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The Multi-Scale Spatial Heterogeneity of Ecosystem Services' Supply–Demand Matching and Its Influencing Factors on Urban Green Space in China

Wudong Zhao [1], Xupu Li [1], Liwei Zhang [1,2,*], Lixian Peng [1], Yu Liu [1], Zhuangzhuang Wang [3], Lei Jiao [1] and Hao Wang [1]

[1] Department of Geography, School of Geography and Tourism, Shaanxi Normal University, Xi'an 710119, China; wudongzhao@snnu.edu.cn (W.Z.); xupuli@snnu.edu.cn (X.L.); plixian@snnu.edu.cn (L.P.); yul@snnu.edu.cn (Y.L.); ljiao@snnu.edu.cn (L.J.); foreva@snnu.edu.cn (H.W.)
[2] School of Geography and Tourism, Xinjiang Normal University, Urumqi 830054, China
[3] State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences (CAS), Beijing 100085, China; zzwang_st@rcees.ac.cn
* Correspondence: zlw@snnu.edu.cn; Tel.: +86-29-8531-0525

Abstract: As population growth and urbanization continue to accelerate, city dwellers are increasingly conscious of the demand for urban green space (UGS) and the ecosystem services (ESs) it provides. Great efforts are made for the supply of certain ESs in UGS. However, less is known about the residents' preferences and the supply–demand matching of UGS types, as well as the various ESs it provides at different spatial scales. Given this, our research establishes a research framework to reveal the heterogeneity of USG types and the supply–demand matching degree (SDM) of ESs from municipal, provincial, and national spatial scales, and examines the correlation between the influencing factors and demands of residents for UGS. This study mainly used the Gini coefficient, the Lorenz curve, Z-scores, the Jenks natural breaks classification method, Pearson correlation analysis, and spatial analysis. The main findings are that (1) the Gini coefficients are 0.433 and 0.137 at the municipal and provincial scales, respectively, indicating that the supply of UGS is more unequal at the municipal scale than provincial scale; (2) the multi-scale demand for ESs between residents has no significant difference. At the provincial scale, the area with low demand is larger than that of high demand, while at the municipal scale, the contrary is the case; (3) the SDM was in a deficit at both the provincial and municipal scales. And as the scaling-up occurred, the spatial heterogeneity of the SDM decreased; (4) the number of influencing factors that significantly affected the UGS type and ESs grew as the scale increased. Among them, the impact of age and COVID-19 on three scales deserves attention. These results identify regions with deficits and surpluses in ESs provided by UGS in China at different scales. This research also advises that attention should be paid to the distribution of UGS between cities within provinces, and future UGS planning should focus on building regional green spaces to promote the well-being of an aging society. The findings in this study would offer insights for managers to improve UGS construction and urban forestry planning in the future.

Keywords: China; ecosystem services; multi-scale; spatial heterogeneity; supply–demand matching; urban green space

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1. Introduction

The global population has exceeded 8 billion by now, and has been rapidly increasing, leading to a great expansion of urban land area from 0.22% to 0.69% of the Earth's land surface in less than three decades [1]. Improvements in the quality of the urban natural environment are vital for enhancing the well-being, comfort, happiness, and health of urban dwellers [2,3]. To mitigate and reverse the disconnection between humans and nature, the construction of urban natural environments is of particular importance [4]. In

2015, the launch of Agenda 2030 by the United Nations announced seventeen Sustainable Development Goals (SDGs), of which goal 11 highlights ensuring equitable access to safe and inclusive urban green spaces (UGSs) [5]. As a crucial natural element in the urban environment, UGSs have become an important issue in urban environmental research due to the fact that they constitute and affect the ecosystem services (ESs) they provide [6].

However, a report on the work of the seventh plenary session of the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) showed that humanity is facing a serious mismatch between the supply and demand of ESs. Existing studies on ESs provided by UGS supply–demand matching mainly examine quantitative mismatches or spatial mismatches [7]. The steps of quantitative research were roughly the same. The supply is often quantified through biophysical models such as the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) and The Revised Universal Soil Loss Equation (RUSLE) models [8,9], and the demand is often indicated by statistical data such as population and gross domestic product (GDP) [10]. The supply–demand mismatch can be identified through hot spot analysis, Pearson correlation analysis, and the supply–demand ratio (SDR) [11,12]. However, insufficient consideration is given to the subjective preferences of different urban groups [13]. Furthermore, for spatial research, the scales of study on supply–demand matching of the ESs provided by UGS vary widely. The current studies mainly focus on individual park green spaces [14] and certain cities [15]. However, studies on the scale of municipal administrative units are mostly confined to economically developed cities, and UGS in economically lagging areas is less known [5]. Plus, few studies focus on the UGS in urban agglomeration regions [16]. Even scarcer is the relevant research on scaling up to the national level. Conducting UGS studies at multiple scales is imperative, since the results from different scales of study differ significantly [17]. Furthermore, studies on the influencing factors of the demand for UGS by residents are mainly concentrated on environmental justice [18] or a single urban scale [19]. Multi-scale studies on UGS can offer future insights for constructing and optimizing UGS structural layouts at various scales, including the municipal, provincial, and national scales. Therefore, our research has pioneered the study of multi-scale supply–demand matching, including a subjective survey.

Meanwhile, different UGS types have been employed in research following the diversity of research scales and functional needs. For instance, small, medium, and large parks and forests, as well as the single largest Lagiewniki forest, cemeteries, and allotment gardens, were differentiated in Lodz, Poland [20]. Although there are national standards for UGS classification in China, the existing UGSs are not well represented [21]. The evaluation index system and implementation plan for Beautiful China construction also focus on park green spaces only [22]. Diverse UGSs differ in their capacity to provide ESs in terms of quantity and types, such as water regulation and storage, local climate, and air quality regulation in large UGSs, physical and mental health promotion, aesthetic appreciation in small UGSs, etc. [23–26]. However, current efforts are more into the residents' demand for a few specific types of ESs in UGS [27], without a comprehensive study of residents' demand for UGS types and ESs, their supply–demand matching, and their integration into planning decisions [28]. Therefore, it is necessary to carry out comprehensive research combining different types of UGS and various ESs to optimize the form of UGS.

Given this, this study aims to explore the supply–demand matching degree (SDM) of ESs provided by UGSs based on valid survey data and statistical yearbook data of China, and to discover the influencing factors of residents' use preferences for UGS types and their ESs at three scales. Compared with previous studies, this paper takes the subjective perspective of residents to represent the demands, conducts research on multi-scales, and also adopts multiple types of ESs and UGSs. Specifically, this research is conducted to (1) analyze the matching characteristics and spatial heterogeneity in supply, demand, and SDM of ESs provided by UGSs at three scales; (2) reveal the patterns of the driving factors of residents' demand for UGS at multiple spatial scales. This research identifies a spatial mismatch relationship between multi-scale ESs provided by UGS, and the influencing factors of UGS type and ESs. Meanwhile, the implications of this study are to support regional land management and provide practical policy recommendations for retrofitting existing UGSs and future UGS planning.

2. Methods and Data

2.1. Study Area

China is a country with a vast territory of 9.6 million square kilometers and diverse geographical and natural conditions (Figure 1A). Urbanization in China has been booming with the reform and opening-up policy. By 2020, there were 902 million urban residents in 293 cities, accounting for 63.89% of China's total population, and the GDP reached RMB 101.60 trillion. Economic development and population growth have led to a decrease in ES supply and an increase in demand in China's urban areas [29,30]. For indicating UGS supply, the per capita UGS was better than the total area due to the people-centered ideology and the large demographic differences in China. Finally, 275 Chinese cities were considered in this study due to limited access to data (Figure 1B).

