

# More Green Is Not Always Better: The U-shaped Relationship Between Greenspace and Mental Health in China

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## Research Article

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More Green Is Not Always Better: The U-shaped Relationship Between Greenspace and  
Mental Health in China

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**Abstract:**

**Background:** Urban green space is generally documented to improve residents' mental well-being, yet most existing studies confine green space measurement within urban built-up areas, overlooking cross-boundary rural-urban natural exposure and the potential adverse mental outcomes of excessive green expansion. **Methods:** Combining 2016–2018 China Family Panel Studies (CFPS) micro-level individual data with provincial macro-statistics, this study constructed an integrated urban-rural per capita green space index and empirically explored the nonlinear linkage between green space exposure and adult mental health. Two-way fixed-effects regressions and moderation analyses were employed. **Results:** Regressions revealed a robust U-shaped association: moderate greenspace access mitigates depression vulnerability, yet excessive green coverage diminishes and ultimately reverses these

psychological advantages. Mechanism analyses showed that elevated per capita greenspace induced three competing suppressors: inadequate neighborhood amenities, widened gaps between environmental expectations and lived realities, and eroded social cohesion. Heterogeneity tests identified stronger U-shaped gradients among middle-aged groups, males, and occupants of substandard dwellings. Crucially, high crime rates severely attenuated the initial protective effects of greenspace. **Conclusions:** The aggregated adverse impacts of these negative pathways counteract greenspace's direct mental health benefits. Consequently, greening policies should be integrated with targeted community governance and local crime prevention to mitigate hidden safety risks and maximize mental health dividends.

**Keyword:** Green space; Mental health; Depression; Crime; Urban-rural continuum; China Family Panel Studies (CFPS)

## **Background**

When evaluating the impact of environmental factors on human well-being, green spaces stand out as a critical external spatial capital whose beneficial effects on individual mental health have achieved widespread academic consensus across multiple disciplines. Several studies consistently demonstrate that, regardless of whether in dense urban areas or rural hinterlands, long-term exposure to green environments or high-frequency utilization of natural spaces is robustly associated with significantly lower risks of psychological disorders such as depression and anxiety, alongside markedly higher subjective well-being and life satisfaction [1-3]. Moreover, routine visits and active utilization of natural spaces not only build psychological resilience but also lower the demand for psychiatric prescriptions across diverse

populations[1,4,5] .

While the psychological benefits of GS are widely recognized, the precise dose-response relationship between GS exposure and mental well-being remains highly contested. Many early epidemiological studies implicitly assumed a monotonic linear relationship. However, a growing body of evidence indicates that the dose-mental health response curve is better characterized by non-linear quadratic dynamics[1,6,7,8,9]. Crucially, the specific shape of this non-linearity is contradictory across the literature. On the one hand, several studies have identified an inverted U-shaped pattern characterized by diminishing marginal returns. This suggests that a moderate dose of green exposure is the most favorable, whereas excessive exposure yields weakened or declining psychological benefits[6,7,10]. On the other hand, contrasting evidence has observed a U-shaped relationship, where intermediate levels of GS exposure paradoxically correspond to the poorest subjective well-being outcomes[11].

From the perspective of behavioral mechanisms and environmental pathways, the intervention of greenspace on subjective mental states is achieved through a complex composite of mediating pathways. Existing scholarship identifies physical activity promotion, neighborhood social cohesion enhancement, and direct stress restoration as the three foundational pathways linking green environments to mental health outcomes[12,13]. Meanwhile, greenspace may function as an ecological barrier that indirectly mitigates the adverse impacts of external environmental shocks on the central nervous system via noise absorption and air pollution reduction. Empirical consensus regarding this ecological mitigation pathway nonetheless remains divided[12]. Furthermore, residents' subjective environmental perceptions, including aesthetic appeal and perceived safety, serve as critical

determinants of actual greenspace usage frequency and the corresponding magnitude of health returns[14]. This emotional buffering capacity of spatial assets becomes particularly prominent in the context of major exogenous shocks. During the COVID-19 pandemic, for instance, accessible outdoor natural spaces functioned as critical supportive infrastructure to alleviate widespread negative emotions and strengthen population psychological resilience[15,16,17]. Taken together, existing studies have mapped a multi-dimensional mechanistic system covering behavioral, social, ecological and perceptual dimensions, which provides a solid analytical foundation for understanding how green environments exert mental health impacts.

However, recent interdisciplinary literature highlights that massive GS expansion can trigger negative dynamics, most notably green gentrification and socio-economic exclusion. Large-scale urban greening often inflates local housing costs and alters neighborhood demographics, inducing financial stress and disrupting established community ties[18]. This cultural and economic displacement transforms upgraded green areas into exclusionary spaces, thereby deteriorating neighborhood cohesion and preventing vulnerable populations from actualizing psychological benefits[19,20].

Furthermore, expanding green coverage can inadvertently trigger perceptual and environmental side-effects. Evidence indicates that unmanaged or excessively dense vegetation may evoke feelings of insecurity, visual occlusion, and psychological distress rather than restoration[21]. Even in carefully planned green environments, competitive indirect pathways exist where increased visitor-related noise or annoyance offsets direct psychological gains[12]. These perceptual deficits are compounded by spatial and fiscal inequalities[22,23]. Specifically, maintaining vast macro-level green endowments imposes municipal burdens that can crowd

out investments in micro-level community infrastructure. When macroscopic greenery fails to mask micro-level sanitation or facility deficits, an "expectation-reality gap" emerges, worsening residents' subjective environmental perception.

