

Article

The Impact of Urban Green Space on Public Health: Evidence from 30 Provinces in China (2012–2023)

Yujie Chen ¹, Weinuo Chen ¹, Lvze Chen ^{2,*}, Shipeng Su ¹ and Min Hou ³

¹ College of Rural Revitalization, Fujian Agriculture and Forestry University, Fuzhou 350002, China; cyj@fafu.edu.cn (Y.C.); cwn@fafu.edu.cn (W.C.); ssp@fafu.edu.cn (S.S.)

² College of Economics and Management, Fujian Agriculture and Forestry University, Fuzhou 350002, China

³ Fuzhou Research Institute of Sustainable Development in Cities Ltd., Fuzhou 350005, China; dwt13115925515@126.com

* Correspondence: clz@fafu.edu.cn

Abstract

The association between urban green space (UGS) and public health represents a core interdisciplinary issue in ecological city construction and the “Healthy China” strategy. However, the underlying mechanisms, contextual constraints, and regional heterogeneity of the impact of UGS on public health at the provincial macro-scale remain insufficiently understood. Existing research primarily examined the health effects of green space at the resident-level micro-scale, with samples often limited to single cities or local urban clusters. Furthermore, limited attention has been paid to the moderating mechanisms and nonlinear threshold characteristics through which green space affects public health. Using panel data from 30 provinces in China from 2012 to 2023, this study empirically investigates the effects, moderating mechanisms, threshold effects, and regional heterogeneity of UGS on public health through two-way fixed-effects ordinary least squares (OLS) regression, moderation models, and threshold regression models. UGS The results show the following: (1) From 2012 to 2023, the overall levels of provincial UGS and public health in China increased, exhibiting a spatial distribution pattern characterized by higher levels in the east and lower levels in the west. (2) The development level of UGSs is significantly and positively associated with provincial public health in China; (3) The health-promoting effects of UGSs exhibit both moderation and threshold characteristics. Environmental regulation, traffic accessibility, and population aging exert positive moderating effects, whereas the level of urbanization exhibits a nonlinear threshold relationship. (4) Regarding regional heterogeneity, the health benefits of green spaces are more pronounced in urban functional zones and coastal regions, whereas key ecological functional zones and major grain-producing areas demonstrate synergies between ecological protection and health improvement. Accordingly, China should strengthen the coordinated advancement of UGS planning and public health protection, optimize the spatial layout of age-friendly green space, improve the supporting environmental regulation systems, and thereby promote the coordinated development of residents’ health and well-being and ecological environmental quality.

Academic Editor: Rebecca Jordan

Received: 17 May 2026

Revised: 20 June 2026

Accepted: 24 June 2026

Published: 27 June 2026

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Keywords: urban green space; public health; population aging; environmental regulation; urbanization

1. Introduction

As a core carrier of both ecological regulation and health promotion, urban green space (UGS) has become a crucial measure for addressing increasing health demands during urbanization. China's urbanization has entered a new stage, characterized by improvements in quality and efficiency. Nevertheless, rapid urbanization has generated serious health challenges and ecological tensions [1]. Furthermore, previous studies have suggested that UGS construction in certain regions may be influenced by "ecological formalism" [2]. Therefore, an in-depth exploration of the relationship between UGS and public health, as well as its underlying constraining factors, is of critical theoretical and practical significance for advancing the high-quality development of Healthy Cities.

Currently, a substantial body of literature has examined the impacts of UGS on health. Existing studies predominantly focus on residents' health at the individual level, while discussions on public health from a macro-perspective remain insufficient. He et al. [3] explored the promoting effects of UGS and greening investment on residents' physical health from the individual perspective. In contrast, Zhang et al. examined the nonlinear effects of UGS on residents' physical and mental health [4,5]. Specifically, green spaces have been proven to reduce the incidence of chronic diseases such as respiratory disorders, cardiovascular diseases, and diabetes [6,7]; in terms of mental health, they exhibit functions including stress alleviation [8], attention restoration [9], improvement in mental state, and enhancement of emotional well-being [10].

From the perspective of public health research, existing studies have mostly focused on key issues such as measurement levels, spatiotemporal evolution, and influencing factors [11–16]. According to the existing literature, individual-level factors such as residents' lifestyles [17], community participation [18], and health literacy [19], as well as social-level factors including environmental quality [20], medical and health services [21], and new-type urbanization [22], are important pathways to improving the level of public health. However, research on the relationship between UGS and public health remains relatively limited. Specifically, Guo et al. [23] empirically found by using a spatial econometric model that there exists not only a spatial synergy effect but also a non-linear threshold relationship based on green space coverage between UGS and public health. Hunter F et al. [24] used Belfast, UK, as the study area and confirmed the long-term positive impacts and co-benefits of urban green space on public health through a natural experiment evaluation. From a sociodemographic perspective, Bressane et al. [25] indicated that UGS construction can positively affect public health, with stronger effects observed in areas with high green space accessibility and greater exposure equity.

Against this background, this study employs panel data from 30 provinces in China covering the period 2012–2023. We construct a regression model with UGS as the independent variable and public health level as the dependent variable to quantitatively examine the public health effects of UGS. Drawing on the moderating-effect model and the threshold-effect model, we explore the moderating roles of population aging, environmental regulation, and transportation accessibility, as well as the threshold effect of urbanization level. We further analyze whether the health benefits of green spaces differ under various constraint conditions and investigate regional heterogeneity in the impacts of UGS on public health from a geographic perspective. The findings of this study can provide theoretical support and a practical reference for the coordinated development of Healthy City construction and ecological environmental governance.

2. Research Hypotheses and Mechanism Analysis

2.1. Research Hypotheses

Direct Impacts of Urban Green Space on Public Health

UGS directly enhances public health through three primary pathways: ecological optimization, behavior guidance, and social interaction. First, from the perspective of ecosystem services, green vegetation effectively purifies the air by reducing pollutants such as PM_{2.5} [26] and minimizing air pollution-induced damage to residents' respiratory and cardiovascular systems [27], while also regulating the local climate to create a more livable environment [28]. Second, based on the Theory of Planned Behavior, the diverse outdoor activity spaces provided by UGS [29] stimulate residents' participation in physical activities and effectively relieve mental stress [30], achieving the coordinated enhancement of physical and mental health. Finally, drawing on Social Capital Theory, UGS serves as an open public platform that promotes harmonious neighborhood relationships [31] and strengthens social cohesion, thereby alleviating loneliness and expanding social support networks. Through these synergistic ecological and social benefits, UGS can comprehensively improve overall public health.