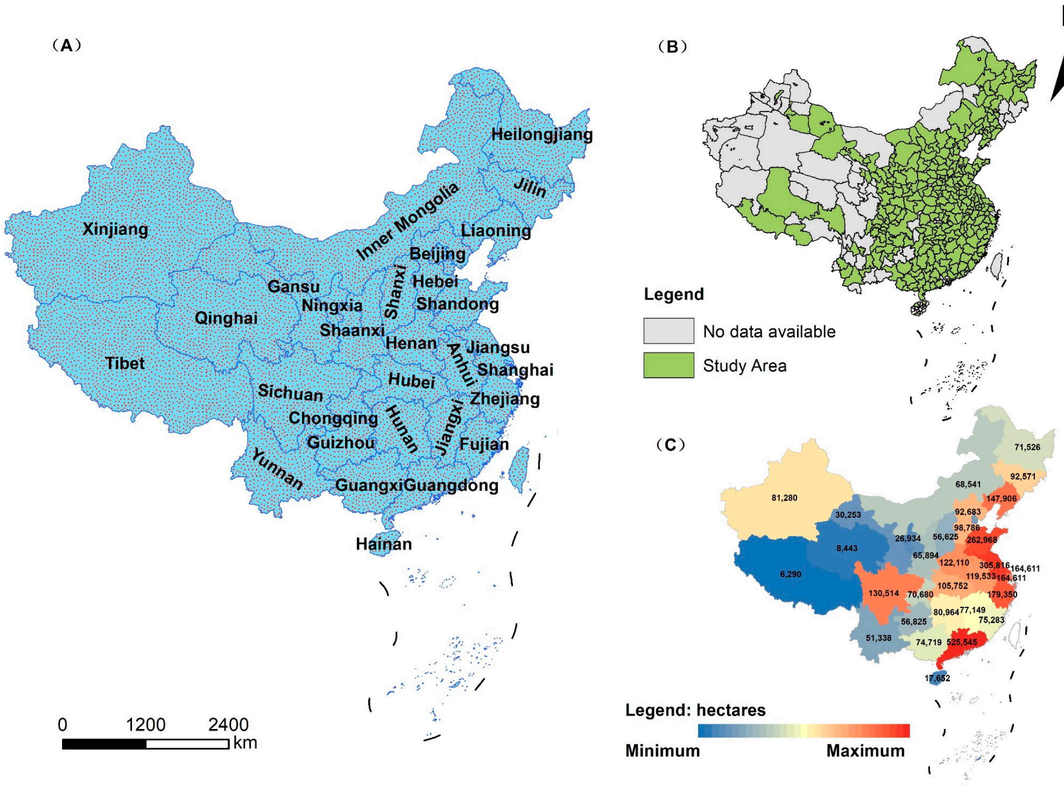

Figure 1. Overview of the study area: (**A**) provincial administrative division; (**B**) the scope of the municipal scale study area; (**C**) urban green space area distribution on provincial scale.

Another consequence of China's rapid urbanization was the neglect of residents' preferences, which has led to a detriment to human well-being. Given the importance of UGS to human well-being, it is very necessary to study its supply–demand matching for future urban forestry planning [31]. At the same time, according to the current classification of UGS in China, the form of UGSs can also be improved.

2.2. Study Framework

The spatial matching of the supply and demand framework was established to assess the SDM of ESs provided by UGSs, and to identify the role of influencing factors at multiple scales in China. In this study, UGS was divided into four types and the ESs provided by UGSs were classified into social services and ecological services, including fourteen types (Figure 2) [32,33]. The data on residents' demand for UGSs and the ESs provided by

UGSs were derived from the information in the questionnaire from 2022 to 2023. In the questionnaire, a six-point scale of ideal frequency for four types of UGS was adopted to quantify residents' demand for UGS types. The ideal frequency of residents for visiting UGS is divided into less than once a month, once a month, once every two weeks, 1–3 times per week, 4–6 times per week, and every day, and these are assigned values from 1 to 6. A five-point Likert scale of the importance of ESs was used to quantify residents' demand for ESs provided by UGSs. The importance of ESs is divided into very unimportant, unimportant, general, important, and very important, and these are assigned values from 1 to 5. The per capita UGS area (m^2/per person) in 2021 was applied as the UGS supply indicator because statistics for 2022 were missing. At the municipal and provincial levels, the per capita UGS area data that came from the UGS area was divided by the number of residents (www.stats.gov.cn, accessed on 1 March 2023). The SDM of ESs provided by UGSs was valued through the supply and demand of ESs. Due to the lack of reliable and appropriate data on the supply of UGS types, this research did not study the SDM of UGS types [21,34]. Furthermore, based on the Chinese socio-economic and demographic characteristics, we selected ten factors that potentially affect the demand of residents for UGS types and their ESs at three scales. The concrete quantification was reflected in a five-point Likert scale in the questionnaire. Residents' perception of the impact factors can be divided into barely any impact, little impact, average impact, big impact, and very big impact, and these are assigned values from 1 to 5. Protected green space is defined as a green space with independent land use, health, isolation, and other functions, and is not suitable for residents to enter. Therefore, residents' preference for it and the ESs it can provide can hardly be reflected in the questionnaire, so protected green space was excluded from this study. Then, ArcGIS was used to carry out the multi-scale spatialization of the above values. Finally, planning guidelines were proposed for future UGS development.

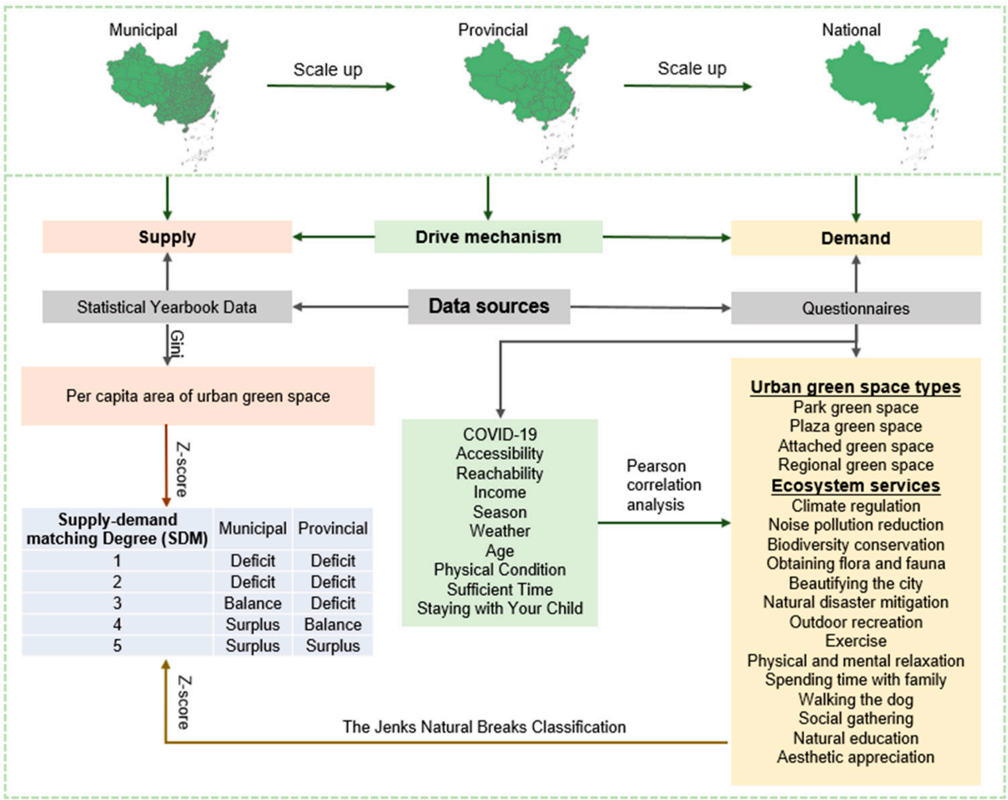

Figure 2. The framework of the multi-scale spatial heterogeneity of ecosystem services supply–demand matching and its influencing factors on urban green space in China.

2.3. Questionnaire Data

2.3.1. Questionnaire Design and Distribution

The questionnaire covered demographic information, influencing factors affecting UGS, and residents' preferences for UGS types and ESs. This study complies with the ethical approval policy of the study area. Then, the questionnaire was distributed online through a widely used professional platform (www.wjx.cn, accessed on 1 March 2022) in two phases: from 9 to 18 March 2022 and from 13 November 2022 to 7 January 2023 (newly added). In order to prevent the repetition of respondents in the two periods, we ensured that each respondent could only fill in the questionnaire once. In the first period, 1050 questionnaires were collected, and in the second period, 1965 questionnaires were augmented. After data screening, 3015 valid responses were obtained.

