, resulting in a reduced population density of 24,000 people per square kilometer while still maintaining a relatively high level. In the process of rapid urbanization, the types, forms, and property rights of public spaces in Nanjing City have been greatly diversified, but the original public space system is occasionally eroded amid high-density development. There is regional differentiation in the population evacuation situation in the study area, and public space construction is constrained by both artificial and natural environments, presenting an imbalanced development status. Therefore, in this process, it is crucial to study and evaluate how the supply–demand matching between public spaces and residents' needs changes in a rapidly developing city.

### *3.3. Data Sources and Processing*

The boundaries of public spaces in Nanjing Old City are relatively blurred, which is largely attributed to a historical lack of comprehensive understanding of the pivotal role of public spaces and a deficiency in relevant planning. This study has been conducted intermittently over the past 20 years. In 2010 and 2020, extensive on-site surveys of public spaces in Nanjing Old City were conducted, combined with references from relevant documents and drawings, such as the *Recent Planning for Optimizing the Layout of Green Spaces in Nanjing Old City* [47], *Controlled Detailed Planning for Nanjing Old City* [48] and *Planning for Urban Green Space System in Nanjing City (2013–2020)* [49]. The investigations utilized high-resolution satellite images taken in 2010 and 2020 obtained from Google Earth, which jointly defined the scope of public spaces in Nanjing Old City, including living streets, squares, urban parks, and waterfront areas (Figure 3). Among these, the scope of parks and squares is much clearer. Living streets refer to slow-system streets primarily serving residents' daily communication needs, while waterfront areas denote riverfront streets that provide residents with spaces for leisure and relaxation. Considering the significant role of densely distributed small public spaces, including small squares, pocket parks, micro and small green spaces, and informal public spaces, in meeting residents' daily life and recreational needs in high-density areas, this study did not set a lower limit for the size of individual public spaces. Mountains and water are not included within the scope of urban construction land, as they do not belong to urban public spaces.

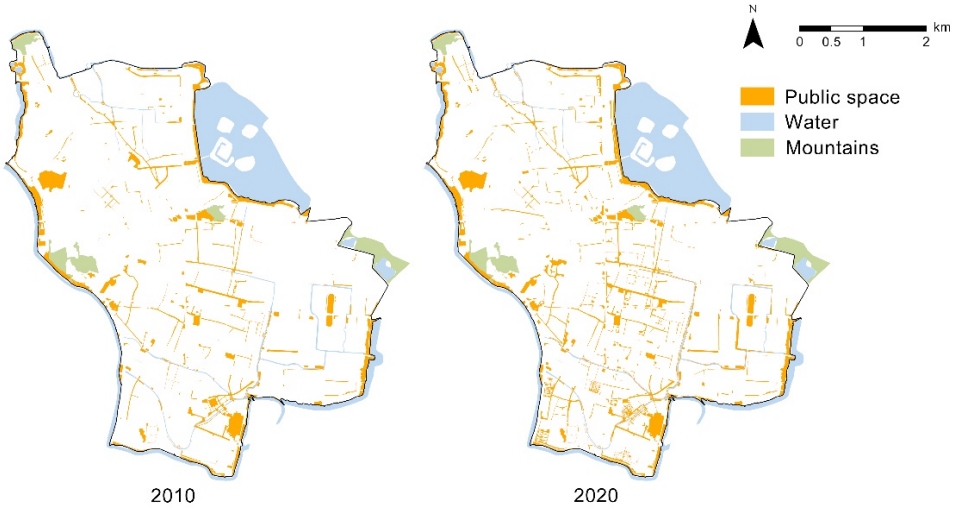



**Figure 3.** Distribution situations of public spaces in Nanjing Old City (2010 and 2020).

In 2010, the total number of public spaces in Nanjing's old city was 326, covering an area of 3.35 square kilometers, accounting for 7.8% of the study area's total area. By 2020, the number of public spaces had increased to 555, and the total area had expanded by 3.44 square kilometers, reaching 6.79 square kilometers, accounting for 15.8% of the study area's total area. These new spaces primarily consist of waterfront areas, plazas outside commercial complexes, and pedestrian zones, gradually established through urban renewal processes with a focus on daily use by citizens.

The public functions of a city rely on a network formed by organized public spaces, and mature public space systems always exhibit hierarchy. Public spaces with clear levels demonstrate hierarchical order in terms of status, service range, and organizational structure. They can attract and support activities at different levels, forming efficient and balanced layout patterns through coordinated relationships [50]. However, there are no uniform criteria for delineating the hierarchical structure of public spaces. According to the Accessible Natural Greenspace Standards (ANGSt) in the UK, city/metro-level green space should be no less than 100 hectares with a maximum service radius of 5 km; district-level green space should be 20 to 100 hectares with a maximum service radius of 2 km; and neighborhood green space should be no less than 2 hectares with a maximum service radius of 300 m [12,51]. Urban public spaces cannot be simply classified into levels based solely on size; public spaces in city centers may not be large in scale but can have regional or even national and international influence. Therefore, the public space hierarchy of Nanjing Old City (Figure 4) is determined by means of on-site investigation and comprehensive judgment according to its importance to the district, city, and region, as well as its influence at home and abroad, reflecting their service levels. Specifically, the "regional-level" public space means the public space with regional, domestic, or even international impact, located in the core area of the city with the service range covering the entire city. "Urban level" public space means the public space with urban importance that serves the whole city, including the main urban node, urban structural axis, main business district, main leisure and cultural venues, urban-level streets, squares, parks, and green spaces. Finally, "district level" public spaces include all public spaces serving the urban districts, typically with a service radius of 0.5 km to 0.5 miles [43,44]. This value is based on the general accessibility standards for urban public spaces, ensuring that most residents can reach these spaces within a short walking distance. Considering the mobility constraints of vulnerable groups and the presence of complex streets and large blocks in Nanjing's old city, the service threshold for this level is set at 0.5 km. This standard represents the potential maximum supply capacity of public spaces. Due to the gravity model's consideration of distance decay, the impact of public spaces located farther away on the overall accessibility of a neighborhood diminishes with increasing distance.