Hypothesis 1. *UGS development has a significant positive impact on public health.*

2.2. Indirect Effects of Urban Green Spaces on Public Health

2.2.1. Moderating Effects

The impact of UGS development on public health may vary with the degree of urban population aging. At a given level of UGS development, an increase in population aging may significantly alter the strength of the association between green space development and public health [32]. Drawing on the Life Cycle Theory, residents' needs differ fundamentally across various life cycle stages. Due to declining physiological functions, the elderly have a greater need for health care and are significantly more sensitive to environmental quality than other groups. The fresh air, low-intensity activity spaces, and quiet surroundings provided by UGSs precisely meet the elderly's core needs for health preservation, rehabilitation, and leisure, effectively alleviating discomfort caused by age-related diseases and improving their quality of life and health status. As a group highly susceptible to environmental resources, the elderly rely more heavily on the ecosystem services provided by green spaces. Their relatively abundant leisure time also leads to significantly higher use of green spaces compared to other groups, thereby fully unlocking the health benefits of green spaces. As the urban aging level rises and the proportion of the elderly population increases, the positive impact of UGS development on public health is further amplified. Based on this, this study proposes the following hypothesis:

Hypothesis 2. *The population aging level plays a positive moderating role in the relationship between UGS development and public health.*

Environmental regulation can influence the quality and effectiveness of UGS development by standardizing and guiding urban development behaviors [33], thereby moderating its role in promoting public health. In line with the Porter Hypothesis, strict environmental regulation can encourage enterprises and urban development entities to optimize resource allocation, reduce pollutant emissions, and prevent pollutant-related damage to green vegetation. This creates a favorable external environment for UGS development, ensuring the stable delivery of ecological functions such as air purification and climate regulation, and thus strengthening the positive impact of green space development on public health. From a public governance perspective, the government fulfills its public

service responsibilities through regulatory measures. Environmental regulation drives cities to incorporate ecological protection and health promotion into their development plans, prompting the government to increase investment in green space development, optimize green space layout, improve supporting facilities, and enhance the quality of green space development. High-quality UGS can more effectively meet residents' health needs, further amplifying the positive effect on public health [34]. Therefore, environmental regulation positively moderates the relationship between UGS development and public health—i.e., the higher the level of environmental regulation, the more pronounced the positive impact of UGS development on public health. Based on this, this study proposes the following hypothesis:

Hypothesis 3. *Environmental regulation plays a positive moderating role in the relationship between UGS development and public health.*

From the perspective of accessibility theory, the extent to which the health effects of public service facilities are realized hinges on the convenience with which residents can access these services [35]. As a key dimension affecting green space accessibility, traffic convenience directly determines the time cost and travel threshold for green space use. When transportation is inconvenient, even high-quality green spaces may be used less frequently due to distance constraints and high travel costs, limiting the full realization of their health benefits, such as air purification and the promotion of outdoor activities. Conversely, improved traffic convenience can reduce barriers to accessing green spaces by enhancing public transportation networks, adding pedestrian walkways, and optimizing cycling systems [36]. This enables residents of all ages and occupations to access green space services conveniently, thereby significantly improving the efficiency of green space utilization. Thus, traffic convenience positively moderates the relationship between UGS development and public health—i.e., the higher the traffic convenience, the more significant the positive impact of UGS development on public health. Based on this, this study proposes the following hypothesis:

Hypothesis 4. *Traffic convenience plays a positive moderating role in the relationship between UGS development and public health.*

2.2.2. Threshold Effect of Urbanization Level

In the initial stage of low urbanization, urban development focuses on industrial expansion and infrastructure construction. During the conversion of agricultural land to urban land, green space planning is often insufficiently systematic, characterized by limited area, fragmented layouts, and single-function use [37]. Consequently, its role in promoting health is severely constrained, and the positive impact remains relatively weak. In the middle stage of urbanization, the agglomeration effect of the urban population becomes prominent, and residents' demands for an ecological environment and healthy living gradually increase. The government begins to increase investment in green space development, leading to steady growth in the quantity of green spaces, a more rational layout, and the gradual emergence of health benefits such as environmental purification and the provision of activity spaces, with the positive impact gradually strengthening. In the advanced stage of urbanization, urban development matures. According to the Environmental Kuznets Curve Theory, the government has sufficient governance capacity to promote the refined development and management of green spaces [38]. Residents' health awareness and the efficiency of green space utilization improve substantially, and the health effects of green spaces are fully unleashed. At this stage, UGS development further improves in response to growing demand for public health, and the marginal health effects

that can be released increase further. Based on this, this study proposes the following hypothesis:

Hypothesis 5. *The impact of UGS development on public health exhibits a non-linear relationship with urbanization level as the threshold, and the positive impact shows a marginal increasing trend with the improvement in urbanization level. The theoretical logical analysis framework of this study is illustrated in Figure 1.*