2.3.2. Sample Representation and Validity

This research covered 275 municipal-level administrative regions with available UGS supply information in 31 provincial-level administrative regions, excluding Hong Kong, Macau, and Taiwan, where the policy of "one country, two systems" is implemented (Figure 3A). On the national scale, the respondents were mainly aged between 19 and 60 years old, and the gender ratio was balanced (Figure 3B). The respondents had a high level of education, which ensured their understanding of the questionnaire [35]. The income groups were evenly distributed among respondents. On the provincial scale, the respondents' age was mainly concentrated at 30–40 years old, while gender was not evenly distributed as on the national scale. Their education was still dominated by high levels of education as on the national scale, and their income was mainly between RMB 1500 and 3499. Overall, there was little difference between the provincial samples.

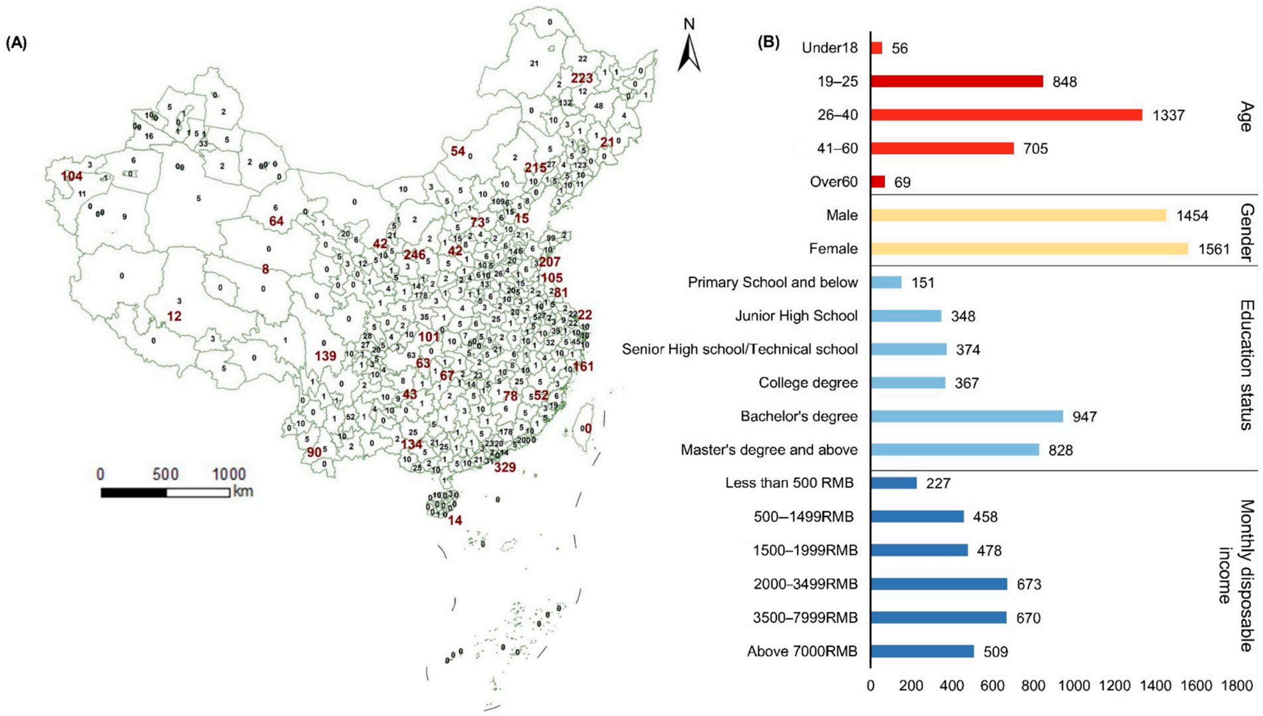

Figure 3. Spatial distribution of the number of questionnaires (**A**), red numbers represent provincial samples and black numbers represent city samples. And the demographic information of the respondents to questionnaires (**B**). (n = 3015).

The reliability and validity of the Likert scale in the questionnaire were detected using Cronbach's alpha, the Kaiser–Meyer–Olkin Measure of Sampling Adequacy (KMO), and Bartlett's Test of Sphericity.

The Cronbach's alpha for the two Likert scales representing the influencing factors and ESs were 0.900 and 0.953, respectively, indicating a strong reliability [36].

$$\text{KMO} = \frac{\sum\sum_{i \neq j} r_{ij}^2}{\sum\sum_{i \neq j} r_{ij}^2 + \sum\sum_{i \neq j} \alpha_{ij}^2} \quad (1)$$

where KMO is the KMO coefficient, which ranges from 0 to 1, and the closer to 1, the better the structural validity of the questionnaire; r_{ij} is the simple correlation coefficient; $\alpha^2{}_{ij}$ 1, 2, 3, ..., k is the bias correlation coefficient. The KMO for the two Likert scales was 0.914 and 0.972, respectively. The significance of Bartlett's test was less than 0.05, demonstrating that the structure of the questionnaire was valid. The outcomes of the three tests showed the satisfactory reliability and validity of the questionnaire.

2.4. Data Analysis

2.4.1. Gini Coefficient and Lorenz Curve

The Gini coefficient was used to measure the equity of UGS distribution in a region [37]. The Gini equation was presented as follows:

$$G = \sum_{i=1}^{n} X_i Y_i + 2\sum_{i=1}^{n} X_i (1 - V_i) - 1 \quad (2)$$

where G represents the Gini coefficient of the UGS supply; X is the proportion of the population; Y is the weight of the UGS index for each indicator; V is the weight of the cumulative UGS index for each indicator; and i = 1, 2, ..., n is the various provinces or municipalities. The Gini coefficient ranges from 0 to 1, indicating complete equality to complete inequality [38]. In general, a Gini coefficient below 0.2 indicates absolute equality, between 0.2 and 0.3 indicates relative equality, between 0.3 and 0.4 indicates relative fairness, between 0.4 and 0.5 indicates a large gap, and above 0.5 indicates a significant disparity [39]. To show a more intuitive picture of the Gini coefficient, the Lorentz curve was also applied [40].

2.4.2. Z-Score to Normalize

The Z-score can be used to normalize the UGS supply and demand and calculate the SDM to ensure their comparability. This method also avoided the complexity of incompatible evaluations owing to differences in the measurement and modeling methods [41]. It can also integrate multiple ESs into a single Z-score for spatial comparison. The equation is as follows:

$$Z = \frac{x - \frac{\sum_{i=1}^{n} x_i}{n}}{\sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \frac{\sum_{i=1}^{n} x_i}{n}\right)^2}{n}}} \quad (3)$$

where Z is the value of the resulting Z-score; x is the value of supply or demand; and n is the number of provincial or municipal districts. After unifying the units of supply and demand, the SDM can be derived after a simple calculation using the following formula [42]:

$$\text{SDM} = Z_S - Z_D \quad (4)$$

where Z_S is the Z-score of supply; Z_D is the Z-score of demand. Regions vary widely among provinces and municipalities; hence, the supply in the above equation was calculated using the per capita UGS area. SDM could account for the degree of matching or mismatching.

2.4.3. The Jenks Natural Breaks Classification Method

The Jenks natural breaks classification method was used to demonstrate and visualize the UGS supply and demand [43]. It is an algorithm based on a small number of clusters, maximizing inter-group variance and minimizing intra-group variance. Compared to other methods such as average segmentation and indexing methods, it ensured the clearest class of data at one metric and one administrative scale [44]. All spatial scales in supply, demand, and SDM were classified into five categories for visualization and grading: "1" and "2" were defined as low values in the supply and demand, "3" as medium value, and "4" and "5" as high values. For SDM, at the municipal scale, "1" and "2" were defined as a deficit, "3" was defined as a balance, and "4" and "5" were defined as a surplus; at the provincial scale, "1", "2", and "3" were defined as a deficit, "4" was defined as a balance, and "5" was defined as a surplus (Figure 2).