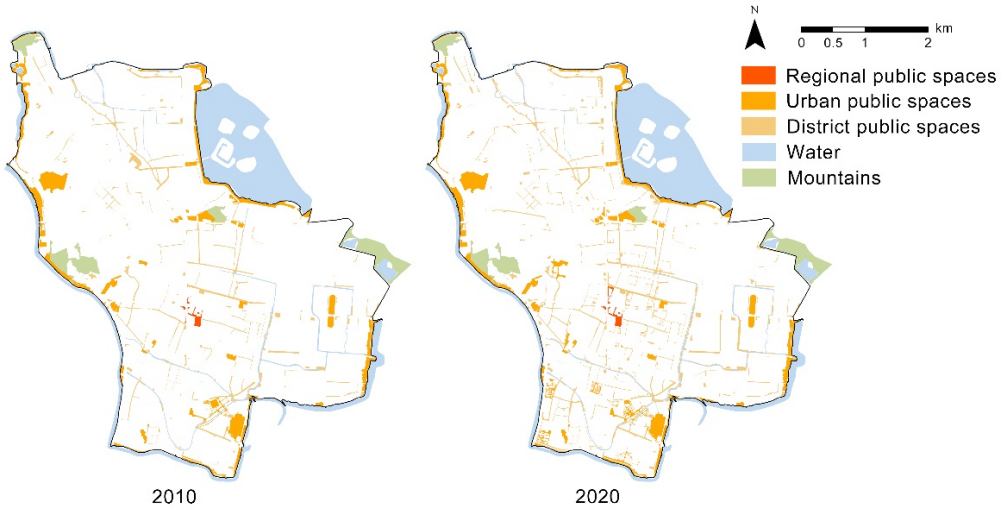



**Figure 4.** Hierarchy of public spaces in Nanjing Old City (2010 and 2020).

The boundaries of blocks used in this study are derived from the *Controlled Detailed Planning for Nanjing Old City*. The population data are sourced from the sixth population census in 2010 and the seventh population census in 2020 in Nanjing.

## 4. Results

### *4.1. The Evolving Characteristics of Accessibility of Individual and Overall Public Spaces*

#### 4.1.1. Analysis of Accessibility of Individual Public Spaces with the Minimum Distance Approach

The natural breaks method was employed to categorize the results of the minimum cost distance from each block to public spaces in the study area into five levels (Figure 5). In 2010, the accessibility to adjacent public spaces in the center of the study area was superior to that in the peripheral area. The areas with the highest accessibility include the Xinjiekou and Fuzimiao districts, where public spaces were more densely distributed. Xinjiekou is Nanjing's modern commercial center, characterized by high-rise buildings, shopping malls, and commercial complexes. There are several public plazas and pedestrian areas in this district, serving as gathering points for shopping, entertainment, and socializing. Fuzimiao is renowned for its rich cultural heritage, featuring high passenger flow and vibrant night markets. It provides spaces for residents and tourists to gather, shop, and experience local traditions, making it a major cultural and social hub. The small block sizes in Xinjiekou and Fuzimiao result in high average accessibility to public spaces. Conversely, the blocks with the lowest accessibility to adjacent public spaces, indicated by the brown areas on the map, were predominantly located in the northern and eastern parts of the study area. These areas had fewer public space distributions and larger block sizes, contributing to lower average accessibility.

In 2020, the accessibility to adjacent public spaces in the center of the study area remained high. However, there was a significant improvement in the accessibility to public spaces in the southern part of the study area, which is closely related to the increase in the quantity and size of public spaces. Nevertheless, the blocks on the eastern and northwest sides of the study area still exhibited relatively low accessibility to adjacent public spaces, indicating a pressing need for an increase in the accessibility of current public space and the number of public spaces in these areas.

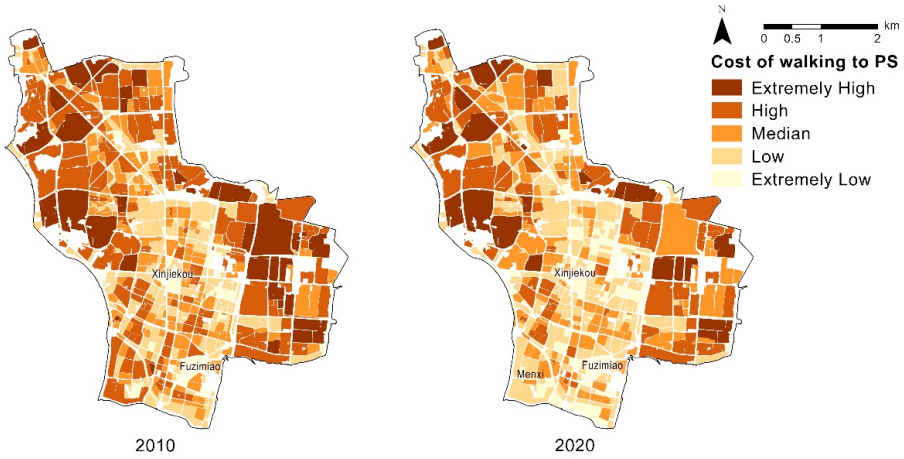



**Figure 5.** Difference in minimum cost distance from blocks to adjacent public spaces in Nanjing Old City.

The results indicate a slight improvement in public space accessibility for each block in 2020 compared with 2010, with the most notable improvement observed in the Menxi area located at the southwest edge of the study area. The Menxi area is one of Nanjing's old districts with a rich historical heritage and intact traditional style. It is characterized by restored traditional buildings and ancient streets and alleys, mixing residential spaces, cultural sites, food shops, and craft stores. This area has undergone a series of urban renewal projects focusing on cultural heritage preservation and cultural tourism development. Public spaces have been renovated and enhanced, and innovative resources have been introduced. Through industrial upgrading, the area has revitalized its underutilized spaces, bringing new vitality to the Menxi area. However, the regions with the poorest public space accessibility in 2010, represented by the darkest colors on the map, did not show improvement in 2020. This characteristic is most pronounced in the eastern and northwestern parts of the study area.