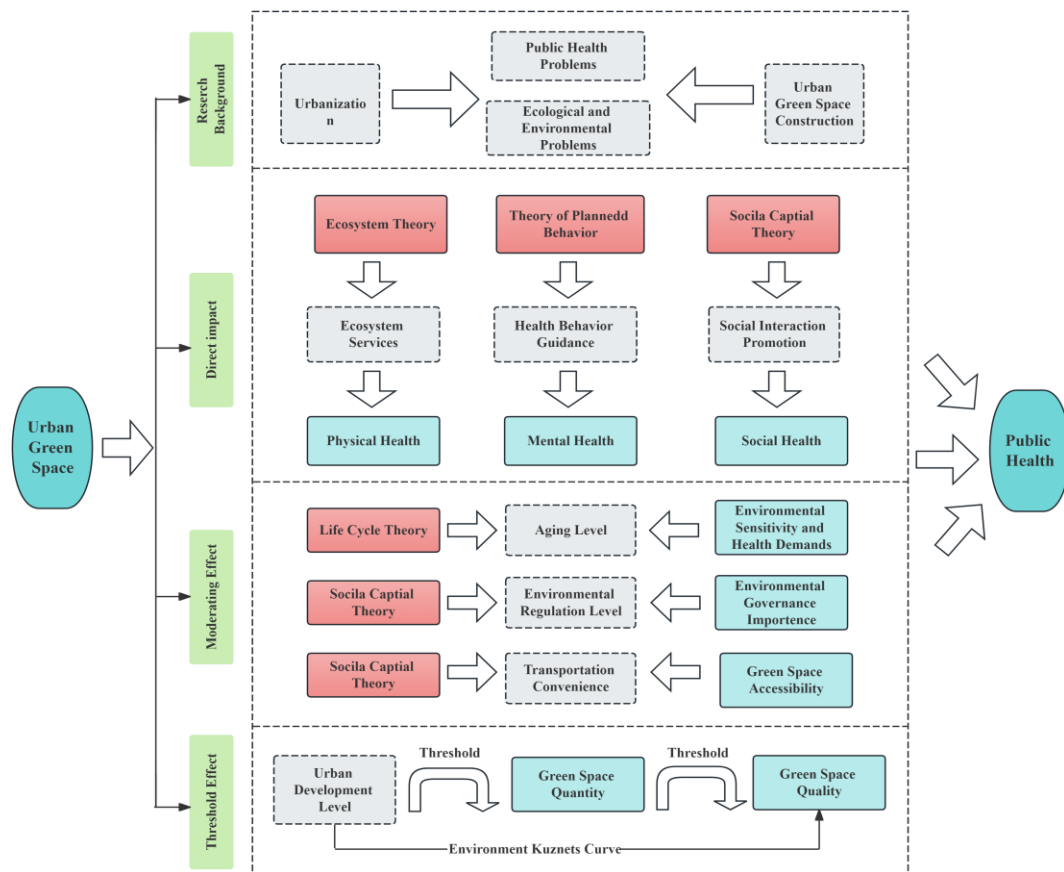


Figure 1. Theoretical Analysis Framework of UGS and Public Health.

3. Materials and Methods

3.1. Variable Definitions

3.1.1. Dependent Variable

Public Health (Health). Following common practice in existing research [15], this paper constructs a public health evaluation index system from three aspects: public health security, environmental exposure risks, and public health benefits. (Table 1) Quantitative assessment is then conducted using the entropy-weighted Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method [39].

Table 1. Public Health Evaluation Indicator System.

Variable Type	Variable Name	Indicator Description	Indicator Property	Source
Public Health Protection	Fiscal Support	Local Fiscal Expenditure on Healthcare (billion CNY)	+	https://www.stats.gov.cn/ accessed on 10 December 2025
	Medical Personnel	Health Personnel Count (persons)	+	https://www.stats.gov.cn/ accessed on 10 December 2025
	Medical Facilities	Number of Hospital Beds (beds)	+	https://www.stats.gov.cn/ accessed on 10 December 2025
Environmental Exposure Risk	Solid Pollutants	General Industrial Solid Waste Emissions (tons)	−	https://www.stats.gov.cn/ accessed on 10 December 2025
	Gaseous Pollutants	Industrial Sulfur Dioxide Emissions (tons)	−	https://www.stats.gov.cn/ accessed on 10 December 2025
	Water Pollutants	Industrial Wastewater Discharge (tons)	−	https://www.stats.gov.cn/ accessed on 10 December 2025
Public Health Benefits	Population Mortality Rate	Annual Deaths/Average Annual Population (%)	−	https://www.nhc.gov.cn/ accessed on 10 December 2025
	Disease Burden Rate	Statutory Report Infectious Disease Incidence Rate (per 100,000)	−	https://www.nhc.gov.cn/ accessed on 10 December 2025
	Maternal Mortality Rate	Annual Maternal Deaths/Annual Live Births (%)	−	https://www.nhc.gov.cn/ accessed on 10 December 2025

3.1.2. Core Explanatory Variable

UGS (Green): Existing studies commonly employ per capita green space area or green coverage ratio to measure UGS levels. However, evidence indicates that the effectiveness of ecosystem services—such as dust retention, sulfur dioxide absorption, and carbon sequestration and oxygen release—depends primarily on the overall scale of green space patches [40]. Although per capita green space and green coverage ratio, as relative indicators, can reflect the spatial distribution characteristics of green space, they are less able to capture the scale effect of total green space on the absolute capacity for air pollutant reduction. To address this, the present study adopts the total UGS area (in ten thousand hectares) of each province as the indicator. This metric corresponds to the aggregate area of park green spaces, production green spaces, protective green spaces, affiliated green spaces, and other green spaces within the built-up areas of cities under the administrative jurisdiction of each province. It provides an intuitive and accurate reflection of the overall scale and spatial supply level of regional urban greening construction and demonstrates strong scientific validity and comparability. The UGS were manually extracted from the China Statistical Yearbook.

3.1.3. Control Variables

To ensure the reliability of the empirical results, this study includes a series of control variables. Based on existing research [41], the following control variables are selected: Industrial Structure (Ind), measured by the proportion of value-added of the tertiary industry to the regional GDP; Population Size (Pop), represented by the logarithm of the total population of each province; Economic Development Level (Eco), represented by the

logarithmic form of per capita regional GDP; Opening-Up (Open), represented by the proportion of total import and export value of goods to regional GDP; Education Level (Edu), represented by the ratio of the number of primary and secondary school students to the number of teachers; Government Intervention (Gov), represented by the proportion of local fiscal general budget expenditure to regional GDP.

3.1.4. Moderating Variables

Environmental Regulation (ER): Using the Peking University Law Database as the search platform, this study systematically compiles data on environmental penalty cases across provinces. After obtaining the raw count, to eliminate the influence of zero values and make the data distribution more stable, a standardized treatment of adding 1 and taking the natural logarithm is applied to the number of regulations in each province. Transportation Convenience (Traffic). Following existing research [36], this is defined as the ratio of the sum of provincial road, railway, and inland waterway mileage to the administrative land area. Population aging (Aging) is represented by the proportion of the population aged 65 and above in the total population. It should be noted that authoritative research shows that the actual relocation intention of the elderly population in China is quite low [41], and that passive relocation, driven primarily by family caregiving, constitutes the vast majority. Therefore, the self-selection bias caused by the active choice of environmental endowments has a relatively limited impact on the measurement of this variable.

