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Perceived Sustainable Urbanization Based on Geographically Hierarchical Data Structures in Nanjing, China

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Abstract: Concentrating on geographically hierarchical data structures and using large-scale satisfaction survey data in Nanjing, this study employs Bayesian spatial multilevel model (MLM) to evaluate Nanjing's perceived sustainable urbanization. In this study, we consider the geographically hierarchical data structures and the city's individual perceptions of sustainable urbanization to explore the effect of environment and self-rated health on perceived sustainable urbanization, controlling for individual sociodemographic attributes and household. Through clarifying the spatial dependence and heterogeneity, this paper provides a flexible framework for assessing sustainable urbanization and dealing with the geographical hierarchical data. In particular, by drawing on existing studies, our questionnaire is more representative of the overall characteristics of Nanjing's population than census data, which can be helpful for understanding whether urbanization is sustainable from individual perspective and further for correcting practices. Based on a survey of 10,077 questionnaires, this paper finds the geographically hierarchical data structures have significantly influenced the evaluation of sustainable urbanization, and the Bayesian spatial MLM is an effective tool for evaluating China's sustainable urbanization. In particular, this paper takes spatial effects into consideration and compares the geographically hierarchical data. Results show that spatial patterns significantly influence the assessment of sustainable urbanization, and perceived pollution, age, education level, and income are the four key factors influencing individual perceived sustainable urbanization.

Keywords: sustainable urbanization; sustainability evaluation; geographically hierarchical data; sustainable cities; urban development; spatial statistics

1. Introduction

The 20th and 21st centuries have seen rapid urbanization worldwide, and urbanization is seen as one of the most important strategies for development [1]. After reform and opening-up launched from 1978, China's urbanization has also dramatically increased [2–5]. From 1978 to 2016, the proportion of China's urban population increased from 17.9% to over 57.35% [6]. China's urbanization growth has been at an unprecedented speed [7] and contributed to promoting China's economic affluence, improving social services [8] and living standards [9]. However, accompanying China's fast urbanization growth are a variety of problems, including environmental pollution [10–13], loss of arable land [14,15], urban–rural inequality and immigration problems [16–18], urbanization and urban identity dilemma [19,20].

Facing the above problems, sustainable urbanization is a valid solution to promote China's sustainable urban development [21], and China's sustainable urbanization has received much research focus [22]. In the process of pursuing sustainable urbanization, finding an effective tool for evaluating

China's sustainable urbanization is timely and necessary. Without a robust and effective evaluation tool, it is very hard to measure and study sustainable urbanization in a convincing way. Extensive research tries to find an effective tool to evaluate China's sustainable urbanization [22]. China's urbanization is unique, for it is neither identical with that of developed countries nor similar to the processes of other developing countries [23]. Thus, finding a suitable method of modeling sustainable urbanization should be derived from China's contemporary realities. However, much extant research tends to employ second hand data and complicated statistical models to examine China's sustainable urbanization such as a hybrid Entropy–McKinsey matrix method [24], a hybrid heterogeneous DEA method [25], etc. The correlations between complicated models and data lack strong support of methodology. There is emerging research exploring new models or methods to assess China's sustainable urbanization [26], but they are short of empirical evidence support. More importantly, the current studies do not notice the spatial dependence and the influence of geographically hierarchical data structures [27,28]. In China, cities have multiple hierarchies, because a city is affected by individuals and its surrounding cities and also belongs to a province. Due to ignoring the geographical data structure in the process of studying a city's sustainable urbanization, either focusing on the data of a city or an entire region lacks rigorous research design. Consequently, the existing evaluation tools have inherent flaws. In order to bridge these research gaps, this paper is timely.

This paper contributes to modeling and evaluating the sustainable urbanization of Nanjing city and understanding of Nanjing's sustainable development, linking these to the city development and citizen's perceptions of city sustainability in China. Specifically, we investigated Nanjing's sustainable urbanization, with Bayesian spatial MLM modeling and putting emphasis on geographically hierarchical data structures. Various urban models have been used to guide the design and practice of sustainable urbanization [26], but a few studies have addressed the geographically hierarchical data structures based on empirical evidence of individual perceptions. Sustainability in this study, to some extent, is understood as livability, and people-oriented perspective is applied to investigate sustainable urban development. Thus, there is an urgent need to evaluate whether a particular practice can be seen as sustainable urbanization. Using survey data from 10,077 Nanjing residents, this study tracked how they perceive sustainable urbanization. Nanjing is the capital of Jiangsu Province, located in the open coastal zone of China, and it is the core city of world-class urban agglomeration in the Yangtze River Delta. After 40-year rapid development, in 2017, Nanjing's GDP grew to 117.5 billion (RMB), exceeding 20,000 US dollars per capita, and its resident population grew to 83.35 million, with the urbanization level reaching 82%. Meanwhile, planning strategies of "the Belt and Road", the Yangtze River Delta, and regional integration in Yangtze River Economic Zone have brought new opportunities for Nanjing's urban development. Nanjing began to pursue high-quality development, high-quality urban life innovation, and green sharing. To be a livable and inclusive city has become the key purpose of Nanjing urban development. According to Urban Master Planning of Nanjing (2018–2035), Nanjing's urban development pays attention to the spatial strategy of ecological priority, and further highlights the three elements of ecology, culture, and city. In addition, continuous optimization of public service facilities and ecological environment, and the establishment of a happy and livable city are also the focus of Nanjing's urban planning. Therefore, in this study, we focused not only on sustainable urbanization at the regional level, but also on individual perceptions of sustainable urban development, considering the impact of spatial hierarchy. Looking in Nanjing city—which has experienced rapid urbanization since the 2000s [29] and is facing many changes in landscape and environmental deterioration—this paper, based on empirical evidence, aims to apply spatial dependence to analyze Nanjing's sustainable urbanization with emphasis on geographically hierarchical data structures.