#### 4.1.2. Analysis of Accessibility of Overall Public Spaces with Gravity Potential Approach

The results of the comprehensive attractiveness analysis of public spaces in Nanjing Old City are shown in Figure 6. The statistical results indicate that, in 2010, the areas with higher attractiveness were mainly concentrated in Xinjiekou, Gulou, Fuzimiao, and the western edges. The Gulou area is an old district formed over the long-term development of Nanjing. Gulou Square is one of the most important geometric axis intersections in the city, serving as a transportation hub, a center for commercial and cultural public activities, and a civic square for leisure and entertainment. This area is also home to numerous historical, cultural, and natural landmarks. The attraction of the western edge of the study area mainly comes from natural leisure areas, such as Gulin Park and the Qinhuai River Scenic Belt, providing green spaces for residents. The high level of attractiveness remained consistent in these areas until 2020, by which time the distribution range of areas with higher attractiveness had expanded. In 2010, the areas with insufficient attractiveness were mainly located in the northern, southwestern, and eastern parts of the study area, all of which were situated on the periphery of the old city. In 2020, the areas with insufficient attractiveness exhibited a significant reduction in size, decreased clustering, and more scattered distribution in the northern and eastern parts of the study area.

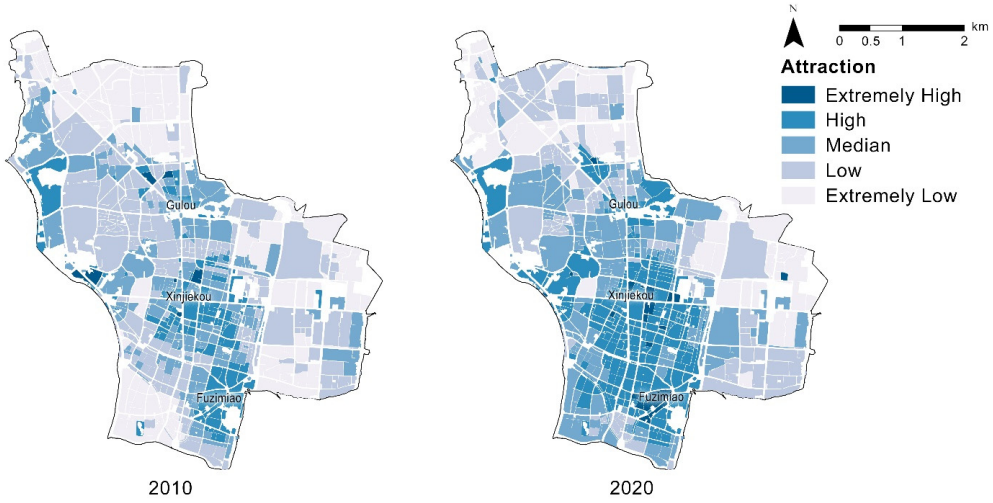



**Figure 6.** Comprehensive attraction classes of public spaces in Nanjing Old City.

The data indicate that, compared with 2010, the overall level of attractiveness in the study area in 2020 increased, and the number of blocks with medium to high attractiveness levels rose significantly, although there was a slight decrease in the number of blocks with extremely high attractiveness. This suggests an overall improvement in the balance of accessibility to public spaces in the area during the process of development. Areas with higher overall accessibility gradually expanded and interconnected from Gulou, Xinjiekou, and Fuzimiao. However, there has been relatively limited improvement in terms of the overall accessibility in peripheral areas, and no new centers of attractiveness have emerged.

### *4.2. Public Space Demand Index*

Based on the available data, the proportions of the population aged 0–19 and aged 65 and above, with education below junior high school and with agricultural accounts, were arithmetically averaged for each block in the study area, then multiplied by the respective population density of each block and normalized to obtain the demand index for each block. The results are subsequently reclassified into distinct categories through equal intervals, as illustrated in Figure 7.

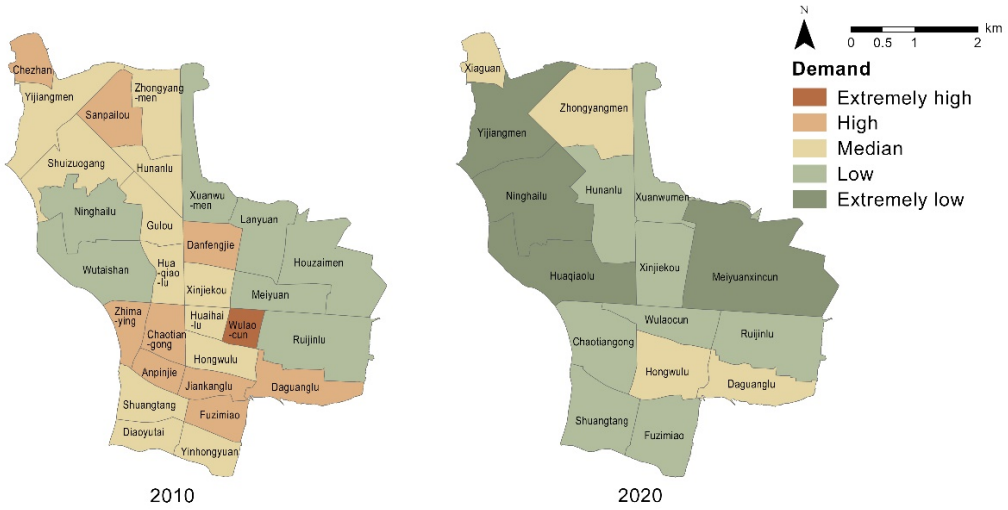



**Figure 7.** Demand index of public spaces in Nanjing Old City.

Specifically, in 2010, areas with low demand indices were concentrated in locations on the east (Xuanwu Gate, Lanyuan, Meiyuan, Houzaimen, and Ruijin Road) and the west side (Ninghai Road and Wutaishan), all of which feature a higher proportion of universities