3.1.5. Threshold Variable

Urbanization Level (Urban): The nighttime light data for China used in this paper are derived from the long-time-series “DMSP-OLS-like” data published on the Harvard Dataverse platform by the research team led by Shi Kaifang [42]. This dataset integrates DMSP-OLS and SNPP-VIIRS data and, through cross-sensor calibration, yields annual nighttime light intensity data for China from 1992 to 2023 that effectively capture dynamic changes in urbanization levels. Compared with traditional single indicators such as the proportion of urban registered population or the area of built-up areas, the mean nighttime light intensity can comprehensively and objectively reflect the overall dynamics of regional population agglomeration, the intensity of economic and social activities, and the expansion of urban built-up areas. It fully captures the multidimensional nature of urbanization levels and effectively avoids measurement biases arising from differences in administrative statistical caliber.

3.2. Model Specification

To systematically examine the relationship between UGS and public health, this paper employs a two-way fixed-effects OLS regression model for empirical testing. The specific model is as follows:

$$Health_{it} = \beta_0 + \beta_1 Green_{it} + \gamma X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

where $Health_{it}$ represents the public health level of region i in year t , $Green_{it}$ denotes the UGS area of region i in year t , and X_{it} is a set of control variables. β_0 is the intercept term, β_1 is the estimated coefficient of the core explanatory variable, γ is the vector of estimated coefficients for the control variables, μ_i represents region-fixed effects, δ_t denotes time-fixed effects, and ε_{it} is the random disturbance term.

Additionally, this study focuses on the moderating effects of environmental regulation (ER), transportation convenience (Traffic), and population aging (Age) in the process through which UGS influences public health. The following model is constructed:

$$Health_{it} = \alpha_0 + \alpha_1 Green_{it} + \alpha_2 M_{it} + \alpha_3 Green_{it} \times M_{it} + \gamma X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

M_{it} represents the moderating variable, including Environmental Regulation (ER), Transportation Convenience (Traffic), and Population Aging (Aging); $Green_{it} \times M_{it}$ represents the interaction term between the core explanatory variable and the moderating variable, and the other symbols are consistent with the previous Equation (1). Before introducing the interaction term, this study applies a centering treatment to M_{it} and $Green_{it}$ to mitigate the multicollinearity problem.

To investigate the threshold effect of urbanization level (urban), this paper further constructs the following threshold model for the impact of UGS on public health:

$$Health_{it} = \varphi_0 + \varphi_1 Green_{it} \times I(Q_{it} \leq \lambda_1) + \varphi_2 Green_{it} \times I(Q_{it} > \lambda_1) + \varphi_3 X_{it} + u_i + \delta_t + \varepsilon_{it} \quad (3)$$

Where Q_{it} denotes the threshold variable; λ denotes the threshold value to be estimated; $I(\cdot)$ denotes the indicator function, which takes the value of 1 if the condition in the parentheses is satisfied, and 0 otherwise; and the other symbols are consistent with Equation (1).

3.3. Data Sources

This study selects 30 provincial-level administrative regions in China from 2012 to 2023 as research units, excluding Tibet, Hong Kong, Macao, and Taiwan. The data are mainly sourced from the China Statistical Yearbook, the National Bureau of Statistics of China, public data trading platforms, and the Peking University Law Database. All data were manually collected from the above open databases and official government platforms following standard procedures. For data processing, after removing outliers, this study uses linear interpolation to fill partially missing values. Finally, a total of 360 sample observations are obtained for the 30 Chinese provinces during 2012–2023. The descriptive statistics for the variables are shown in Table 2.

Table 2. Descriptive Statistics.

VarName	Mean	SD	Min	Max	Source
Health	0.2748	0.1758	0.0128	0.8703	Refer to Table 1
Green	9.9622	9.3514	0.4000	55.7500	https://www.mohurd.gov.cn/ (accessed on 15 December 2025)
Ind	0.5060	0.0875	0.3446	0.8485	https://www.stats.gov.cn/ (accessed on 15 December 2025)
Pop	8.2112	0.7413	6.3474	9.4498	https://www.nhc.gov.cn/ (accessed on 15 December 2025)
Eco	9.3372	0.4648	8.5984	10.8067	https://www.stats.gov.cn/ (accessed on 15 December 2025)
Open	0.2641	0.2650	0.0076	1.3541	https://www.stats.gov.cn/ (accessed on 15 December 2025)
Edu	0.0705	0.0097	0.0514	0.0940	https://www.stats.gov.cn/ (accessed on 15 December 2025)
Gov	0.2483	0.1015	0.1066	0.6430	https://www.stats.gov.cn/ (accessed on 15 December 2025)
ER	5.5164	2.6117	0.0000	9.8610	https://www.pkulaw.com/ (accessed on 15 December 2025)
Traffic	1.0435	0.5480	0.0940	2.2994	https://www.stats.gov.cn/ (accessed on 15 December 2025)
Aging	0.0106	0.0037	0.0052	0.0222	https://www.nhc.gov.cn/ (accessed on 15 December 2025)

Urban	8.4090	9.9748	0.1227	50.5777	https://dataverse.harvard.edu/ (accessed on 15 December 2025)
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Notes: In the table, “Health” stands for Public Health, “Green” stands for UGS, “Ind” stands for Industrial Structure, “Pop” stands for Population Size, “Eco” stands for Economic Development Level, “Open” stands for Opening-Up, “Edu” stands for Education Level, “Gov” stands for Government Intervention, “ER” stands for Environmental Regulation, “Traffic” stands for Transportation Convenience, “Aging” stands for Population Aging, and “Urban” stands for Urbanization Level. The definitions of all variable abbreviations in subsequent tables are consistent with those in this table.

4. Results

4.1. Typical Case Analysis

Figure 2 illustrates the spatiotemporal evolution of UGS levels in China from 2012 to 2023: the overall green space level exhibits a continuous monotonic upward trend, and the proportion of low-value areas nationwide has significantly decreased. Spatially, areas with high green space coverage are prominently concentrated in the eastern coastal provinces. This spatial pattern aligns with the gradient distribution of regional economic development levels, urban planning investment capacities, and natural climatic conditions. Although some central and western regions still maintain relatively low levels of green space, they exhibit a distinct catch-up effect over time through continuous improvements. This evolution displays clear stage-specific characteristics: UGS experienced a steady increase from 2012 to 2018, followed by a sharp rise from 2018 to 2023. The overall enhancement and spatial transformation likely reflect the significant achievements of China’s recent efforts to advance ecological civilization construction, the further implementation of the “National Forest City” initiative, and the strengthening of synchronized urban ecological space and greening policies across regions.