2.4.4. Pearson Correlation Analysis

To explore how factors influenced residents' demand for UGS types and their ESs, we used a Pearson correlation analysis to calculate their correlations [7]. The specific formula for the Pearson correlation coefficient is

$$r = \frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right)}{\sqrt{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}\sqrt{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2}} \tag{5}$$

where r is the Pearson correlation coefficient; X is the Z-score of the impact factors; and Y is the Z-score value of the affected UGS type or ESs. The range of r is between -1 and 1. When $r = 0$, this means that there is no relationship between X and Y; when $0 < r < 1$, X and Y are positively correlated; when $-1 < r < 0$, X and Y are negatively correlated.

3. Results

3.1. Municipal-Scale Urban Green Space Supply–Demand Matching, and Demand Influencing Factors

3.1.1. Urban Green Space Supply–Demand Matching

The results showed that only five cities experienced the highest level of UGS supply (Figure 4). The majority of cities (78.9%) exhibited a low level of supply, with only 6.2% categorized as having a high level of supply. The Gini coefficient of UGS per capita was 0.433, indicating a relatively unequal distribution across municipalities (Figure 4).

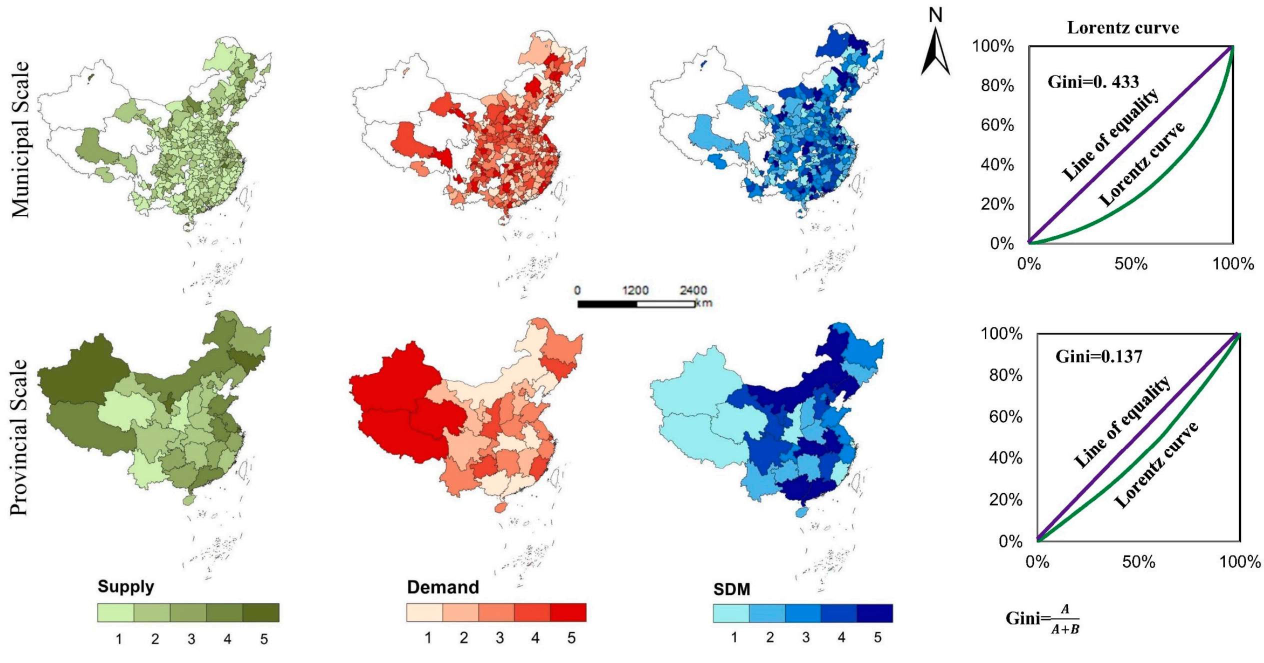

Figure 4. Supply of urban green space, demand for ecosystem services, the degree of supply and demand matching (SDM), and the Lorentz curve at the provincial and municipal scales.

The spatial distribution of UGS demand was more equal than that of supply at the municipal level. There were 38 cities with the highest level of demand, surpassing those with the highest level of supply (Figure 4). Approximately 44% of the cities had a high level of demand, and 33.1% had a low level of demand. The demand for each ES was evenly distributed across all municipalities and showed no significant spatial aggregation (Figure 5A). The most demanded ES was "aesthetic appreciation", with 152 cities (55.5%) showing high levels, followed by "biodiversity conservation" and "natural disaster mitigation", both of which were shown at high levels by 145 cities (53.0%). "Natural disaster mitigation" was shown at the lowest level in only six cities, while "biodiversity conservation" at the lowest level had 42. The ES types with the lowest level of demand were "noise pollution reduction" and "beautifying the city", of which 88 (32.1%) and 89 (32.4%) cities were at high levels.

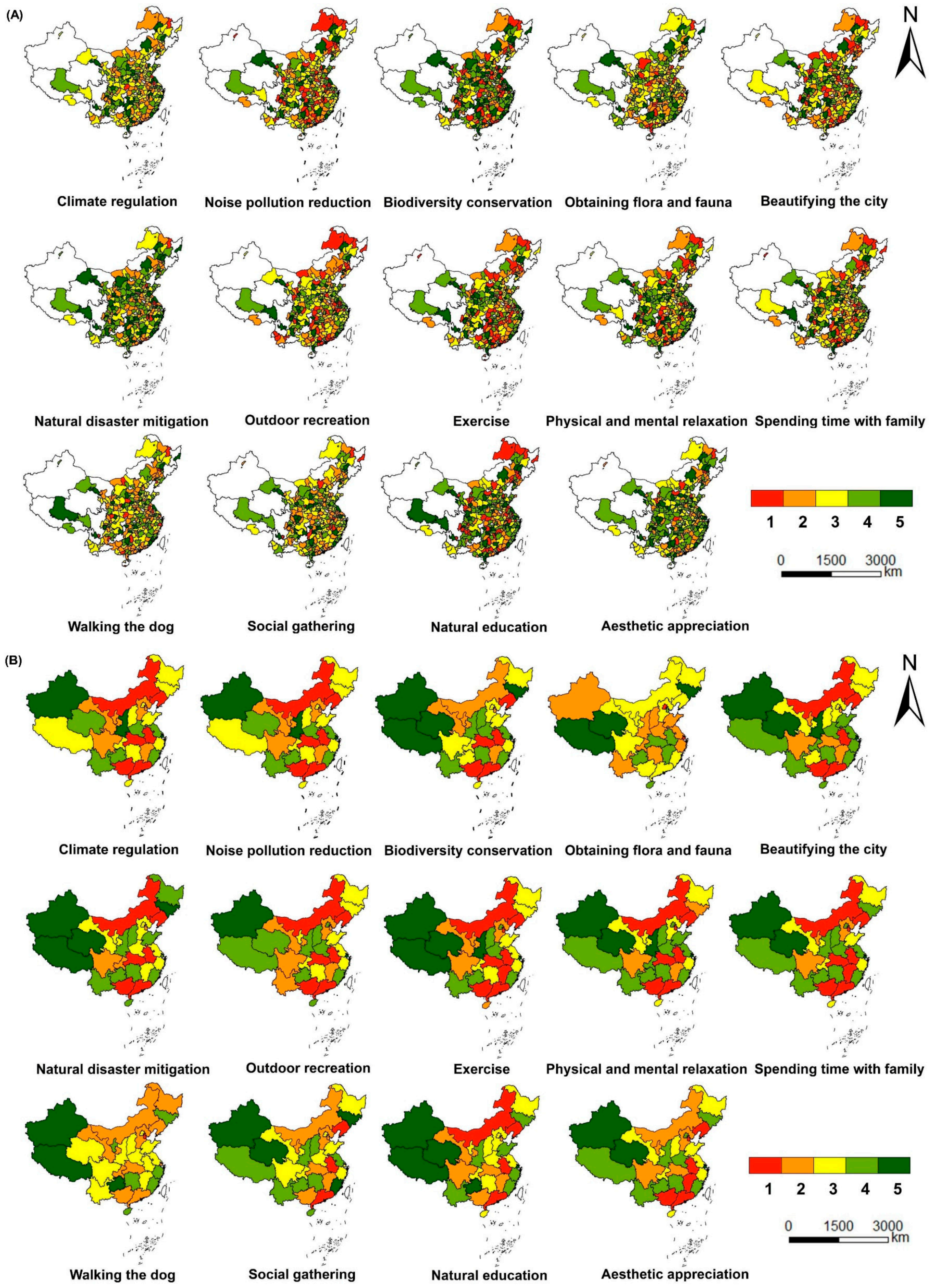

Figure 5. The demand for each ecosystem service of UGS on the municipal (**A**) and provincial (**B**) scale; 1 to 5, low to high demand.