and administrative land, and a lower proportion of residential area. That represented a generally higher level of resident education and a lower population density, resulting in overall lower demand indices. Areas with extremely high or higher demand indices were concentrated in the southern part of the study area (including Wulao Village, Zhimaying, Chaotiangong, Anpin Road, Jiankang Road, Confucius Temple, and Daguang Road) and some blocks in the northern part of the study area (the station, Sanpailou, and Danfeng Street), all of which had a significant proportion of vulnerable groups, especially those with lower educational levels, and a higher overall population density, contributing to higher demand indices. In summary, in 2010, the southern part of the city was a gathering place for vulnerable groups such as those with lower educational levels and older people, with areas with higher and the highest demand accounting for more than half of the entire old city in terms of year-on-year comparisons. The second-highest demand areas were in the northwestern part of the study area, which also served as a settlement for those with lower educational levels.

In 2020, the administrative divisions of Nanjing Old City were adjusted. According to the new administrative divisions and population census data, the blocks with lower demand indices included Meiyuan New Village on the east side and Yijiangmen, Ninghai Road, and Huaqiao Road on the west side, all of which exhibited lower population density and a lower proportion of vulnerable populations. Blocks with moderate demand indices included Xiaguan and Central Gate on the north side and Hongwu Road and Daguang Road on the south side, all of which showed a higher degree of aging and a higher proportion of individuals with lower educational levels compared with other areas, contributing to relatively higher demand indices. It is noteworthy that in areas with extremely low demand indices, Meiyuan New Village exhibited a higher degree of aging, while Huaqiao Road and Ninghai Road had a larger proportion of young populations. Therefore, areas with an extremely low demand index in the study area still manifested certain public space needs, albeit relatively lower compared with other areas. This also reflects the overall high proportion of disadvantaged people in the study area and the fact that the demand for public space in the region has not declined significantly in response to out-migration. Figure 7 shows that the public space demand index in the study area has not completely dropped to an extremely low level, indicating that the need for public space still exists. Even though a small number of residents have moved out, the remaining residents, especially vulnerable groups, continue to rely on public spaces for recreation, socialization, and daily needs. Given the relatively stable socioeconomic structure of the community, the overall demand for accessible public spaces does not decrease rapidly.

The residents' demand indices in 2010 were generally higher than those in 2020. In 2010, the residents' demand was concentrated at higher and medium levels, whereas in 2020, it shifted towards lower levels. This change is attributed to the population evacuation policies implemented in the old city during this period. Significant variations exist in population changes among different blocks. In 2010, the regions with relatively higher demand indices were predominantly located in the southern part of the study area, correlating with urban functional zoning. The southern part constituted a large number of old residential areas. Consequently, in 2020, this region experienced the most noticeable decline in demand indices. In contrast, the decline in demand was less pronounced in the northern part of the study area, with the Central Gate and Xuanwu Gate blocks maintaining unchanged demand index levels.

After a decade of population changes, there has been a general decrease in population density and the proportion of vulnerable populations in the study area. The demand indices for each block show a trend of either maintenance or decline. Meanwhile, the overall distribution characteristics of the indices continue to feature greater demand in the southern part than in the north. Specifically, the demand center in the southern part has shifted towards the southeast, while the demand center in the northern part has further migrated towards the central area.

### *4.3. Fitting of Demand and Public Space Accessibility*

#### 4.3.1. Fitting of Demand and Accessibility of Individual Public Space

The local Moran's I analysis reveals a LISA map, indicating distinct spatial clustering characteristics between the accessibility to adjacent public spaces in the study area and resident demands. As shown in Figure 8, four different correlation cluster types are identified, namely, High Accessibility–High Demand, Low Accessibility–Low Demand, Low Accessibility–High Demand, and High Accessibility–Low Demand.