This paper is organized as follows. The Section 1 is the introductory chapter, and the Section 2 positions the paper against the relevant research and identifies the research gap. Methodology is described in the Section 3, including the dataset. The Section 4 provides the key descriptive statistics of models and gives the research results. The Section 5 presents the discussions and conclusion.

2. Evaluation on Sustainable Urbanization

The dramatically increasing levels of urbanization has received great research concern for city sustainability [30,31], because sustainable urbanization can fulfill the principle of sustainable development [32]. Urban sustainability can be used as a measurement for assessing the extent to which a city has reached sustainability [33]. China's urbanization experienced rapid development and now is pursuing sustainable development as well.

After launching reform and opening-up policies from 1978, China has witnessed the fast growth of urbanization [9]. The urbanization level was less than 20% in 1978 while it is estimated to reach 60% in 2020 [34]. Besides, China's road to urbanization is unique, because China has a strict administrative hierarchy [35], so the inner correlations between different levels of cities must be considered. Because of the rapid urbanization, China has managed numerous achievements in economic development and improvement of infrastructure and social services. Meanwhile, a series of problems follow urbanization. The increasing gap in income between rural and urban areas results in the urban migration. Also, many cities have unbalanced economic structures [36]. Plenty of actions and policies are implemented for the degraded environment resulted from the rapid urbanization process [22]. Nevertheless, China is still facing plenty of arduous tasks to promote the quality of people's livelihood and to coordinate the improvement of ecological degradation and economic development. Sustainable development is the only way to tackle the problems [37]. Thus, China has considered sustainable development as the national strategy after the Ten Strategic Policies for Environment and Development were launched.

Given the concerns of accomplishing sustainable urbanization, it is important to effectively evaluate it [38]. Xu and Zhang, through conducting a comprehensive literature review, put forward six perspectives for evaluating China's sustainable urbanization: eco-environmental protection, land development, energy utilization, population growth and migration, housing, and policy [22]. These perspectives provide a comprehensive evaluation of the concept of sustainable urbanization. Cornelissen, Berg, Koops, Grossman and Udo introduced fuzzy set theory to assess sustainable development. Although sustainable development is an objective research field, fuzzy set theory links human expectations about development. The research results of fuzzy set theory provide empirical evidence to support decisions regarding sustainable development [39]. Shen, Zhou, Skitmore, and Xia used a hybrid Entropy–McKinsey Matrix method in evaluating sustainable urbanization. The matrix can be helpful with assessing sustainable urbanization performance by locating the urbanization state point [24].

In addition to a variety of assessment tools, there are plenty of indicator systems of sustainable urbanization in current literature [22]. Due to different research aims, different indicators are selected to assess sustainable urbanization [40]. Besides, sustainable urbanization is a complex concept consisting of many aspects, including economic, environmental, and social well-being [41], so evaluating sustainability is in need of multi perspectives. Based on Ng, Cook, and Chui's multi-perspectives, Cohen similarly also conducts a systematic review of urban sustainability to evaluate the current assessment of urban sustainability and concludes a series of flaws in current literature. The majority of studies still use the three pillars model (economic, social, and environmental sustainability) as the principle-based assessment framework. Although there are some weaknesses in the assessment provided by the three pillars model, it has been a widely acceptable model until now [31]. More importantly, the most important problem existing in literature is the lack of inhabitants' perceptions. Various indexes provide some controversial indicators which are incongruous with sustainability. These flaws in the existing assessment model highlight the weaknesses of assessment based on the three pillars model and meanwhile promote the interests in the more integrative conceptualizations [42]. Although the three-pillar model is a basic framework for regional sustainable urbanization and applicable for research using second-hand data, the three-pillar model does not take individual perceptions of sustainable urbanization into consideration. Thus, this study connected the three-pillars model and individual perceptions of sustainable urbanization. In addition to the review research, many scholars develop a variety of indicator systems, but the main limitation in practice results from the large inconsistencies between them, and thus it is a need to find an effective way to select effective indicators [22]. Among

the hundreds of indicators, income level has evident association with development problems in the context of rapid urbanization. Fast growing cities with low and middle income have more problems that are most acutely felt [32]. Education also plays an important role in talent mobility, because education can improve a person's abilities of gathering information and obtaining an appropriate job available in remote areas [43,44]. Besides, age also has significant effects on urbanization. Recently, a large number of young professionals flooded into China's first-tier cities—like Beijing, Shanghai, and Guangzhou—for promising career prospects, regardless of air pollution and traffic problems [45]. However, older adults prefer to stay at home. Therefore, we can see that rich relevant research has established plenty of index systems of assessing sustainable urbanization, but a few studies consider the individual level. A sustainable city usually describes the current conditions of cities, such as eco-environmental protection, proper use of resources, individual welfare, and satisfaction of basic human needs [46]. According to the existing research, assessing sustainable urbanization at an individual level is innovative and necessary. Additionally, there is extensive research investigating the indicators of sustainable urbanization, and we select several key indicators in the survey. These indicators have been tested and show low level of inconsistency, which will be explained in a detailed way in the methodological section. In order to ensure cost-efficiency and a particular degree of compatibility with extant research, this paper is also based on the three pillars model and then designed a survey to collect first hand data.