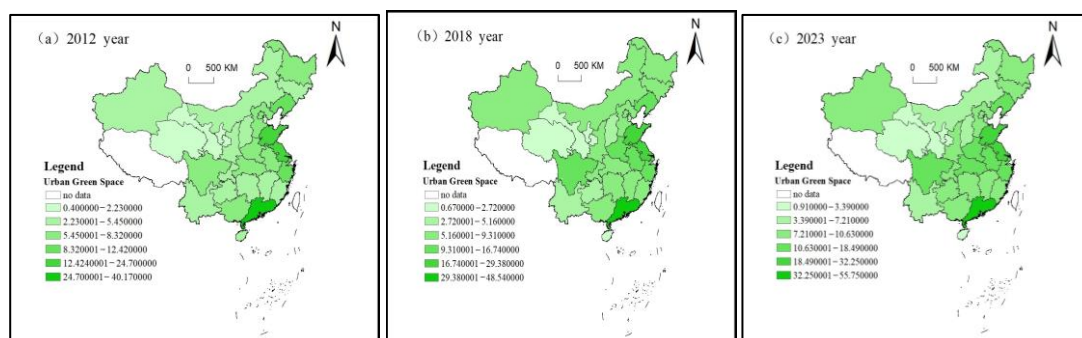


Figure 2. Spatial distribution of UGS across Chinese provinces in different years. Notes: Figures 2 and 3 are based on the standard map GS (2016)2923 issued by the Ministry of Natural Resources, with the original boundaries remaining unchanged.

Figure 3 illustrates that China’s provincial public health levels from 2012 to 2023 exhibited an evolutionary trend characterized by “overall temporal escalation and a spatial pattern of higher levels in the east and lower levels in the west.” From a temporal perspective, the overall level of regional public health shows a sustained and stable upward trend. In 2012, over 70% of provinces nationwide were in the low-public-health-level range, with only a few major eastern provinces, such as Shandong, Henan, and Guangdong, in the high-level range. By 2023, the proportion of provinces in the high-level range reached 26%, the proportion of provinces with medium or above health levels exceeded 60%, and the proportion of provinces with low health levels stabilized at

around 20%. This indicates that China's provincial public health levels have entered a relatively mature stage.

From a spatial perspective, provincial public health levels generally displayed a distribution pattern of “higher in the east, lower in the west, with core agglomerations,” and this overall pattern remained relatively stable. High-public-health-level areas have consistently concentrated in three major regions: the eastern coastal provinces of Guangdong, Jiangsu, and Shandong; the central provinces of Henan and Hubei; and the western province of Sichuan. Leveraging their economic strength and abundant medical resources, these regions have formed high-value clusters. Conversely, low-level areas have long been concentrated in northwestern regions like Ningxia and Qinghai, as well as some remote southwestern provinces. Constrained by their geographical location and factor endowments, these regions have remained at low levels of public health over the long term.

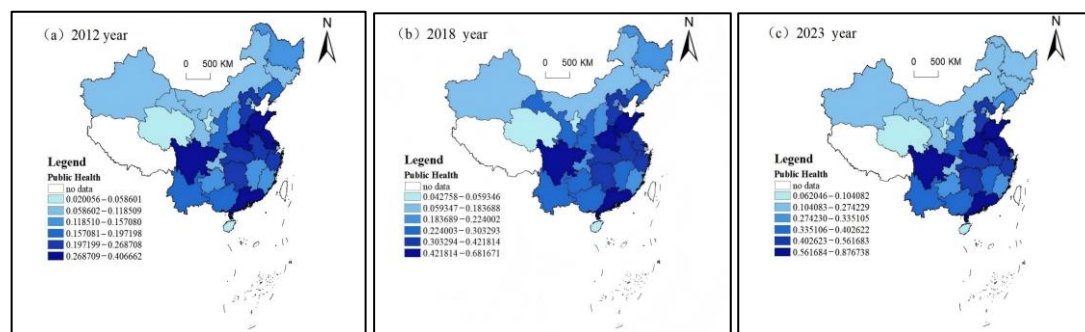


Figure 3. Spatial distribution of provincial public health levels across Chinese provinces in different years.

4.2. Baseline Regression Analysis

To mitigate potential multicollinearity arising from correlations among explanatory variables and their impact on model parameter estimation accuracy, this study employed the Variance Inflation Factor (VIF) to assess multicollinearity. The test results indicate that the average VIF across all variables is 3.78, well below the critical threshold of 10. Therefore, it can be concluded that the empirical model does not suffer from severe multicollinearity problems.

Table 3 reports the estimated impact of UGS on public health. Column (1) includes only the core explanatory variable and year-fixed effects. The result shows that the estimated coefficient for UGS is 0.013, which is significant at the 1% level. Based on Column (1), Column (2) introduces the control variables of this study. The analysis reveals that the estimated coefficient for UGS is 0.0074, significant at the 1% level. Column (3) adds region fixed effects to the specification in Column (2). The result shows the estimated coefficient for UGS is 0.0208, significant at the 1% level. This indicates that for every one-unit increase in UGS area, the provincial public health level increases by approximately 1.9%. Regarding the control variables, the regression coefficients for industrial structure, population density, economic development level, and opening-up are all positive (Column 3) and significant at the 10% level or higher. This suggests that improvements in regional industrial development, population agglomeration, economic growth, and the level of opening-up play an important role in promoting public health. Based on the above analysis, Research Hypothesis 1 of this paper is validated.

Table 3. Baseline regression results of UGS on public health.

	(1)	(2)	(3)
	Health	Health	Health
Green	0.0132 *** (0.0022)	0.0074 *** (0.0010)	0.0208 *** (0.0032)
Ind		0.4694 *** (0.1329)	0.3836 *** (0.1149)
Pop		0.1647 *** (0.0195)	0.2377 (0.1640)
Eco		0.0590 (0.0391)	0.1704 *** (0.0292)
Open		−0.2416 *** (0.0637)	0.0432 (0.0406)
Edu		−2.1991 *** (0.6445)	1.3044 (0.9024)
Gov		0.1052 (0.1440)	0.3120 * (0.1604)
Constant	0.1434 *** (0.0280)	−1.7472 *** (0.4195)	−3.8500 ** (1.4057)
Observations	360	360	360
Region-Fixed	NO	NO	YES
Time-Fixed	YES	YES	YES
Adjusted R2	0.6024	0.9117	0.9801

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Cluster-robust standard errors are reported in parentheses.