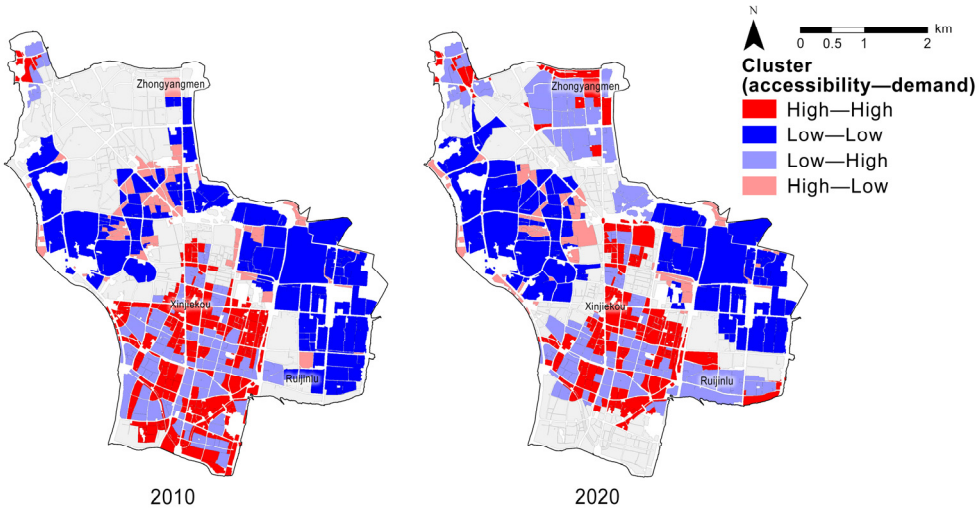



**Figure 8.** Equity map of public spaces distribution in Nanjing Old City.

Class I districts: High demand and high accessibility. Both residents' demand and public space accessibility are high, and the relation between demand and accessibility is basically balanced. Although it means that more of the population potentially compete for public spaces, adjacent public spaces have high accessibility and diversified space types. The fitting results show that adjacent public space resources have better accessibility to adjacent public space for residents with a high demand for public space, which is in line with the logic of equity. In 2010, these areas were concentrated in the central and southern parts of the study area, constituting 33.8% of the total number of blocks. By 2020, there was a decrease in clustering on the southern side, with more high–high clustering observed in the northern part of the study area. The proportion of blocks with high–high clustering decreased to 26.8% of the total. Overall, Class I districts are mainly composed of smaller blocks with a strong living atmosphere, and moderate competition for the use of public space is conducive to stimulating spatial vitality. This area exhibits a pattern of intersecting distribution with Class III districts.

Class II districts: Low demand and low accessibility. Both residents' demand and public space accessibility are low, and the supply and demand of urban public spaces are coordinated at a low level. At present, the mean size of the blocks is significantly greater than that of other districts. Most of the lands are used for government organs, enterprises and public institutions, and supporting housing. A significant part of urban public life has been internalized into enclosed courtyards as isolated areas in the city, which has considerably reduced urban space vitality. These types of blocks cover a large scope and are widely distributed, which has a significant impact on the accessibility and vitality of urban public spaces. In 2010, 18.1% of the number and 30.6% of the area of blocks belonged to this type, concentrated in the central-western part and eastern side of the study area. By 2020, this proportion decreased to 15.3% and 29.4%, respectively.

Class III districts: High demand and low accessibility. Existing public spaces cannot meet the residents' basic demands. From the perspective of spatial equity, it is a district where public spaces urgently need development. Vulnerable populations such as those with a low education background and migrant populations account for a large proportion,

so the demands for public spaces are the highest in the four classes. However, the existing public spaces are deficient and are of the monotonous type, with poor accessibility, leading to large gaps between provision and residents' demands. In 2010, the proportion of blocks belonging to this type was 14.0%, and the area was 14.6%, but by 2020, it had slightly increased to 15.6% and 21.3%, respectively. This area often intersects with Class I districts, with its distribution center shifting from the central and southern parts in 2010 to the central and northern parts in 2020.

Class IV districts: Low demand and high accessibility. Blocks belonging to this class have compact sizes and strong publicness. The adjacent public spaces are diversified and have high accessibility, which can be well utilized. The supply of public spaces in such districts can meet the adjacent residents' demands, and these spaces have a spillover effect to some extent. This type has the fewest number of blocks among all types, accounting for 12.0% in number and 5.8% in area in 2010 and decreasing to 10.4% in number and 4.9% in area in 2020. These types are primarily distributed around Area Type II, with no significant changes in distribution location.

Comparing the results of the spatial correlation analyses from a decade ago and now, there has been a decrease in the number and area of significantly clustered blocks, indicating that the distribution of accessibility to adjacent public spaces and resident demand is becoming more inclined towards a random pattern, and the overall clustering trend has declined. Among the significantly correlated spatial results, only the proportion of blocks belonging to the "Low Accessibility-High Demand" type has increased. This suggests that there is a spatial misalignment between the development of public spaces and the growth in resident demands. From 2010 to 2020, although the total amount of public space in Nanjing's old city significantly increased and the population density and proportion of vulnerable populations generally decreased, the accessibility of adjacent public spaces for vulnerable groups with high demand for public spaces deteriorated. This highlights the exacerbation of spatial inequality over the decade. The reason for this phenomenon is that the increase in the amount of public space in Nanjing Old City often comes from urban renewal projects, and those projects could have impacts on the surrounding residents, which is manifested in the out-migration and renewal of the population and the decline in the proportion of socially disadvantaged groups. Those areas to which the socially vulnerable groups migrate are usually in areas with few urban renewal projects, resulting in the spatial misalignment between the development of public space and the increase in demands. This spatial misalignment is particularly evident in the Central Gate and Ruijin Road blocks, where many have transitioned from "Low Accessibility-Low Demand" to "Low Accessibility-High Demand". In other words, resident demands have increased, but the development of public spaces is inadequate and unable to meet the growing needs of the local residents.

#### 4.3.2. Fitting of Demand and Accessibility for Overall Public Space

The local spatial correlation characteristics between the overall accessibility to public spaces and resident demand in the study area are illustrated in Figure 9. The results indicate that the distribution locations and scales of four distinct correlation clustering types differ significantly. These types are High Accessibility–High Demand, Low Accessibility–Low Demand, Low Accessibility–High Demand, and High Accessibility–Low Demand.

Class I districts: High demand and high accessibility. In 2010, these areas were concentrated in Xinjiekou and the southern Confucius Temple area, with the number proportion accounting for 26.3% of the total and the area proportion accounting for 15.8%, making it the most prevalent type. In 2020, there was no apparent clustering in the southern blocks, and the clustering in the Xinjiekou area remained unchanged, with small scattered high–high clustering areas on the northern side. Overall, the proportion of blocks with high–high clustering significantly decreased to 17.7% in number and 9.4% in area, marking a noticeable decline.