The analysis of sustainable urbanization is vital in urban planning, and more importantly, its usefulness can be extended to study smart sustainable cities [47]. A smart sustainable city is closely integrated with urban sustainability, because it needs to be supported by the level of infrastructure aiming to tackle sustainability challenges (economic, environmental, and social development) and to promote quality of urban life [48]. In addition, the concept of smart cities is closely related to the field of spatial planning, and the extant research shows the impacts of smart cities on the objectives of urban sustainability, since the two concepts have common goals: the smart cities' approach is to achieve sustainability and high quality of life for citizens [49]. From a spatial planning perspective, urban sustainability can be achieved through connecting existing and new green space, improving multi-tropical transport systems, etc. [50]. Therefore, it can be concluded that the concept of smart sustainable cities is important for studying sustainable cities. Although a few studies have noticed the spatial factors, there is insufficient research exploring urban sustainability from a spatial perspective that accounts for geographically hierarchical data structures.

It is crucial that existing research designs can be able to report the multi-dimensional relationships of urbanization, but spatial factors are not widely considered in the extant research. Dahal and Lindquist adopt an innovative framework of urban patch hierarchy and investigate the factors driving urban growth, and the results show that spatial variability is evidently affecting the urban growth and management [27]. Therefore, more spatial factors should be taken into considerations regarding research of sustainable urbanization. Liao and Wei examine spatial variations of urban growth patterns in Dongguan, China through non-spatial and spatial logistic regression models [28]. The spatial logistic model reveals the spatially varying relations between urban growth and the underlying factors such as environment protection and the urban development policy. Research considering spatial effects on urban development reveals their significant application in sustainable urbanization research. Modeling the ecological impacts of human activities during the urbanization, Sui and Zeng developed a GIS-based spatial analysis. Spatial analysis was conducted and found the size of desakota regions should be controlled in order to make sure the sustainable development [51]. Although a few studies start to notice the spatial analysis, the existing research does not take geographical hierarchical data into consideration. In order to fill the gap, this study, based on geographically hierarchical data structures and China's strict administrative hierarchy [35], compared the sustainable urbanization within different hierarchy between individual level and district level (*Jiedao*).

3. Methodology

3.1. Method

In the process of evaluating the perceived sustainable urbanization, the study employs Bayesian spatial multilevel model (MLM) to take geographically hierarchical data structures into consideration. Hierarchical simultaneous autoregressive (HSAR) is developed based on the spatial simultaneous autoregressive model [52,53]. A hierarchical structure exists in geographical and economic data sets [54]. Traditional multilevel modeling literature expects differences between correlations within regions and regions [55]. In other words, because they are influenced by the same effects, the results at lower levels within the same region are usually correlated with each other, this correlation is referred to as ‘vertical group dependence’ [56]. However, traditional multilevel modeling cannot test horizontal dependence, which is a kind of spatial dependence related to a single-level spatial data econometric approach, and the horizontal dependence results from spillover or interaction within a region because of geographic proximity [56]. In our study, we expect to introduce vertical and horizontal dependence to our model, which can help to understand the difference of sustainable urbanization between spatial heterogeneity at regional levels and spatial interaction at lower levels. In theory, Bayesian spatial MLM can supply a methodological framework to jointly take spatial heterogeneity and spatial interaction into account. Particularly, through identifying the hierarchical data structure, this method makes regression coefficients of evaluating sustainable urbanization more accurate and effective [56,57]. In addition, regional effects measured by the method can help to explore spatial patterns of sustainable urbanization at the regional level. Moreover, Bayesian spatial MLM can explicitly estimate the spatial interaction strength at a lower level through distinguishing the measure from confoundedly regional effects [56].

The aim of this study is to investigate the determinants of sustainable urbanization. According to Gelman et al. (2004), the Bayesian nonspatial MLM is

$$\begin{aligned} \text{sustainableurbanization}_{jk} &= \alpha + \beta EP'_{jk} + \theta SH'_{jk} + \gamma DS'_{jk} + \delta TL'_{jk} + \varphi UF'_K + u_k + \varepsilon_{j,k} \\ u_k &\sim N(0, \sigma^2); \varepsilon_{j,k} \sim N(0, \sigma_e^2); \{\alpha, \beta, \gamma, \delta, \varphi\} \sim N(0, b); \sigma^2 \sim \text{inverse gamma}(e, f); \sigma_e^2 \sim \text{inverse gamma}(e_0, f_0) \end{aligned} \quad (1)$$