4.3. Robustness Checks

To verify the reliability of the baseline regression results, this study conducts robustness tests focused on four aspects, with the results shown in Table 4. First, the dependent variable was replaced: the method of measuring it was altered by re-estimating the indicator system weights using Principal Component Analysis (PCA). The results show that the impact of UGS on public health remains significantly positive at the 1% level, and the direction of the effect is consistent with the baseline regression. Second, to replace the regression model, the sample was split using the k-fold method ($k = 3$), and the Double Machine Learning random forest model was employed for re-estimation. The results indicate that the impact of UGS on public health is significantly positive at the 1% level, highly consistent with the baseline regression results. Third, the research sample was adjusted: after excluding nine national park pilot provinces (Beijing, Jilin, Heilongjiang, Zhejiang, Fujian, Hubei, Hunan, Yunnan, and Qinghai), the impact of UGS on public health remains significantly positive at the 1% level. This suggests that UGS's promoting effect on public health remains robust even after accounting for the influence of special policies. Fourth, to remove outliers, two-way winsorization at the 1st and 99th percentiles was applied to the full sample. The results show that the impact of UGS on public health is significantly positive at the 1% level, again highly consistent with the baseline regression results.

Table 4. Robustness Check Results.

	(1)	(2)	(3)	(4)
	Replacing the Dependent Variable	Replacing the Regression Model	Adjusting the Research Sample	Removing Outliers
Green	Health 0.0604 *** (0.0203)	Health 0.0118 *** (0.0017)	Health 0.0235 *** (0.0026)	Health 0.0201 *** (0.0033)
Control Variables	YES	YES	YES	YES
Constant	22.2809 ** (8.7200)	0.0002 (0.0019)	−4.0051 ** (1.7052)	−3.7754 ** (1.3886)
Observations	360	360	252	360
Region- and Time-Fixed	YES	YES	YES	YES
Adjusted R2	0.9668	—	0.9830	0.9798

Notes: **, and *** denote significance at the 5% and 1% levels, respectively.

4.4. Endogeneity Tests

While robustness checks were conducted above through methods such as replacing the dependent variable and changing the regression model, which to some extent alleviated the issue of selective bias in the empirical analysis, endogeneity problems such as potential reverse causality, omitted variables, and selection bias among the explanatory variables may still exist. To address this, this study employs two approaches to mitigate endogeneity issues. First, a one-period lag is applied to both the core explanatory variable and all control variables. The results are shown in Column (1) of Table 5. The analysis indicates that, under the assumption of lagging the core explanatory variable and all control variables by one period, UGS still significantly improves public health levels at the 1% significance level. Second, the Instrumental Variable (IV) method is adopted. Drawing on the approach of existing research [43], this study constructs an instrumental variable (IV) by interacting the one-period-lagged park green space area with the precipitation data from 1980. This instrumental variable is chosen based on the following considerations: Regarding relevance, the one-period-lagged park green space area is significantly temporally dependent on the current period's UGS area, as green space construction builds upon historical stock. Introducing historical precipitation via the interaction term further enhances the instrumental variable's predictive power for the endogenous explanatory variable. Regarding exogeneity, the 1980 precipitation data are historical natural data that are exogenous to the current error term. The interaction term affects the current period only through historical pathways, and after controlling for fixed effects, it satisfies the exclusion restriction, thereby ensuring the validity of the instrument. As shown in Columns (2) and (3), the C-D Wald F statistic is 134.717, which is higher than the critical value of 16.38. The impact of the instrumental variable IV on UGS is significant at the 1% level; therefore, there is no weak instrument problem. Simultaneously, the *p*-value corresponding to the LM statistic is 0.0131, indicating that the instrumental variable does not suffer from under-identification. In conclusion, after undergoing these two types of endogeneity tests, UGS is still shown to significantly improve public health levels.

Table 5. Endogeneity Test Results.

	(1)	(2)	
	Lagged One-Period Variable Test	Instrumental Variable Test	
	Health	Green	Health
L_Green	0.0199 *** (0.0031)		
IV		0.0480 *** (0.0124)	
Green			0.00295 *** (0.0031)
Control Variables	YES	YES	YES
LM statistic			6.149 **
C-D Wald F statistic			134.717 [16.38]
Observations	330	360	360
Region-Fixed	YES	YES	YES
Time-Fixed	YES	YES	YES
Adjusted R2	0.9826	0.9890	0.5527

Notes: **, and *** denote significance at the 5% and 1% levels, respectively.

4.5. Moderating Effect Analysis

Column (1) reports the test results for the moderating effect of population aging on the process of UGS influencing public health. The analysis indicates that the interaction term between population aging and UGS positively promotes improvements in public health levels at the 1% significance level. This implies that in an aging society, the “health return rate” of investing in UGS is higher. Based on the above analysis, Research Hypothesis 2 of this paper is validated.

Column (2) of Table 6 presents the estimation results for the moderating effect of environmental regulation. The analysis shows that the estimated coefficient of the interaction term between environmental regulation and UGS is 0.0007, which is statistically significant at the 1% level. This indicates that environmental regulation plays a significant positive moderating role in the process by which UGS affects public health, meaning that effective environmental policies can strengthen UGS’s promoting effect on public health. Based on the above analysis, Research Hypothesis 3 of this paper is validated.

Column (3) presents the estimation results for the moderating effect of transportation convenience. The analysis reveals that the interaction term between transportation convenience and UGS has a positive and significant effect on public health at the 5% level. This suggests that transportation convenience plays a significant positive moderating role in the process through which UGS influences public health. In other words, the more convenient the transportation in a region, the higher the accessibility of UGS, and consequently, the more pronounced its health benefits. Based on the above analysis, Research Hypothesis 4 of this paper is validated.

Table 6. Moderating Test Results.