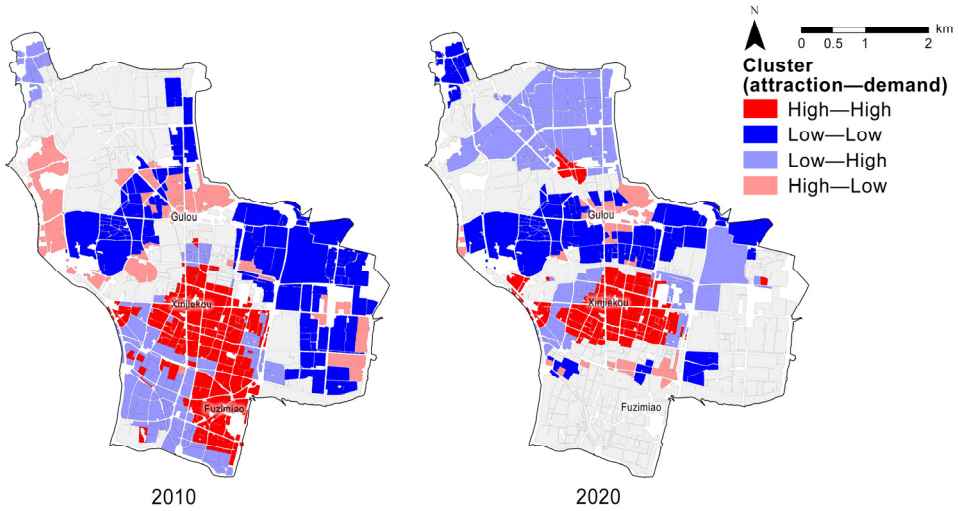



**Figure 9.** Spatial correlation between overall accessibility and resident demands.

Class II districts: Low demand and low accessibility. In 2010, the blocks accounted for 21.1% in number and 24.6% in areas that belonged to this type, concentrated in the western, northern, and eastern parts of the study area. By 2020, the proportion of blocks of this type had slightly decreased to 20.2% in number and 20.4% in area, with the low–low clustering area on the eastern side disappearing and the northwest corner transitioning into a low–low clustering area.

Class III districts: High demand and low accessibility. In 2010, the proportion of blocks belonging to this type was 21.5% in number and 14.4% in area. By 2020, the number proportion decreased to 17.3%, while the area proportion increased to 20.6%, indicating that blocks with a bigger area converted to this type. This type is predominantly distributed on the periphery of the high–high clustering blocks of Type I. In 2010, it was mainly located in the southwestern part of the study area, while in 2020, it was more prevalent in the northern region.

Class IV districts: Low demand and high accessibility. This type has the fewest number of blocks among all types, accounting for 0.9% in number and 1.1% in area in 2010 and decreasing to 0.6% and 0.4%, respectively, in 2020. Blocks of this type are scattered around low–low clustering blocks. In 2010, they were mainly located around Gulou and on the eastern and western edges of the study area. In 2020, the clustering area for this type had significantly reduced.

Comparing the evaluation results of 2010 and 2020, the proportion of blocks within the study area where there is a correlation between overall accessibility to public spaces and resident demand decreased from 78.9% to 61.1% in number and from 66.2% to 54.3% in area. The spatial correlation between the overall accessibility to public spaces and resident demand was weakened. Specifically, areas with positive correlations, where overall accessibility to public spaces and resident demand are in a state of high–high or low–low clustering, decreased from 47.4% to 37.9%, while areas with negative correlations decreased from 30.5% to 23.3%.

Similar to the changes in the accessibility of nearby public spaces, the proportion of "Low Accessibility-High Demand" neighborhoods, which best reflect the accessibility of public spaces for vulnerable groups, has relatively increased over the past decade. Geographically, these neighborhoods have also shown a similar shift from the southernmost part of the old city to the northernmost part. This indicates that, at an overall level, public space construction over the past decade has not favored areas with higher needs from vulnerable groups. Due to the spatial disparity between areas with extensive public space development and those with high demand from vulnerable groups, the development of public spaces has exacerbated spatial inequality. The other three types of neighborhoods also show some similarity in the distribution of supply–demand fit for individual and

overall public spaces, indicating that the distribution and changes in the accessibility of nearby and overall public spaces for residents tend to be consistent.

#### 4.3.3. Temporal–Spatial Evolution of the Matching Relationship between the Accessibility to Public Spaces and Their Demands

This study indicates that the matching relationship between the accessibility to public spaces and demand from vulnerable groups exhibits spatial differentiation at the block level. In both 2010 and 2020, the adjacent and overall accessibility to public spaces in the study area exhibited an overall pattern of being high in the center and low at the edges. However, areas with low resident demand are only present on the western and eastern edges. As a result, there are various matching relationships between supply and demand in different areas. Further, combined with spatial correlation analysis, it is observed that, from the perspective of temporal–spatial changes, there are clear spatial clustering characteristics in the supply and demand matching relationships of public spaces in the study area. In the central region, including areas like Xinjiekou, Wutaishan, and Meiyuan, the changes in supply and demand remain relatively stable over time. In these areas, there was no significant improvement in the accessibility to public spaces, and resident demands have decreased to varying degrees. Specifically, Xinjiekou is in a state of high-value supply and demand balance stability, while Wutaishan and Meiyuan are in a state of low-value supply and demand balance stability. In the southern part of the study area, the regions of Mendong and Menxi transitioned from supply–demand imbalance to supply–demand balance. The main reason is the increase in the number of public spaces, accompanied by a significant enhancement in both adjacent and overall accessibility. Meanwhile, the Central Gate area in the northern part and Ruijin Road in the southeast of the study area have shifted from a low-value supply and demand balance to a state of supply–demand imbalance. The primary reason is the limited development of public spaces, coupled with an increase in resident demand compared with other areas.