where, j and k refer to individual and district level indicators. Sustainable urbanization is associated with a series of individual and area indicators. EP and SH are perceived environmental pollution and self-rated health. DS represents social factors related to sustainable urbanization, such as education attainment, income, age, residence, and so on. TL refers to location variables, and UF represents the urban form variable at district level. These vectors of $\{\alpha, \beta, \theta, \gamma, \delta, \varphi\}$ represent fixed regression coefficients on which the study focuses. Diffuse priors are explained by fixed regression coefficients, and the largest variance of b is 100. The vector u can help to understand the unobserved contextual effects on perceived sustainable urbanization disparity at district level, which presents a dependent normal distribution, $N(0, I\sigma^2)$ [58]. Using MLM to estimate district level unobservables can capture the heterogeneity between districts so as to understand how perceived sustainable urbanization varies across space. Also, the method can detect the possible relationships of sustainable urbanization of municipalities in the same district. The vector ε means the residuals at individual level, and it also meets the independent normal distribution $N(0, \sigma_e^2)$. In addition, there are two variance parameters σ^2 and σ_e^2 which are inverse gamma distributions, and their scale and shape parameters are (e, f) and (e_0, f_0) respectively [59].

However, when we used graphically-clustered data to model perceived sustainable urbanization by MLM, there may exist two shortcomings. Firstly, because of possible spatial dependent effects, the independent assumption on random effects (u) at district level may be violated, meaning that aggregated perceived sustainable urbanization may be spatially correlated at the district level [58]. The existing studies have indicated that the nonspatial MLM can lead to biased estimation of inefficient

fixed effect and random effects [60,61]. Leroux et al. put forward a conditional autoregressive prior (LCAR) to focus on potential spatial dependence effects [62]. This method explains u

$$\begin{aligned} u_k | \mathbf{u}_{-k}, W, \lambda, \tau^2 &\sim N\left(\frac{\lambda \sum_{k \sim l} u_l}{1 - \lambda + \lambda w_{k+}}, \frac{1}{\tau^2(1 - \lambda + \lambda w_{k+})}\right), \\ \mathbf{u} &\sim MVN(0, \Omega_{LCAR}); \Omega_{LCAR} = \tau^2(L_W - W); \\ L_W &= \text{diag}(1 - \lambda w_{k+}); \tau^2 \sim \text{gamma}(e', f'); \text{logit}(\lambda) \sim \text{logitbeta}(2, 2) \end{aligned} \quad (2)$$

where, w_{k+} refers to neighbor number in district k , while \mathbf{u}_{-k} is random effects excluding k . W represents spatial weights matrix, and its measurement is based on geographical contiguity. $w_{kl} = 1$ means the districts of k th and l th have the same boundaries, that is, $k \sim l$, or $w_{kl} = 0$. Regarding LCAR, $E(u_k | \mathbf{u}_{-k})$, meaning the conditional expectation of u_k , presents the weighted mean of random effects. The spatial correlation parameter λ tests the spatial dependence intensity, and the precision parameter τ^2 is measured by the inverse of the variance parameter. According to Congdon [60], $\mathbf{u} \sim MVN(0, \Omega_{LCAR})$ is the Gaussian Markov random field to indicate the full conditionals of all k random effects.

Secondly, the assumption of the homogeneous effects of environmental pollution on perceived sustainable urbanization across districts may be false. Due to the complexity and non-observability of geographical factors, the relations between perceived sustainable urbanization and environmental pollution may change across districts. We made the regression slopes of housing variables vary across districts by taking spatial heterogeneity into account.

$$\begin{aligned} \text{sustainableurbanization}_{jk} &= \alpha + \beta_k EP'_{jk} + \theta SH'_{jk} + \gamma DS'_{jk} + \delta TL'_{jk} + \varphi UIF'_K + u_k + \varepsilon_{j,k} \\ \beta_{k,p} &= \beta_p + \theta_{k,p}, p \\ &= 1, 2, 3, \dots, p; \mathbf{u} \sim MVN(0, \Omega_{LCAR}); \theta_{k,p} \sim N\left(0, \frac{1}{\tau_p^2}\right); \varepsilon_{j,k} \sim N(0, \sigma_\varepsilon^2) \\ \{\alpha, \beta_p, \gamma, \delta, \varphi\} &\sim N(0, b); \tau_p^2 \sim (e^n, f^n) \text{logit}(\lambda) \sim \text{logitbeta}(2, 2) \end{aligned} \quad (3)$$

where, β_p and $\theta_{k,p}$ are the fixed effects and random effects of housing variables, and they are different in different districts. There are some advantages on above flexible spatial multilevel modeling method. Spatial dependence of $\theta_{k,p}$ and \mathbf{u} can be captured at the same time. Moreover, the model includes the cross-level interaction to understand the heterogeneous effects on perceived sustainable urbanization at district level. The study conducted the analysis via employing R-INLA [63].

3.2. Data and Variables

The data of this study are based on a large-scale perceived sustainable urbanization and environmental pollution survey conducted in Nanjing in 2017. Nanjing is located in the Yangtze River Delta, Jiangsu Province, Eastern China, and the Yangtze River traverses it (Figure 1). Nanjing is the sixth-largest economic center globally and one of the three core cities within the Yangtze River Delta. In addition, there is an urban population of 6.55 million (8.16 million total population) in Nanjing. Second only to Shanghai, it is the largest commercial center in the East China. Moreover, due to the rapid urbanization, Nanjing's construction land use has arrived at $8.40 \times 10^3 \text{ hm}^2$ of ecological land [64]. Thus, Nanjing is a classic representative of rapidly growing urbanization.