The number of cities with SDM at levels “1”, “2”, “3”, “4”, and “5” was 36 (13.09%), 82 (29.82%), 72 (26.18%), 52 (18.91%), and 33 (12%), respectively, indicating an overall deficit in SDM. The UGS volume of cities along the southeast coast was well planned, with medium supply, high demand, and no shortage of SDM (Figure 4). In the northeast region, with varying levels of supply and demand, most showed a relative surplus in SDM. However, a higher level of SDM deficit appeared in the central region. For each ES, the number of cities with surplus SDM was much lower than the number with high demand. “Natural education” showed the highest level of SDM among all the ESs, of which 74 cities were at surplus levels (Figure 6A), followed by “exercise”, “biodiversity conservation”, and “noise pollution reduction”, which were in surplus in 66, 64, and 61 cities, respectively. Among all the ESs, “climate regulation” was the most mismatched SDM, with 198 cities in deficit and 23 cities in surplus. Following this were “outdoor recreation”, “aesthetic appreciation”, and “social gathering”, with 148, 143, and 140 cities falling into the deficit category, respectively.

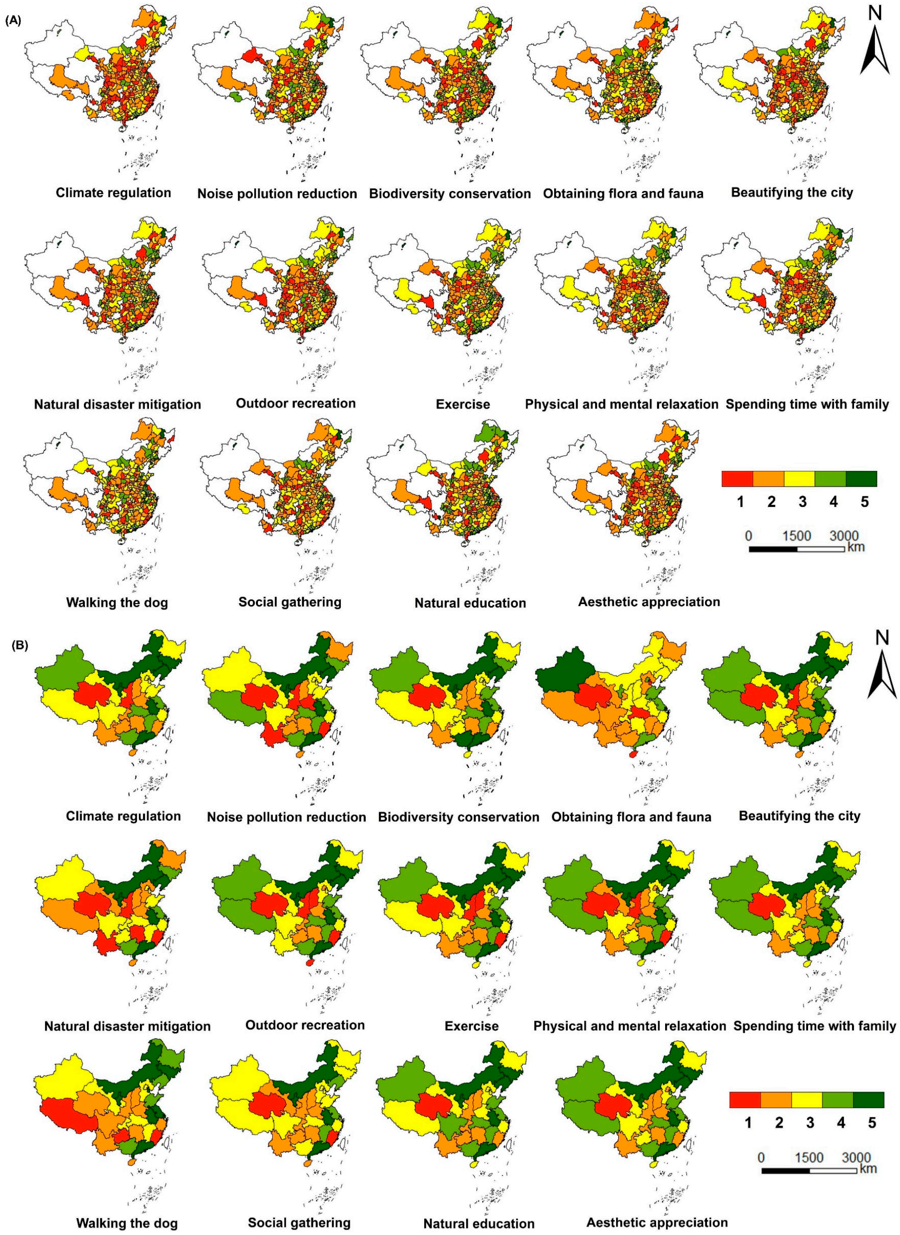

Figure 6. The supply–demand matching degree (SDM) of ecosystem services in UGS on the municipal (**A**) and provincial (**B**) scales.

3.1.2. The Influencing Factors on the Demand for Urban Green Space Types and ESs

The number of influencing factors that significantly affected the demand for UGS types and ESs accounted for 18.33% of all influences at the municipal scale (Table S1). The type of UGS was mainly influenced by age ($p < 0.01$), whereas other factors such as accessibility, season, weather, and sufficient time were not significant ($p > 0.05$) (Figure 7A). Among all the UGS types, plaza green space was the least impacted, while regional green space was the most affected. For ESs, age ($p < 0.05$) and COVID-19 ($p < 0.05$) were the most influential factors, while other factors such as accessibility, reachability, weather, and sufficient time were at insignificant levels ($p > 0.05$). The most affected ES was "obtaining flora and fauna". The other ESs were only affected by one or two factors.