## 5. Discussion

Rapid urban development often negatively impacts the physical structure and accessibility of public spaces. This is one of the reasons why public space construction in developing countries lags behind that in more well-off cities [32]. However, in China, local governments have gained increased autonomy in urban development over the past few decades, with the deepening of reforms in social, economic, and cultural sectors. Consequently, the physical and social forms of public spaces have undergone profound and diverse changes. Traditional types of public spaces, such as city squares, pedestrian streets, and green parks, along with various new types of spaces, have continually emerged. This has led to significant improvements in the quantity, quality, and publicity of public spaces. Nanjing is a city in China representative of the balance between urban renewal and historical preservation. The aim of this paper is to analyze the changes in both adjacent and overall accessibility to public spaces in the study area under the combined influence of rapid urban development and public space construction. Additionally, it explores the spatial distribution correlation with the demand of socially vulnerable groups, which is conducive to clearly evaluating the degree of equity of public space distribution at different time periods. Research conducted at the block scale can enhance spatial accuracy and achieve more refined management and development of cities.

### *5.1. Changes in the Supply and Demand for Public Space in Nanjing Old City*

Overall, for the majority of the blocks in Nanjing Old City, the supply of public spaces meets or exceeds the usage needs of socially vulnerable groups. However, approximately 28.1% of the total number of blocks and 22.1% of the total area of blocks in the study area still experienced a state of supply–demand imbalance in 2010. Although there was a decrease in this proportion from 2010 to 2020 in the number of blocks with supply–demand imbalance at the overall level, it increased in the area of as well as the number and area of that at the

individual level. There is still significant room for improvement, which highlights the need for further optimization in addressing the spatial misalignment between the development of public spaces and changes in vulnerable group demands.

The results of the spatial correlation test indicate that, on the one hand, although a large amount of new public space has been added to the old city of Nanjing over the past decade, the proximity of public space to vulnerable groups has not been strengthened in the process of urban renewal; rather, it has been weakened. In areas where the distribution of public space at the individual level has been significantly improved, the proportion of disadvantaged groups has been reduced. On the other hand, Figure 6 shows that the overall accessibility of public space has improved from 2010 to 2020. Simultaneously, Figure 9 indicates that there is a reduction in the spatial correlation between the demands of vulnerable groups and the overall accessibility of public spaces. In other words, despite the development and construction of public spaces, the alignment between the supply of public spaces and the needs of vulnerable groups has decreased. It is evident that public space construction has not prioritized the needs of vulnerable groups, exacerbating the supply–demand imbalance for these groups. The underlying reason for this manifestation may stem from the complexity of the allocation mechanism at the overall level of public spaces. The distribution of public spaces in the city is influenced by numerous factors, including the land use types, economy indicators, and the current infrastructures. Therefore, it is challenging to ensure that the construction of public spaces perfectly aligns with the needs of vulnerable groups. Moreover, public spaces are classified into three levels based on their service levels in this study. However, the service levels of public spaces are influenced by various factors, including area, location, number of facilities, and management conditions. The differences in service levels between public spaces within the study area are far more complex than the simple classification into three levels. Additionally, there are differences in the needs and preferences for public space use among vulnerable groups, which further increases the complexity of service distribution within the public space system. A more accurate analysis necessitated a mutual fitting of public spaces with different service qualities and levels of attractiveness with the spatial differentiation of socially vulnerable groups.

### *5.2. Reasons for the Changes in Public Space in Nanjing Old City*

Guided by the overall urban planning, the Nanjing Municipal Government endeavored to evacuate the population to areas outside of the old city between 2010 and 2020, which effectively reduced the population density of the old city [52,53], alleviated the pressure on the urban infrastructure, and improved the living environment of the residents. A series of conservation and renewal plans have also been implemented in Nanjing Old City. The focus of public space construction was on "spot enhancement", highlighting the integration of historical culture, natural landscape, and modern life. A number of green street spaces and various levels of public spaces were added. However, some existing public spaces were occupied by urban construction projects.

The research results indicate that the changes in the density of socially vulnerable groups within the old city are a result of the combined effects of reduced overall population density and the decreased proportion of vulnerable populations. There is spatial differentiation between areas where the proportion of socially vulnerable groups has decreased and areas where overall population density has decreased. The neighborhoods with the highest residential population density in the old city have not undergone significant changes, while areas with a higher proportion of socially vulnerable groups experienced substantial transformations from 2010 to 2020. In particular, areas where the proportion of socially vulnerable groups increased, such as Central Gate and Daguang Road, were characterized by an undersupply of public spaces in 2020, with limited urban renewal projects and the constrained development of public spaces, all of which contribute to this shift.

### *5.3. Suggestions for Public Space Optimization in Urban Renewal*

The limitation of public space development caused by urban construction activities is a common problem in old cities in China, as well as other high-density cities across the world. The mismatch of supply and demand between population mobility and public space development is a unique problem in Nanjing Old City, which is why we need to analyze these changes from a spatial–temporal perspective. Nanjing is one of the rapidly developing cities, reflecting the physical characteristics and changes of public spaces in continuously evolving urban environments. The synergic relationship between public space distribution and vulnerable groups' demand in Nanjing Old City is deeply associated with factors such as historic origin, geographic features, social culture, and development process on the one hand and is also dynamically changed with the transition of future social, economic form, and human settlements on the other hand.

We suggest that in cities facing urban renewal needs, special attention should be given to the usage habits and needs of socially vulnerable groups in the process of adjusting and upgrading the existing public space system, providing convenience for the regular use of public spaces and guiding the prioritized allocation of public space resources to areas in the old city with a higher proportion of socially vulnerable populations. As a public welfare measure, the location of public spaces may influence their relative attractiveness and can be used to address certain market failures and even achieve the redistribution of spatial resources to some extent [54]. However, while enhancing both adjacency and overall accessibility to public spaces, it is crucial to focus on specific user groups. This ensures that public space construction does not lead to an "equity illusion", where the supply of public spaces in gentrifying neighborhoods increases while the demands of socially vulnerable groups decrease [55,56].