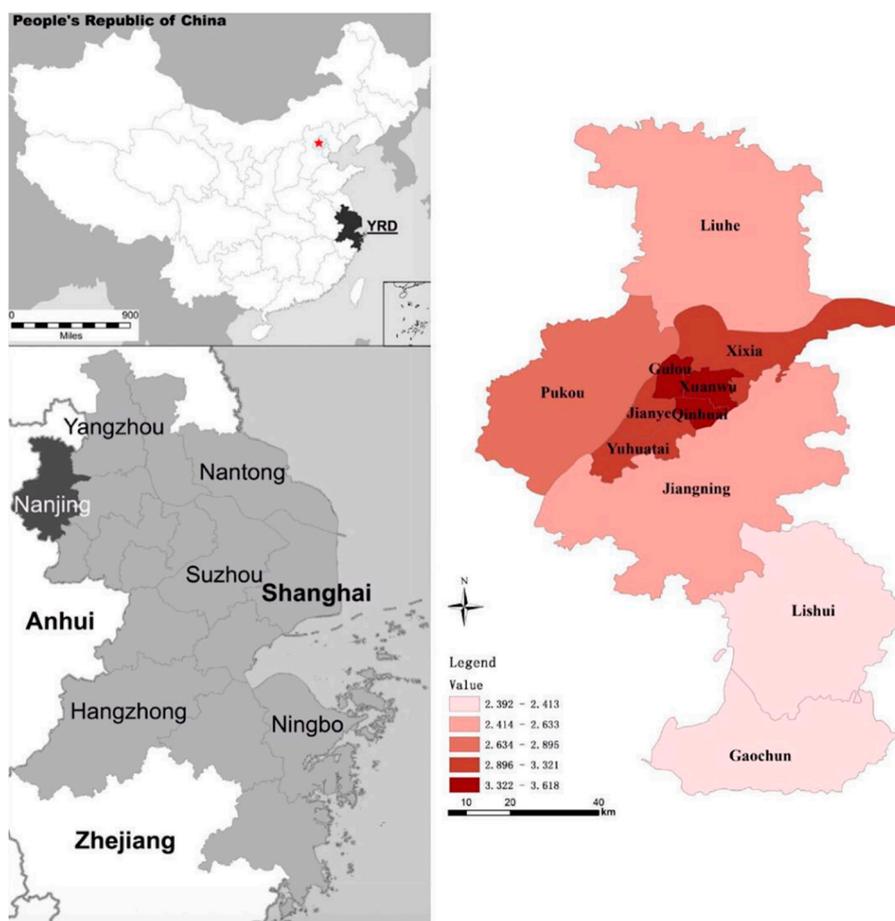


Figure 1. Spatial pattern of perceived sustainable urbanization in urban Nanjing. Note: The left white-black figure was quoted from Chen, Gao, and Yuan (2016)'s research [65].

This survey is the first and comprehensive reflection at individual level, collecting the residents' sociodemographics and assessment of their perception of sustainable urbanization, environmental pollution, and self-rated health. Researchers spent three months conducting on-the-spot surveys to distribute questionnaires, which helped to ensure that the questionnaires were done by respondents themselves. This survey aims at evaluating residents' perceived sustainable urbanization, self-rated health status, and their satisfaction with environmental protection. Four district-level variables, including population density, urban infrastructure and facilities, crime percentage, and median educational level, were included in the model because they were helpful with expounding the sources of sustainable urbanization at the district level. There were four general indicators that were perceived by respondents, including perceived sustainable urbanization, perceived traffic air pollution, perceived noise pollution, and perceived landfill pollution. Self-rated health was on an individual behavior. The survey includes current residents who have lived in Nanjing at least 1 year, including 87 Jiedao (communities) totally. In addition, we chose spatial stratified random sampling strategy, with about 0.2% of population of in each district of Nanjing (11 districts in total). There were 16,540 questionnaires sent out and 13,275 were returned where 10,077 were valid. Following the studies of Ma et al. [58] and Ma et al. [66], our questionnaire is based on theories of livable cities and the three-pillars model to examine the Nanjing's perceived sustainable urbanization. The questionnaire belongs to spatially-clustered survey, which can reflect the effects of sustainable urbanization at the regional and individual levels. More importantly, the questionnaire can help us to analyze the spatial dependence and heterogeneity effects of Nanjing's perceived sustainable urbanization through controlling geographical contextual effects and individual sociodemographic attributes in Nanjing.

Also, the questionnaire is reported to be more representative of the overall characteristics of Nanjing's population than census data [67].

We collected the data of residents' overall sustainable urbanization perceptions from detailed survey questions based on three perspectives of environment, economic and society. These questions focus on the following six dimensions: environmental protection, land use, living standards, access to transport, safety, and social welfare. In the process of survey, respondents answered the rate of their satisfaction for above six dimensions, and the results range from 5 (very satisfied) to 1 (very dissatisfied). In terms of the weights of each dimension, respondents were asked about the importance of them. We used the weights to calculate the overall sustainable urbanization scores for each respondent, and to help understand the heterogeneity of sustainable urbanization. The overall scores meet a continuous normal distribution, and the mean is 3.017 (SD = 0.493) (Table 1), indicating that perceived sustainable urbanization is modeled as a continuous variable.