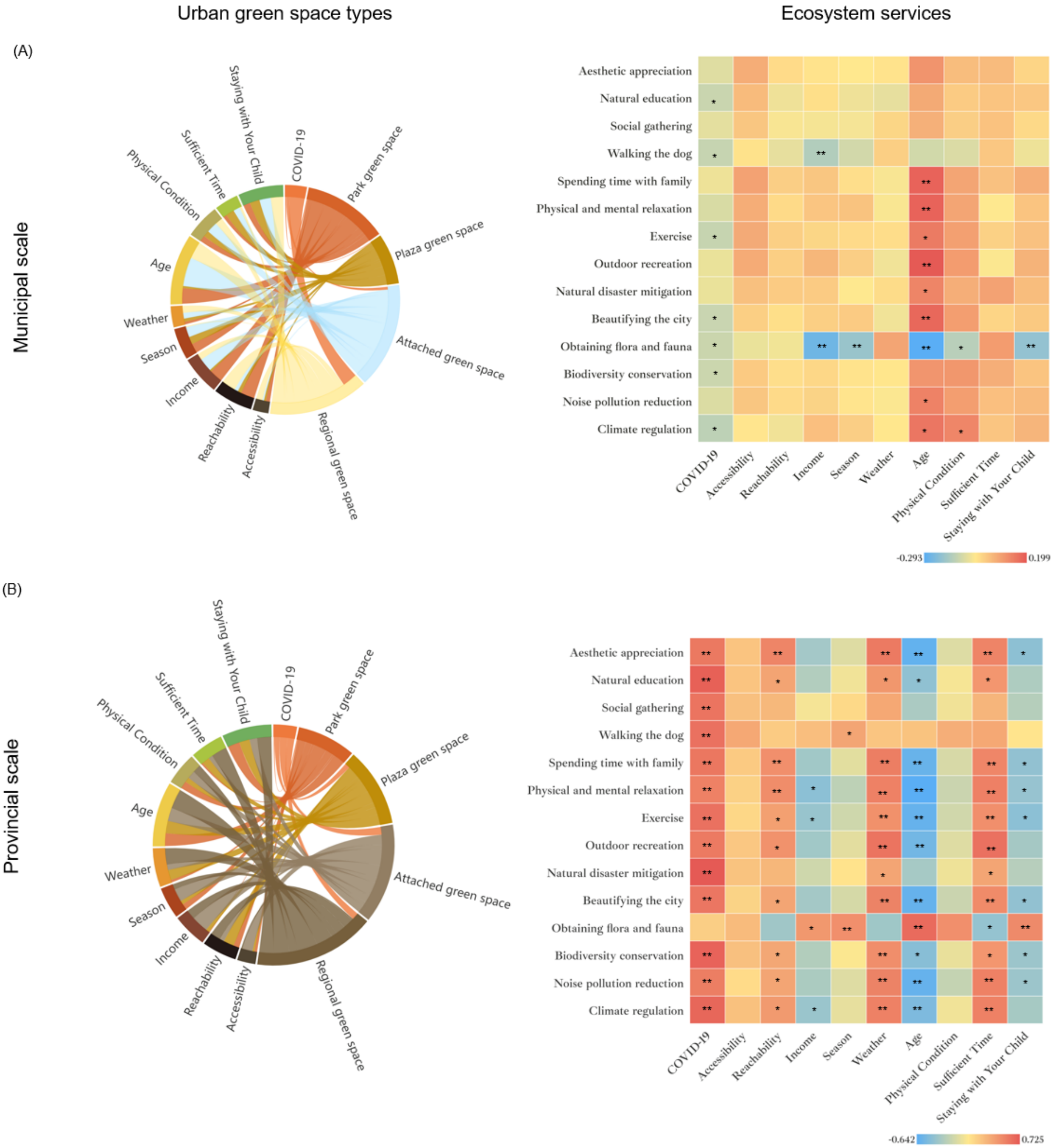

Figure 7. *Cont.*

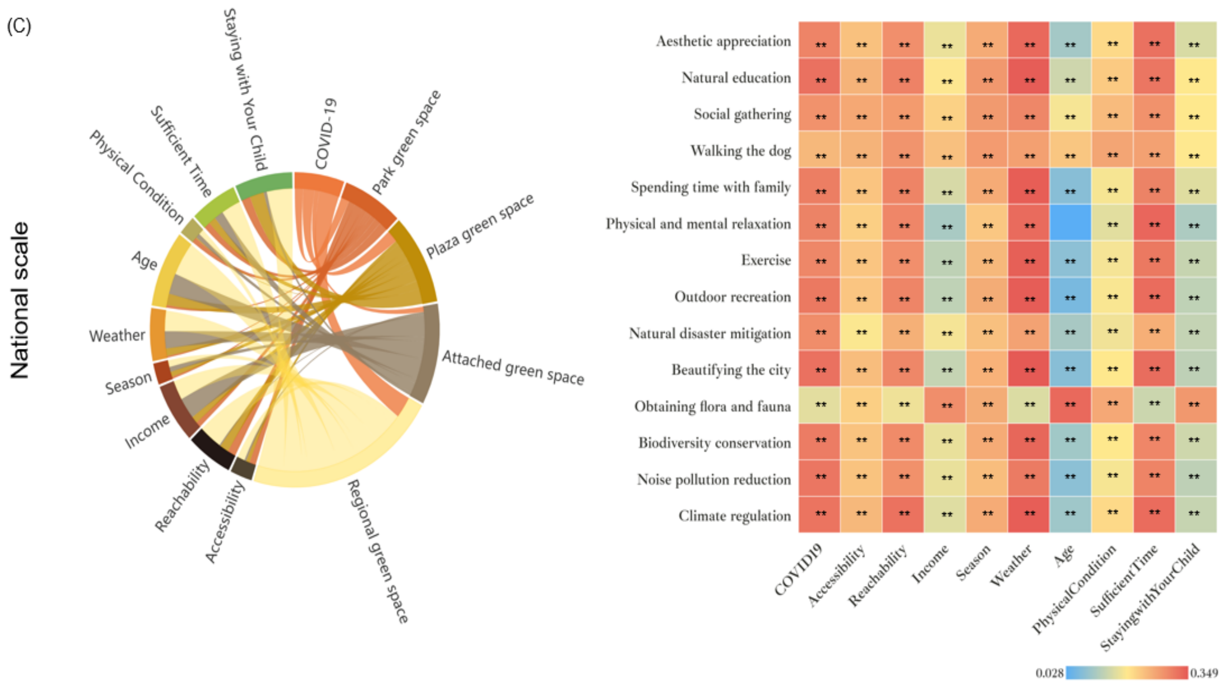

Figure 7. Chord diagram of correlation coefficients between influencing factors and urban green space types in municipal scale (**A**), provincial scale (**B**), and national scale (**C**); the larger color block area of the influencing factor and urban green space type indicates a more intense impact. Heat map of correlation coefficients between influencing factors and ecosystem services; the correlation is weaker when it is closer to 0.1. *, $p < 0.05$; **, $p < 0.01$.

3.2. Provincial-Scale Urban Green Space Supply–Demand Matching, and Demand Influencing Factors

3.2.1. Urban Green Space Supply–Demand Matching

The findings showed that more UGSs were available in eastern provinces, especially along the southeastern coast, compared to the western provinces (Figure 1C). However, the western and northern regions had higher per capita UGS than the eastern regions, which had a high urban population (Figure 4). Among these regions, the provinces with the best supply at the "5" level were Xinjiang, Ningxia, Jilin, and Shanghai, while the worst-supplied at the "1" level were Qinghai, Shaanxi, Yunnan, and Tianjin. The Gini coefficient of UGS at the provincial scale was 0.137, indicating a more equitable distribution compared to the municipal scale (Figure 4).

Less variation in the ES demand among residents existed at the provincial level than at the municipal level. The strongest ES demands (level 5) were in three western provinces: Xinjiang, Tibet, and Qinghai (Figure 4). The minimal ES demands (level 1) were in seven provinces: Inner Mongolia, Liaoning, Anhui, Hubei, Guangxi, Guangdong, and Tianjin. Across all ES categories, the spatial patterns of resident demand were largely consistent, with only minor deviations (Figure 5B). The most pronounced deviation was in "obtaining flora and fauna". The most demanded ESs were "physical and mental relaxation" and "spending time with family", with 15 and 14 provinces at high levels, respectively.

Spatial heterogeneity in SDM decreases with scale. The northeast, while performing well at the provincial scale, had varying, mismatched levels at the municipal scale. The provinces with surplus SDM (level 5) were Inner Mongolia, Liaoning, Tianjin, Anhui, Hubei, Guangxi, and Guangdong (Figure 4). Except for Anhui and Tianjin, these provinces had medium supply and low demand, but surplus SDM. The provinces with the most deficit SDM (level 1) were Shaanxi, Fujian, Xinjiang, Tibet, and Qinghai. Xinjiang, Tibet, and Qinghai had medium or high supply and high demand but deficit SDM. For each ES category, the SDM at the provincial scale was generally better than at the municipal scale (Figure 6B). Qinghai had level 1 (most deficit) SDM for all ESs except "walking the dog".

Shaanxi and Fujian had seven ES types at level 1 (most deficit). "Obtaining flora and fauna" had the most deficit SDM, with 14 provinces at levels 1 and 2. SDM in 14 provinces were at surplus and equilibrium levels in "beautifying the city", "physical and mental relaxation", "spending time with family", "natural education", and "aesthetic appreciation".