	(1)	(2)	(3)
	Environmental Regulation Fitting Results of Equation (2)	Transportation Convenience Fitting Results of Equation (2)	Population Aging Fitting Results of Equation (2)
	Health	Health	Health
Green	0.0153 *** (0.0037)	0.0140 *** (0.0031)	0.0155 *** (0.0030)
Aging × Green	0.5428 ***		

ER × Green	(0.1566)	0.0007 *** (0.0001)	
Traffic × Green			0.0090 ** (0.0039)
Control Variables	YES	YES	YES
Constant	−2.6730 * (1.3655)	−2.2950 ** (1.0799)	−3.8400 *** (1.0027)
Observations	360	360	360
Region-Fixed	YES	YES	YES
Time-Fixed	YES	YES	YES
Adjusted R2	0.9835	0.9847	0.9829

Notes: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

4.6. Threshold Effect Analysis

According to the theoretical analysis presented earlier, in the process of rapid urban development, UGS has a nonlinear impact on public health. To test this hypothesis, this study employs a threshold panel regression model to examine whether the urbanization level has a threshold effect. The threshold effect test results, based on 500 bootstrap iterations, show: an F-statistic value of 41.41, a *p*-value of 0.022, and a threshold estimate of 22.476. These results indicate that, through the process by which UGS affects public health, the urbanization level exhibits a significant threshold effect.

Further analysis of the regression results in columns (1) and (2) of Table 7 reveals that UGS consistently exerts a significant positive impact on public health, regardless of whether the urbanization level crosses the threshold. However, when the urbanization level exceeds 22.476, this promoting effect becomes more pronounced. This finding supports the study's research hypothesis, namely that the positive impact of UGS on public health strengthens as urbanization increases. Based on the above analysis, Research Hypothesis 5 of this paper is validated.

Table 7. Threshold Test Results.

	(1)	(2)
Urbanization Level Fitting Results of Equation (3)		
	Health	Health
Green (Urban ≤ 22.476)	0.0199 *** (0.0032)	
Green (Urban > 22.476)		0.0733 * (0.0302)
Control Variables	YES	YES
Constant	−3.3790 ** (1.4631)	3.8967 (8.6849)
Observations	324	33
Region-Fixed	YES	YES
Time-Fixed	YES	YES
Adjusted R-squared	0.9834	0.9886

Notes: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

4.7. Heterogeneity Analysis

Given China's vast territory and the distinct geographic locations and development trajectories across its regions, the impact of UGS on public health may be heterogeneous. Therefore, based on the National Major Function Zone Plan, this study categorizes the 31

provinces into three types: Key Ecological Function Zones, Major Grain-Producing Areas, and Urbanized Zones. Concurrently, the sample is divided into coastal and inland regions based on each province's geographical location.

Table 8 presents the results of the heterogeneity regression analysis in this paper. The results in column (1) show that in Key Ecological Function Zones, the estimated coefficient for the impact of UGS on public health is 0.0142, which is statistically significant at the 5% level. This indicates that the achievements in ecological construction in Key Ecological Function Zones can be effectively translated into improvements in people's livelihoods. As a core lever for ecological construction in such zones, the development of UGS cannot only anchor and achieve the core goal of ecological protection but can also tangibly enhance residents' public health levels, successfully realizing a win-win scenario for both ecological and health benefits. From the results in column (2), it is evident that UGS in Major Grain-Producing Areas also has a significantly positive impact on public health at the 1% level. This suggests that, under the core development directive of strictly protecting farmland and ensuring food security, the construction of UGS in these areas can proceed in tandem with grain production. These regions are not limited to grain production alone; the ecological and health-promoting effects of green spaces can still be effectively highlighted even within a development framework that prioritizes farmland. Further analysis of the estimation results in column (3) reveals that the positive enhancing effect of UGS on public health is most prominent in Urbanized Zones, with an estimated coefficient of 0.0297, which is significant at the 1% level. Compared with Key Ecological Function Zones and Major Grain-Producing Areas, green spaces in Urbanized zones exhibit greater magnitude and stronger effects in improving public health. The reason for this is that Urbanized Zones are core areas with a high concentration of population, economy, and various urban service functions. The spatial coverage and accessibility of green spaces can benefit a larger population, and their health-service functions—such as ecological wellness, recreational fitness, and environmental purification—can be more fully realized, thereby demonstrating a public health improvement effect that surpasses that of the other two types of regions.

Table 8. Heterogeneity Test Results.

	(1)	(2)	(3)	(4)	(5)
	KE Zones	MGP Area	U Zones	C Regions	I Regions
	Health	Health	Health	Health	Health
Green	0.0142 ** (0.0059)	0.0142 *** (0.0043)	0.0297 *** (0.0041)	0.0234 *** (0.0037)	0.0133 *** (0.0030)
Control Variables	YES	YES	YES	YES	YES
Constant	−0.5053 (2.3549)	−3.5964 * (1.9238)	−3.0993 (2.2713)	−4.7082 * (2.4955)	−1.4202 (1.1780)
Observations	120	144	96	132	228
Region-Fixed	YES	YES	YES	YES	YES
Time-Fixed	YES	YES	YES	YES	YES
Adjusted R2	0.9832	0.9848	0.9868	0.9810	0.9852

Notes: In the table, “KE Zones” stands for Key Ecological Function Zones, “MGP Areas” stands for Major Grain-Producing Areas, “U Zones” stands for Urbanized Zones, “C Regions” stands for Coastal Regions, and “I Regions” stands for Inland Regions. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Columns (4) and (5) report the impact of UGS on public health from the perspective of geographical location heterogeneity. The analysis results show that the estimated coefficients for the impact of UGS on public health are both significantly positive at the 1%

level in both coastal and inland regions. This indicates that the positive enabling effect of UGS on public health possesses clear geographical universality; its positive role is not constrained by geographical differences between coastal and inland areas and can stably exert its utility in both major regions of China. Further considering the difference in coefficient values, the estimated coefficient for coastal regions is 0.0234, which is notably higher than 0.0133 for inland regions. This suggests that while the positive influence is consistently directed, there is significant heterogeneity in the strength of the effect across locations. UGS in coastal regions yields a higher marginal benefit in terms of health empowerment. This characteristic arises because coastal regions have experienced faster urbanization, have more scientific planning and layout for UGS, and have more complete supporting facilities. Consequently, the health-service functions of green spaces, such as ecological wellness and environmental purification, can be more fully realized, ultimately leading to a stronger public health improvement effect than in inland regions.