Table 1. Summary of key variables and sociodemographic attributes in perceived sustainable urbanization

Variable Names	Percentage (%)	Mean	SD
Perceived sustainable urbanization		3.017	0.493
Perceived traffic air pollution		3.621	0.591
Perceived noise pollution		2.463	0.405
Perceived landfill pollution		2.892	0.437
Self-rated health		2.281	0.392
Age_20–29	57.43		
Age_30–39	20.12		
Age_40–49	13.51		
Age_50–59	4.25		
Age_60+	4.69		
Female	32.59		
Monthly income_below 3999 (RMB)	29.81		
Monthly income_4000–5999 (RMB)	42.97		
Monthly income_6000–9999 (RMB)	18.52		
Monthly income_10,000–14,999 (RMB)	5.23		
Monthly income_15,000+ (RMB)	3.47		
Low education	10.77		
Secondary education	25.96		
Tertiary education	63.27		
Log of distance to the nearest subway station		7.32	11.473
Log of distance to the nearest green park		7.86	12.065
Log of distance to the nearest hospital		6.58	9.371
Population density (1000 persons/km ²)	27.19		
Urban infrastructure and facilities	0.41		
Crime percentage	3.64		
Median educational level	32.51		

Note: RMB means renminbi, which is the official currency of China.

Following Ma et al. [66], this study pays attention to the three following dimensions of environmental pollution: noise pollution, traffic-related air pollution, and landfill pollution (such as industrial, municipal, and construction waste). In order to evaluate the perceived environmental pollution, the following questions were designed: how do you assess the exposure to noise pollution, traffic-related air pollution, and landfill pollution in your neighborhood? The answers range from 5 (very high) to 1 (very low). The results of perceived environmental pollution indicate that the percentage of three measure category has an obvious variation. The means of perceived exposure to noise pollution, traffic-related air pollution, and landfill pollution are 2.46, 3.62, and 2.89 respectively (Table 1). Figure 1 reports the average perceived sustainable urbanization scores for each district in urban Nanjing. According to Figure 1, people residing in the inner city were more satisfied with sustainable urbanization development than those based in suburbs, which may be explained by

convenient transportation routes and various amenities in the inner Nanjing [66]. Moreover, we can see a clustering spatial pattern from Figure 1. Then, according to the spatial weights matrix in Model 3, we calculated the Moran's I to examine the spatial dependence. The Moran coefficient is 0.179 with $p < 0.01$, demonstrating a based justification for combining the spatial dependence effect with MLM while we explored the neighborhood effect of environmental pollution.

In terms of individual and neighborhood level variables, our survey also provided detailed information, including self-rated health, socioeconomic, and demographic characteristics. We measured the self-rated health through asking the following question: Generally speaking, how do you feel about your overall health status [66]? The scores of this question are from 1 (very good) to 5 (very bad). The mean value of self-rated is 2.28 with SD = 0.392. Socioeconomic and demographic characteristics including age, gender, education, and monthly income. In addition, we chose three location variables to examine the local urban amenities, including the distance to subway station, green park, and hospital. Also, following Ma [58] and Zhou et al. [68], we selected four district-level variables from the 2010 sixth Census to explore observable contextual effects on sustainable urbanization. These variables included population density, urban infrastructure and facilities, median education level, and crimes number per 1000 people, which can help us understand the sources of sustainable urbanization at the district level. Moreover, cross-level interaction in the model between district and individual variables can explain that the effects of environmental pollution and self-rated health on sustainable urbanization vary within local contexts [58].

4. Estimation Results

A single-level regression model, MLM and spatial MLM were estimated with the individual and district-level covariates. The three models, a single-level regression model, MLM, and spatial MLM, are increasingly complex. In order to make comparisons of the three models, we adopted two widely employed indexes in Bayesian inference: deviance information criterion (DIC; [69]) and marginal log-likelihood. DIC can calculate the sum of the posterior mean of the deviance and the number of effective model parameters (P_D). The smaller value of DIC and larger log-likelihood refers to a better model fit [69]. The results of model comparisons are shown in the Table 2. There is a substantial decrease in DIC values of single-level regression and MLM, from 10,371.29 to 10,293.27, indicating the importance of unobserved district effects. The decrease explains the disparity in perceived sustainable urbanization in Nanjing. Similarly, we observed the decrease in DIC values for spatial MLM compared with the MLM. The incorporation of spatial correlation in district random effects in the spatial MLM decreases to 10,098.76, compared with MLM. The significant decrease reveals the fact that we need to consider district random effects as spatially dependent, instead of as independent.

Table 2. Results of model comparison

	DIC	P_D	Log-Likelihood
Single-level regression	10,371.29	45.09	−5932.91
MLM	10,293.27	127.81	−5548.36
Spatial MLM	10,098.76	169.47	−5498.79

Note: DIC is deviance information criterion; P_D is the number of effective model parameters; Log-likelihood is marginal log-likelihood from model.

Table 3 shows the estimation results of spatial multilevel model. The λ , the spatial correlation parameter is 0.712, in a 95 percent credible interval of [0.321, 0.879], which demonstrates the large correlations among district-level random effects. The results indicate the strong associations between pollution and perceived sustainable urbanization. Perceived landfill pollution and perceived traffic air pollution have stronger effects on individual perceptions of sustainable urbanization than perceived noise pollution. Pollution is contrast to sustainable urbanization, and according to the results, pollution problems contributed to the request of sustainable development [13,70]. Among the three kinds of

pollution, landfill pollution has the largest effects, which means the visible pollution still plays the most important role in shaping individual perceptions of sustainable urbanization.