3.2.2. The Influencing Factors on the Demand for Urban Green Space Types and ESs

The number of influencing factors that significantly affected the demand for UGS types and ESs accounted for 45% of all influences at the provincial scale, which had a stronger influencing degree than the municipal scale (Table S2). None of the four UGS types were significantly affected by COVID-19, accessibility, reachability, or physical condition ($p > 0.05$) (Figure 7B). Age was the sole factor influencing all four types, with regional green space being the most affected ($p < 0.01$). The order of effects of age on UGS types from largest to smallest was regional green space > attached green space > park green space > plaza green space. Plaza green space was only significantly affected by age ($p < 0.05$).

Regarding ESs, several factors significantly affected most ES types. First, COVID-19 had a very significant impact on all ESs except "obtaining flora and fauna" ($p < 0.01$). Second, sufficient time influenced all ESs except "walking the dog" and "social gathering" ($p > 0.05$). Furthermore, weather and age affected eleven ESs, and reachability affected ten ESs. Accessibility and physical condition did not noticeable impact any ESs ($p > 0.05$). Third, the most affected ESs were "exercise" and "physical and mental relaxation", each influenced by seven factors. The next were "climate regulation", "noise pollution reduction", "biodiversity conservation", "beautifying the city", "spending time with family", and "aesthetic appreciation", each influenced by six factors. The least affected ESs were "social gathering", "walking the dog", and "natural disaster mitigation".

3.3. National-Scale Urban Green Space Supply–Demand Matching, and Demand Influencing Factors

3.3.1. Urban Green Space Supply–Demand Matching

The Statistical Yearbook compiled by the Chinese National Bureau of Statistics present three indicators of UGS supply at the national level: UGS areas, park green space areas, and green coverage of built-up areas. However, the absence of statistics for other UGS types except park green spaces suggested a lack of diversity in UGS supply. This study quantifies residents' demand for UGSs at a national scale by determining their ideal frequency of and their preference for ESs. Residents' demand for UGS types are, in descending order, attached green spaces, park green spaces, plaza green spaces, and regional green spaces, and their means were 4.070, 3.933, 3.798, and 3.372, respectively (Figure 8). Residents' demand for ESs ranged between 3 and 4. The most demanded ESs were "physical and mental relaxation" and "beautifying the city", while the least demanded ES was "obtaining flora and fauna".

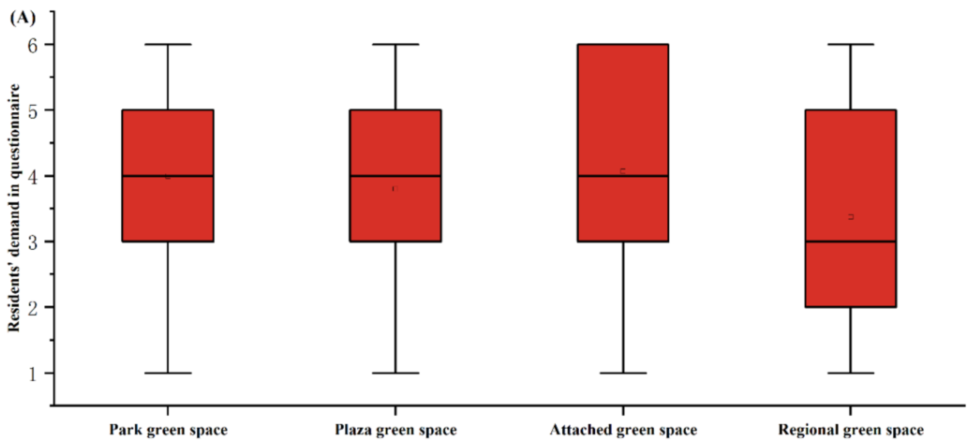

Figure 8. *Cont.*

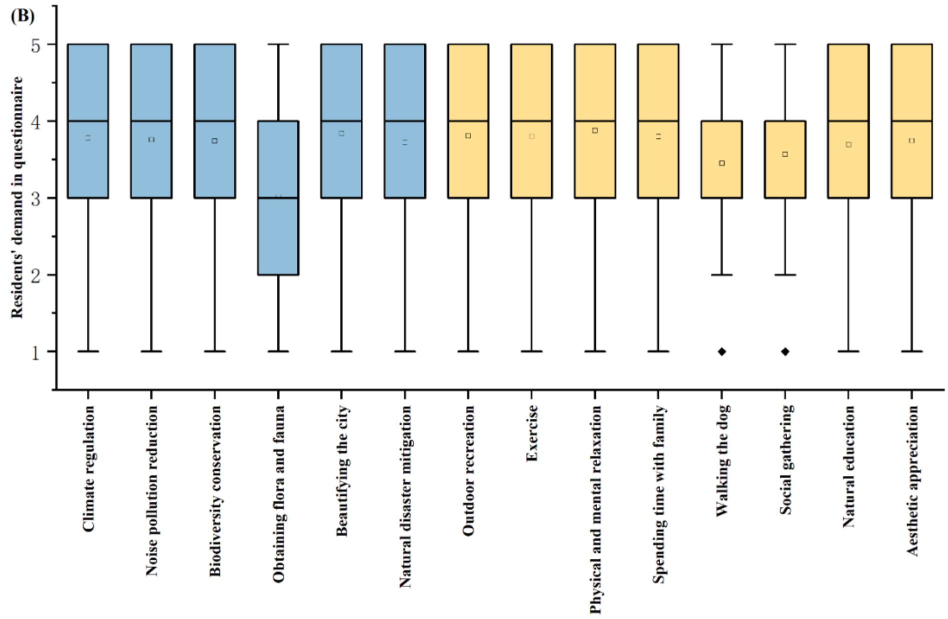

Figure 8. Box plot diagrams for residents' demand for (**A**) urban green space types and (**B**) ecosystem services at the national scale. The abscissa is the classification of urban green space and ecosystem services, and the ordinate is the residents' choice value of the Richter scale for which the higher the value, the stronger the demand. The box indicates the median (inner line) with 25%~75% of observations; the bars indicate the upper and lower quartiles; the hollow square represents the mean; the solid diamond represents the outlier.

3.3.2. The Influencing Factors on the Demand for Urban Green Space Types and ESs

The number of influencing factors that significantly affected the demand for UGS types and ESs accounted for 86.67% of all influences at the national scale (Table S3). The effects of influencing factors on UGS types and ESs were stronger with this scale. For the UGS types, accessibility, season, and physical condition had little impact on any UGS type (Figure 7C). The most influential factors were COVID-19, age, and staying with your child, each affecting three UGS types. Regional green space was the most susceptible UGS type, affected by seven factors ($p < 0.01$), while park green space was the least susceptible, affected only by COVID-19 and staying with your child. Most ESs were highly susceptible ($p < 0.01$), except for "physical and mental relaxation", which was not affected by age significantly ($p > 0.05$).

4. Discussion

4.1. Multi-Scale Spatial Mismatching Relationship

The findings showed that the patterns of geographic differentiation in the SDM spatial mismatch vary across different scales. First, at the provincial scale, surplus SDM regions (level 5) are vertically distributed in the north and south parts of China, while deficit SDM regions (level 1) are horizontally aggregated in the west and east parts. This probably indicates that the spatial matching of ES supply and demand between provinces is not clustered, implying an influence not only from geographic factors (such as topography, climate, and precipitation) but also anthropogenic factors [45]. For instance, Inner Mongolia's diverse internal environment offers a substantial amount of UGS (24.03% of urban area), which corresponds to a level 4 supply [46]. However, its lower level of economic development resulted in a lower level of demand (level 1) and surplus SDM (level 5) in this area. This phenomenon aligns with studies conducted in the Beijing–Tianjin–Hebei region [47].

Second, the spatial distribution of SDM and supply changes as the scale becomes smaller. Specifically, the smaller the scale, the more unequal the supply, and the greater the spatial heterogeneity of ESs. For instance, surplus SDM appears along the southeast coast in

Guangxi and Guangdong provinces. However, there are still cities in deficit SDM that exist in Guangxi and Guangdong provinces at the municipal scale. The findings demonstrate that if UGS planning is carried out based only on the total amount of the large region without targeting the characteristics of people and UGS's distribution, it is difficult to meet the differentiated needs of people [41]. In this setting, ensuring the equitable distribution of UGS in cities within a province is necessary, which proves the importance of scientific and fine planning of UGS at small scales.