### *5.4. Implications and Limitations of the Study*

The equitable distribution of public spaces directly impacts the allocation of public facilities and welfare. Recognizing the reduced subjective initiative and limited mobility of socially vulnerable groups when using public spaces, this study considers walking accessibility as the primary evaluation premise. This involves acknowledging distance as the foremost evaluation factor for access to public spaces, aiming to closely align with the usage characteristics of socially vulnerable groups. However, this study only considers the area and distribution of public spaces without incorporating the quality of these spaces into the evaluation system. Given that the economic capabilities of socially vulnerable groups often lead them to live in neighborhoods with relatively poorer environments, the service levels of the public spaces they encounter may be lower than the average. Therefore, the evaluation of supply and demand for public spaces in Nanjing Old City needs to further incorporate quality evaluation factors to achieve a more equitable distribution. The renovation and construction efforts should further consider the actual needs of socially vulnerable groups, integrating the supplementation of public spaces with the daily lives of residents. This approach can guide public resources to actively tilt towards socially vulnerable groups, fostering a more inclusive distribution of public spaces.

## 6. Conclusions

In recent years, there has been extensive research on the accessibility and distribution equity of green spaces, while other types of public spaces, which constitute important components of urban spaces, have received much less attention. The United Nations Sustainable Development Goal 11 and its specific Target 7 state that "by 2030, provide universal access to safe, inclusive and accessible, green and public spaces, particularly for women and children, older persons and persons with disabilities" [57]. This goal presents a task for countries worldwide to enhance the accessibility and equitable distribution of public spaces based on residents' needs. Public spaces, including streets and squares, complement the contribution of green spaces in promoting social interaction and enhancing human well-being. Public spaces, as spaces dominated by artificial factors, can be more

closely aligned with people's daily lives and provide a wide range of public services and health benefits. The equity of the use of public spaces by socially vulnerable groups is a crucial perspective for achieving equity in the allocation of spatial resources and services and also a fundamental basis for optimizing the pattern of urban public spaces.

It can be seen that although the old city renewal and environmental renovation projects in Nanjing are continuously being carried out, the quantity, quality, and publicness of urban public spaces were significantly improved during the period 2010 to 2020; the benefit to vulnerable groups is relatively small because there are differences in the accessibility of public spaces among groups of different ages, educational levels, and incomes. The construction of public spaces has not been tailored to meet the needs of vulnerable groups, resulting in increased inequality in the distribution of inefficiently used public resources and exacerbating equity issues in public facilities.

From a temporal and spatial perspective, this study offers new insights and recommendations for research on equitable access to urban public spaces based on the needs of vulnerable groups. This study proposes the composition and quantification methods of large-scale urban public spaces and explores a comprehensive method for the accessibility assessment of public spaces for both individual and overall public spaces using minimum cost distance and gravity potential methods. It employs bivariate local Moran's I to investigate the matching relationship and temporal–spatial evolution between the accessibility of public spaces and residents' demand indices, guiding a scientific approach to fair public space distribution. This approach can provide a more robust and effective basis for balancing the supply and demand of urban public spaces, offering an effective tool for assessing and improving the accessibility and equitable distribution of public spaces based on the needs of vulnerable groups. For instance, it can be applied to urban renewal projects to ensure that newly developed or re-planned public spaces can serve city residents more equitably, especially vulnerable groups. It can also assist urban planners and administrators in understanding the dynamic relationship between public space distribution and social demand, thereby allowing them to formulate policies and landscape planning initiatives that prioritize equity, and it provides decision-making recommendations and foundations for future urban spatial optimization.

In future research, comparative studies across different cities or countries could help clarify common patterns and specific solutions in public space management, thus enhancing the accessibility equity for vulnerable groups. The shaping of public spaces is a dynamic process. Therefore, it would be of considerable benefit to track the changes in the accessibility of public spaces over time from a temporal–spatial perspective, especially when policies aiming to improve equity are implemented. This study recommends that in planning new public spaces, proximity, especially for vulnerable groups, should be prioritized as the foremost consideration. Observations, interviews, and empirical data at the micro-level can be combined with the macro-planning scale, and methods such as participatory mapping or public participation geographic information systems (PPGISs) can be employed to encourage the participation of vulnerable groups. For example, detailed observations and surveys can be conducted in typical public spaces, such as parks, plazas, or streetscapes. These spaces can be analyzed in detail to observe how they are used at different times of the day and week. Surveys can be distributed to public space users, and in-depth interviews can be conducted with regular users, thereby identifying their needs more accurately and promoting the optimization of urban public space patterns that balance supply and demand.

Recognizing the reduced subjective initiative and limited mobility of socially vulnerable groups when using public spaces, this study considers walking accessibility as the primary evaluation premise, which is to identify distance as the foremost evaluation factor for the accessibility to public spaces, aiming to closely align with the usage characteristics of socially vulnerable groups. The renovation and construction efforts should further consider the actual needs of socially vulnerable groups, integrating the supplementation of public spaces with the daily lives of residents. This approach can guide public resources to

actively tilt towards socially vulnerable groups, fostering a more inclusive distribution of public spaces.

**Author Contributions:** Conceptualization, N.X.; methodology, N.X. and P.W.; software, P.W.; validation, N.X.; formal analysis, N.X. and P.W.; investigation, N.X.; resources, N.X.; data curation, N.X.; writing—original draft preparation, N.X.; writing—review and editing, N.X. and P.W.; visualization, P.W.; supervision, N.X.; project administration, N.X.; funding acquisition, N.X. All authors have read and agreed to the published version of the manuscript.

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**Data Availability Statement:** The data presented in this study are available from the corresponding author upon reasonable request. The data are not publicly available due to some of them being used in other studies that have not yet been publicly published.

**Conflicts of Interest:** The authors declare no conflicts of interest. The funders had no role in the design of the study, in the collection, analyses, or interpretation of the data, in the writing of the manuscript, or in the decision to publish the results.

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