Table 3. Estimation results of spatial multilevel model

	Posterior Median	2.50%	97.50%
Intercept	4.138 *	3.992	4.527
Perceived traffic air pollution	−0.801 *	0.698	0.884
Perceived noise pollution	−0.743 *	0.798	0.876
Perceived landfill pollution	−0.873 *	0.801	0.912
Self-rated health	0.799	0.765	0.874
Age_20–29	−0.217	0.176	0.323
Age_30–39	−0.231	0.137	0.398
Age_40–49	0.203	0.156	0.412
Age_50–59	0.166 *	0.099	0.197
Age_60+	0.751 *	0.671	0.865
Female	0.034	0.078	0.107
Monthly income_below 3999	−0.058	0.047	0.109
Monthly income_4000–5999	−0.085	0.057	0.121
Monthly income_6000–9999	0.107	0.096	0.164
Monthly income_10,000–14,999	0.134 *	0.097	0.176
Monthly income_15,000+	0.189*	0.165	0.274
Low education	0.047	0.035	0.087
Secondary education	−0.008 *	0.003	0.081
Tertiary education	0.046 *	0.032	0.125
Log of distance to the nearest subway station	0.031 *	0.015	0.066
Log of distance to the nearest green park	0.027*	0.021	0.064
Log of distance to the nearest hospital	−0.012	0.09	0.039
Population density	0.005	0	0.012
Urban infrastructure and facilities	−0.947	0.801	1.202
Crime percentage	0.017	0.011	0.054
Median educational level	0.035	0.013	0.069
Urban infrastructure and facilities * Perceived traffic air pollution	0.226 *	0.098	0.312
Median educational level * Perceived traffic air pollution	0.215 *	0.071	0.403
Urban infrastructure and facilities*self-rated health	0.135 *	0.096	0.339
Median educational level*self-rated health	0.107 *	0.091	0.209
Individual level variance			
σ_e^2	0.265	0.232	0.306
District level variance			
Variance (intercept)	0.067	0.042	0.103
λ	0.712	0.321	0.879

Note: * $p < 0.05$; omitted dummy variables include male and age below 20.

Besides, we found the most significant socioeconomic and locational variables in Table 3. Age is a positive factor. People in the sample who are over 50 years old responded more to the survey and have more consciousness of sustainable urbanization. Older adults have more worries about living standards, access to transport, safety, and social welfare, so age positively affects their perceptions of sustainable urbanization. Unlike old adults, young people do not spend much energy on adopting to new urban living, and they seem to enjoy the enriched social life resulting from urbanization [45,71]. Therefore, old adults pay more attention to the sustainability of urbanization and have more thoughts of urbanization. Additionally, the rapid urbanization is closely associated with a wide range of human welfare outcomes, including health disparities between groups with different socioeconomic status [5]. According to the research results of Miao and Wu, urbanization affects lifestyle and then health of high-income group in more urbanized areas. From Table 3, we found sustainable urbanization had large positive effects on individuals who earn over 10,000 RMB monthly, which conforms to Miao and Wu's research. Similarly, sustainable urbanization has an equally important role in individual lifestyle, so it has strong association with high-income level groups [32]. In Table 3, members of the sample

having a salary over 10,000 RMB showed significant correlation with sustainable urbanization. Lastly, according to Table 3, we found education level has significant association with perceived sustainable urbanization, especially higher education. Higher education has positive and significant effects while lower education level plays negative roles. Higher education contributes to the increased abilities of getting jobs in competitive cities, so it works as an internal function of influencing talent mobility between cities [43,44].

Moreover, the model includes the cross-level interaction to understand the heterogeneous effects on perceived sustainable urbanization at district level. Cross-level interaction in the model between district and individual variables can explain that the effects of environmental pollution and self-rated health on sustainable urbanization vary within local contexts. The interactions between urban infrastructure and pollution, and education and pollution are satisfied with perceived sustainable urbanization. All the perceived sustainable urbanization is found to be associated with self-rated health. Individuals who have better education level and living environment are more likely to report better self-rated health [72].

In order to confirm whether the model parameter estimates are robust enough to the choices of hyperprior parameters, a sensitivity analysis was conducted. We used a noninformative prior logitbeta (1,1) to deal with the hyperpriors for the spatial correlation parameter (λ), which approximates a (0,1) uniform distribution. Another hyperprior with logitbeta (4,2) favors a λ value close to 0.60. About the two district-level variance parameters, hyperpriors of log-gamma (1,0.1), log-gamma (1,0.01), and log-gamma (1,0.001) were used for testing the sensitivity of the variance estimates. With different hyperpriors, we tested the sensitivity of the effects of perceived pollution on perceived sustainable urbanization, and the results are shown in the Table 4. According to the Table 4, the coefficient estimates are stable, because a few differences exist, confirming that the results in Table 3 are robust and credible.