4.2. Influencing Factors for Urban Green Space Types and Ecosystem Services

This study identifies the correlation between the influencing factors and residents' demand for UGS types and ESs spatially. We found that the effect of influencing factors weakens as the scale decreases, especially in terms of ESs. This transformation with scale can be attributed to the spatial spillover effect, signifying a phenomenon where the development of one aspect of a thing drives the development in other aspects [48]. As the scale increases, the number of units decreases, and the spatial spillover effect decreases, thereby amplifying the influence at smaller scales [49]. Therefore, in the future planning of UGSs, relevant departments should duly consider the factors that may affect residents' access to UGSs from a small scale as far as possible. And the spillover effect of the ESs that UGSs can provide at multiple scales should also be taken into account in urban planning. Second, COVID-19 had a significant effect on ES demand. This is because questionnaires were distributed during and after the severe lockdown phase in China. Residents were still anxious because of the increased risk of disease after the lockdown ended, which increased the impact on UGSs, and this effect was more pronounced in ESs than in UGS types. Previous studies have confirmed that UGSs remained essential for people's various demands during COVID-19 [50]. In future major public health events, the ESs that UGSs can provide should be valued. Furthermore, regional green space is the most susceptible type of UGS due to its definition, as it is located outside urban built-up land [21]. Regional green space has important benefits for biodiversity conservation, air pollution mitigation, soil, and water conservation [51]. Yet these benefits are often overlooked because of their vulnerability to external pressures. It is proposed that greater attention should be paid to the diversity of constituent elements to maintain the function of regional green space to fulfill its ESs [52].

4.3. Future Planning Guidelines for Urban Green Space

The deficit and surplus assessment of ESs provided by UGSs at different scales could inform the identification of priority areas for ES development in future UGS planning. For example, the phenomenon where the three western provinces of Xinjiang, Tibet, and Qinghai had medium or high supply and high demand, but a deficit in SDM deserves attention from policymakers. It has been proven that capital and land factors are important factors affecting the development of UGSs in western China [53]. For the calculation of the supply–demand matching of specific types of ESs, emphasis can be placed on certain aspects of construction when planning specific UGSs. It is worth noting that residents' adaptive behavior is often not fully integrated into UGS planning [54].

This research suggests that future UGS planning should consider both the area and the type of UGS. Residents manifest diverse and high-priority demands for the ESs provided by UGSs. Different types of UGS have different roles [20]. For instance, regional green spaces can conserve natural and cultural resources the best due to their location and size. While protected green space may be less accessible, it performs a major role in protecting the lives of its inhabitants and sanitary isolation [21]. However, the current policy disproportionately emphasizes park green space regulation and ignores other UGS types in China [22]. Including more UGS types in the UGS specifications will better cater to residents' needs for various ESs and optimize the form of UGS in the future.

Furthermore, the allocation of UGSs across cities within a province should be paid attention to in UGS planning. Results show that SDM varies significantly at both provincial and municipal scales within the same province. This means that natural and geographic factors alone are not enough to explain SDM differences. Demographic and economic factors also play a role. Therefore, future UGS planning should consider not only UGS on a large scale but also UGS on a small scale. This approach can help to mitigate the spatial heterogeneity and mismatching of SDM by developing policies that transfer ESs and UGSs from high-SDM regions to low-SDM regions, akin to the flow of ESs [55]. Meanwhile, some studies have shown that more attention should be paid to the protection and transformation of existing UGSs rather than focusing solely on the construction of new UGSs [56]. The multi-scale SDM obtained from this study can serve as scientific support for future UGS planning and redistribution.

Last but not least, socio-cultural factors that affect residents' demands for UGS types and ESs should be considered in UGS planning. This is in line with the idea of people-centered urban construction. For example, age and accessibility emerge as two factors that have large and small effects in our study, respectively. Age has a significant effect on UGS type and ESs preferences at all three spatial scales, which is associated with China's severe aging problem [57]. The number of people over 65 years old has surged by 81.62% from 96.92 million in 2003 to 176.03 million in 2019 in China [58]. Research indicates that elderly people prefer large UGSs and feel excluded from small UGSs [59]. However, the findings in our research show that residents have the greatest difficulty with the regional green spaces. This presents a potential challenge to the well-being of the elderly. Moreover, elderly people underscore the importance of maintaining small UGSs to prevent them from becoming overgrown [59]. This requires managers to strengthen the maintenance of these small UGSs (parks, plazas, attached green spaces). In addition, future UGS planning should prioritize the needs of the elderly by providing more elderly-friendly facilities [60]. Accessibility (the ease of access, such as tickets or reservations) did not show a significant effect in this research, except for ESs at the national scale. This indicates that UGS in China provides adequate accessibility to residents, an aspect that managers should continue to uphold.

4.4. Uncertainties and Future Prospects

Based on previous research, this study has been comprehensively upgraded, which is reflected in the increase in sample size and the construction of a multi-scale spatial framework. However, some uncertainties still exist in this research. First, although we do our best to fill in the data, we cannot avoid sample representative gaps in individual cities, which is inevitable in questionnaire surveys [61]. And we believe that the data from neighboring cities in one province are a good representative of the results for that city. We hope that better questionnaire survey methods can be used to solve this problem in the future. Second, the supply data of certain indicators are lacking in some municipalities; especially in western cities, the lack of supply data for some indicators affects the accuracy of the analysis to some extent, while the Social Values for Ecosystem Services (SoLVES) model can be employed to refine the data acquisition in certain areas in further research [62]. Second, this study is predicated on the subjective demands of individuals. Future studies could be enhanced by incorporating quantitative measures of ESs such as water yield, carbon sequestration, and soil conservation. As they are fundamental resources for industrial production, combined with people's subjective perception, more comprehensive planning opinions would be generated [63]. At the same time, the combination of future research with remote sensing images and UGS maps can also enhance the comprehensiveness of this study. Furthermore, in the post-epidemic era, the role of health isolation that is played by protected green spaces should also be paid attention to in future research. In addition, this paper mentioned the difference between UGSs on multi-scales, but in fact, the dynamic change in time is also a direction worthy of study, for example, combining the current and historical UGS map-related research.

5. Conclusions

This study was designed to dissect, identify, and quantify the diversity of UGSs, the supply and demand matching, and the influencing factors that affect residents' demand for the ESs that UGSs provide, as well as their different types, at three different spatial scales. The results show that (1) the supply of UGS is more unequal at the municipal scale than at the provincial scale; (2) the SDM deficit regions were widely distributed; (3) although the supply and demand of ESs in a province are generally well matched, there will still be areas of deficit within the province; (4) as the scale increases, the number of influencing factors that significantly affected the UGS type and ESs grow. Age and COVID-19 are two factors that change over the three scales and require attention. Based on the results, this study helped to identify SDM deficit and surplus regions on different scales, and some implications for future UGS planning are determined. For example, take both the area and type of UGS into account, balance the distribution of UGSs among cities within a province, and accommodate for the socio-cultural factors that influence residents' preferences, such as enhancing the convenience of regional green spaces for the elderly. The findings in this research help us to better understand the spatial heterogeneity and influencing factors of SDM for ESs provided by UGSs at multiple scales. The methodological systems and SDM values can inform UGS planning and allocation in China to address current deficiencies in UGS construction and provide insights for UGS development worldwide. The influencing factors at different scales could optimize future UGS planning and enhance human well-being at different scales.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/f14102091/s1: Table S1: Correlation coefficient between influencing factors and urban green space types, ecosystem services at the municipal scale. *, $p < 0.05$; **, $p < 0.01$. Table S2: Correlation coefficient between influencing factors and urban green space types, ecosystem services at the provincial scale. *, $p < 0.05$; **, $p < 0.01$. Table S3: Correlation coefficient between influencing factors and urban green space types, ecosystem services at the national scale. *, $p < 0.05$; **, $p < 0.01$.

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