5. Discussion

This study finds that UGS has a significant positive effect on public health at the provincial level in China, providing new macro-level evidence for the global literature on urban ecology and public health.

Existing international studies on the health effects of UGS have predominantly relied on community-level cross-sectional data or single-city analyses. For example, recent studies such as those by Belcher et al. [43] focusing on urban England and Wales, and Zhang et al. [44] examining specific urban neighborhoods, have identified the health-promoting and inequality-buffering effects of green spaces at the micro-level. Although these localized studies provide granular insights, their applicability to large-scale regional planning is often limited. Given China's vast territory and the significant disparities in natural resources and socioeconomic conditions across its provinces, few studies have explored this issue at the national level. Using a 12-year macro-level panel dataset covering 30 Chinese provinces, this study goes beyond the geographical limitations of traditional single-city research. It demonstrates the broad relevance and regional heterogeneity of the health benefits of green space at a macro-spatial scale, providing an important macro-level complement to the international literature.

Furthermore, a notable contrast emerges when our findings are compared with international research on urbanization and the benefits of green space. In many developed European and North American countries, urbanization has reached a relatively mature stage, accompanied by well-established green infrastructure. Consequently, in prominent studies focusing on these developed nations—such as the works of Petersen et al. [45] on older adults and Serrano et al. [46] in small- to medium-sized cities, it is generally concluded that the health benefits of green spaces exhibit a stable or linear growth trend. However, China is still undergoing a transitional phase of rapid urbanization. This study shows that, unlike the linear patterns commonly reported in the Western literature, the health-promoting effect of UGS in China exhibits significant nonlinear characteristics. Specifically, when the urbanization coefficient exceeds 22.476, the health-promoting effect of UGS demonstrates a marginal increasing trend. This finding extends the application of the Environmental Kuznets Curve (EKC) to public health, suggesting that in advanced stages of urbanization, more refined urban governance may enable green spaces to generate higher marginal “health returns.”

When exploring the boundary conditions of the health benefits of green space, the international literature—heavily influenced by Western environmental justice paradigms—often focuses on micro-level social demographic attributes. Highly cited works by Rigolon et al. [47] and Wolch et al. [48] emphasize environmental inequities in the United States, focusing primarily on variables such as income, race, and education. In

contrast, grounded in China's dual macro-transition of rapid population aging and ecological civilization construction, this study introduces "environmental regulation" and "population aging" into the model as macro-level moderating variables. The findings reveal that strict environmental regulations implemented by the government can further unleash the health effects of UGS. This not only verifies the Porter Hypothesis at the macro-level but also provides a vital top-down institutional blueprint for countries worldwide. Moreover, the positive moderating effect of the aging level deepens the "Life Cycle Theory," highlighting the universal urgency of creating age-friendly, resilient ecological spaces for vulnerable populations at the national level amid global population aging.

Despite the above contributions, this study encounters certain limitations concerning the selection of the core explanatory variable and causal inference. Although the total area of provincial UGS is adopted, this absolute quantitative metric predominantly reflects the spatial "quantity" of green space provision, largely overlooking its multidimensional attributes. Furthermore, constrained by the statistical scope of the macro-level provincial panel data, several potential confounding factors remain incompletely controlled within the current methodological framework. These unobserved confounders include intra-provincial social inequality driven by economic divergence, the heterogeneous quality of local healthcare systems, dynamic exposure to localized air pollution, and microclimate variations. These intertwined macro- and micro-level variables may exert independent or synergistic impacts on public health.

It is important to note that, from a sociological perspective, the mere physical provision of green space (quantity) does not automatically translate to health benefits. Sociologically, an individual's willingness to engage with UGS is shaped by their neighborhood's social environment and subjective well-being. Although this study employs macro-level provincial data to capture overall scale effects, the underlying micro-mechanism relies heavily on positive sociological attitudes toward green environments, which ultimately mediate the macroscopic health outcomes observed in this study. Therefore, future research can integrate multi-source remote sensing data and micro-level population profile data to explore further intra-provincial heterogeneity in the health effects of UGS, the differential health impacts across various green space types, and the negative externalities associated with transportation facilities. The findings can provide empirical support and serve as references for decision-making in the construction of precision-oriented healthy cities.

6. Conclusions

Using panel data from 30 Chinese provinces spanning 2012–2023 and employing methods such as two-way fixed-effects OLS regression, moderation models, and threshold regression models, this study systematically investigates the impact and mechanisms of urban green space (UGS) on public health. The following core conclusions are drawn:

From 2012 to 2023, the overall level of provincial UGS and public health in China showed an upward trend, with a spatial distribution pattern of "high in the east and low in the west."

Urban green space (UGS) has a significant positive effect on public health. This conclusion holds after robustness tests involving replacing the explained variable, changing the regression model, adjusting the sample, and endogeneity treatment, indicating a statistically reliable positive association. Specifically, after controlling for other variables, a one-unit increase in UGS area can improve the public health level by approximately 1.9%.

The health-promoting effect of UGS exhibits both moderation and threshold characteristics. An analysis of moderating effects shows that environmental regulation, transportation convenience, and population aging all play a positive moderating role in the process of UGS influencing public health: effective environmental policies and convenient

transportation networks can strengthen the health-enabling effect of green space, and in the context of an aging population, the health return on investment in UGS is higher. Threshold effect tests indicate a threshold for urbanization level. When the urbanization level surpasses this threshold (22.746), the promoting effect of UGS on public health significantly strengthens, exhibiting a non-linear characteristic. Heterogeneity analysis reveals that the health effects of UGS exhibit significant regional differences but possess locational universality.

From the perspective of Major Function Zones, the health-enabling effect of green space is strongest in Urbanized Zones. At the same time, both Key Ecological Function Zones and Major Grain-Producing Areas have a significant positive impact on public health, achieving synergy among ecological protection, food security, and health improvement. From a coastal–inland perspective, the health effects of green space in coastal regions are significantly higher than in inland regions, yet both regions exhibit a significantly positive influence, confirming the universality of the effect.

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

Funding: This research received no external funding.

Data Availability Statement: All raw data contained in this study can be provided on demand based on editorial needs. If in doubt, please consult the corresponding author.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflicts of interest.

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