Table 4. Sensitivity analysis based on different hyperpriors

	Priors	M/SD	Perceived Traffic Air Pollution	Perceived Noise Pollution	Perceived Landfill Pollution	Self-Rated Health
λ	logitbeata (1,1)	0.592	0.076	0.057	0.103	0.141
		0.188	0.043	0.039	0.026	0.033
	logitbeata (2,2) ^a	0.574	0.076	0.057	0.103	0.141
		0.169	0.043	0.038	0.026	0.033
	logitbeata (4,2)	0.603	0.076	0.057	0.103	0.141
	0.197	0.043	0.039	0.026	0.033	
	logitbeata (0.5,0.5)	0.606	0.076	0.057	0.103	0.141
		0.199	0.043	0.039	0.026	0.033
District-level variance (intercept)	Loggamma (1,0.1)	0.074	0.076	0.057	0.103	0.141
		0.019	0.043	0.039	0.026	0.033
	Loggamma (1,0.01)	0.063	0.076	0.057	0.104	0.141
		0.012	0.043	0.038	0.026	0.033
Loggamma (1,0.001)	0.067	0.076	0.057	0.103	0.143	
	0.015	0.043	0.039	0.026	0.033	
	Loggamma (1.5 × 10 ⁻⁵) ^a	0.064	0.076	0.057	0.103	0.141
		0.013	0.043	0.039	0.026	0.033
District-level variance (Perceived noise pollution)	Loggamma (1,0.1)	0.039	0.076	0.057	0.103	0.141
		0.008	0.043	0.039	0.026	0.033
	Loggamma (1,0.01)	0.037	0.076	0.057	0.103	0.141
		0.006	0.043	0.038	0.026	0.033
Loggamma (1,0.001)	0.021	0.076	0.057	0.104	0.143	
	0.004	0.043	0.039	0.026	0.033	
	Loggamma (1.5 × 10 ⁻⁵) ^a	0.018	0.076	0.057	0.103	0.141
		0.003	0.043	0.039	0.026	0.033

Note: fixed regression coefficient estimation is identical with differences observed in the fourth decimal; ^a hyperpriors employed in the research of sustainable urbanization in Nanjing.

5. Conclusions

Drawing on a large-scale survey in Nanjing China, we established the spatial multilevel models to explore the spatial patterns and how individuals perceived sustainable urbanization. Rapid urbanization contributes to China's economic affluence, improving social services [8] and living standards [9]. However, a series of problems follow this rapid urbanization, including poor quality of housing [73], poor public transport [74], environmental pollution [66], and waste management [75]. Our results reveal that spatial factors affect significantly the assessment of sustainable urbanization according to the estimations of the three models. Besides, among the socioeconomic factors, perceived pollution, age, education level, and income are the four key factors influencing individual perceived sustainable urbanization. Regarding pollution, the visible pollution has stronger effects on perceived sustainable urbanization. Old adults have more consciousness of sustainable urbanization compared with young adults. Young age also has negative effects on perceived sustainable urbanization. High level of income has a significantly positive role in perceived sustainable urbanization. Similarly, a high level of education shows positive effects on perceived sustainable urbanization. The perceived sustainable urbanization in this study provides strong strategies for developing Nanjing's sustainable urbanization. The research results reveal the role of spatial hierarchy in Nanjing's sustainable urbanization, especially the individual perceived level. Regarding individual perceptions of sustainability, it was drawn from fieldwork, and the data were gathered first-hand. In addition, three-pillars model is widely used in cities or regions [31]. The approach we used required us to notice the different spatial hierarchies (individual and district levels).

More importantly, this study improves the existing understanding on sustainable urbanization research in several ways. Firstly, we got rid of factor index paradigm, and instead, we collected data of sustainable urbanization from individuals. For instance, the dominant method in current research involves employing a three-silo approach and selecting indicators by economic, social, and environmental concerns [31]. However, this approach does not take individual perceptions into consideration. Sustainable urbanization is influenced by individual and a city's sustainable development should consider individual ideas and thoughts, and thus this study is timely and necessary. We focused on the individual perceptions and collected data via a survey, and our results can be complementary to the existing research.

Secondly, concentrating on geographically hierarchical data structures, we employed multilevel models to examine the spatial patterns. We conducted a single-level regression model, MLM, and spatial MLM with the individual and district-level covariates. The three models are increasingly complex. According to the estimations of model fit, we found spatial MLM has the best effects, which means the spatial factors play a significant role in studying sustainable urbanization in Nanjing China. The multilevel spatial model approach can be an efficient way to deal with the geographical hierarchical data.

The multilevel spatial model approach that was applicable in Nanjing city can be used widely in China's other cities. Studying sustainable urbanization in cities, we cannot avoid the hierarchical data structures (individual and district level) and individual perceptions. Therefore, based on the features of sustainable urbanization research, this approach has great generalizability and can be used in other cities. However, there are some reflections in this study as well. First, we used our first-hand data. Although we conducted a large-scale survey, compared with the population of Nanjing, it seems insufficient. In addition, cross-sectional data cannot provide causal claims of the relationships between pollution, health, and sustainable urbanization. In future research, panel data will be able to tackle the problem. Second, in this study, we put emphasis on how environmental pollution and self-rated health are two major problems, because in the process of China's urbanization development, individual health is exposed to environmental pollution [65]. We focused on the spatial distribution of individual health and environmental pollution. We designed an indicator index based on the existing research and research rationale. However, the index does not contain all relevant variables. For future research, choosing different key indicators is needed based on different research purposes. In spite of these flaws, this study contributes the body of knowledge concerning sustainable urbanization through rigorously examining the spatial patterns and determinants of sustainable urbanization.

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