In addition to the characteristics of green spaces themselves, crime rates represent another important contextual factor that may influence the mental health benefits of green space exposure. According to Crime Prevention Through Environmental Design[24] and Prospect–Refuge Theory[25], the physical configuration of urban environments shapes opportunities for crime. Moderate neighborhood greening encourages outdoor activities, promotes social interaction, and strengthens neighborhood cohesion, thereby enhancing natural surveillance and contributing to safer public environments[26,27]. However, excessively dense or poorly maintained green spaces may reduce visual accessibility and perceived environmental safety, discouraging residents from using these spaces and potentially creating conditions conducive to crime[8,16,28]. Such safety-related conditions may substantially weaken the psychological benefits of green spaces, particularly in socioeconomically disadvantaged neighborhoods where unequal access to high-quality green infrastructure further exacerbates environmental health disparities[1,18,23,29]. Nevertheless, although objective crime rates have been recognized as an important contextual factor linking green spaces and mental health[30], limited research has examined whether crime moderates the nonlinear (U-shaped) relationship between green space exposure and mental health, especially within China's urban–rural continuum.

Nevertheless, the mental health benefits of greenspace exposure exhibit pronounced heterogeneity, with effect sizes highly contingent upon spatial configuration, ecological quality,

and typological diversity. Empirical evidence indicates that landscapes featuring high structural complexity, typified by mature tree canopies and rich biodiversity, exert more robust psychological restorative effects relative to structurally simplified green spaces[21,31]. Beyond compositional ecological attributes, the spatial distribution of greenspace fundamentally shapes its health returns. A network of highly accessible, dispersed pocket parks consistently delivers greater stress-alleviating benefits than a single, geographically isolated central park[32]. Collectively, the therapeutic capacity of urban natural environments is jointly determined by their ecological integrity and perceived qualitative attributes, including safety perceptions, supporting amenities, and integrated blue-green spatial elements[28].

Further micro-level evidence indicates that the health returns of greenspace assets are characterized by pronounced non-uniformity across socio-economic strata and demographic groups, revealing specific vulnerability-mitigation mechanisms[23,33]. For children and adolescents, exposure to high-quality natural environments effectively suppresses externalizing behavioral problems while significantly improving attention spans and emotional self-regulation capabilities[34]. Notably, although socio-economically disadvantaged groups reap larger marginal health improvements from greenspace exposure, they are simultaneously far more vulnerable to negative quality shocks; this implies that the unequal spatial distribution of high-quality greenspace resources can endogenously reinforce and exacerbate stratified health inequalities[23,33].

Existing domestic and international studies have conducted extensive empirical research on the relationship between greenspace and residents' mental health, yielding solid empirical findings. Nevertheless, extant literature presents prominent systematic limitations in three

dimensions: spatial perspective, mechanism deconstruction, and empirical data support. In terms of spatial research, most studies focus merely on greenspace within urban built-up areas, artificially breaking the urban-rural green continuum from the perspectives of ecosystems and individual human behaviors[7,35]. This static spatial framework fails to account for the two-way population mobility amid China's urban-rural transformation. It ignores the fact that urban residents often cross administrative boundaries to access suburban wilderness, forest parks, and other natural environments for psychological relief and mental restoration, as well as the daily mobility of rural residents migrating to urban areas. This flaw leads to obvious biases in greenspace exposure measurement and cannot reflect residents' actual exposure to natural environments. Second, in terms of mechanism research, existing studies predominantly verify the positive health effects of greenspace, including anxiety relief, physical activity promotion, social cohesion enhancement, and mitigation of air pollution[9,13,35,36]. However, few studies conduct causal identification and mechanism tests on the negative externalities caused by excessive expansion or over-densification of greenspace, making it difficult to fully depict the complex relationship between greenspace and residents' mental health. In terms of empirical data, most existing studies rely on questionnaires collected at specific time points and in limited regions[7,8,9,35]. Such data lacks sufficient sample representativeness and temporal continuity, and large-scale, nationally representative, long-term panel micro-econometric evidence remains scarce, restricting the reliability and generalizability of existing conclusions. Overall, the limitations in spatial observation scope, positive and negative mechanism testing, and high-quality longitudinal data prevent current research from fully and accurately revealing the complete causal path through which greenspace affects residents'

155 mental health.

156 To address these critical research gaps, this study rigorously investigates the nonlinear (U-  
157 shaped) association between per capita green space coverage and residents' mental health  
158 across China. Combining micro-level longitudinal data from the 2016–2018 China Family  
159 Panel Studies (CFPS) with provincial macro-level green space and public security statistics,  
160 this study constructs a matched micro–macro panel dataset that mitigates the common method  
161 bias prevalent in conventional cross-sectional research.

162 The present study advances existing literature in three notable regards. First, this study  
163 develops an integrated urban-rural per capita green space index. This comprehensive indicator  
164 better captures residents' actual cross-boundary environmental exposure. Second, this study  
165 unpacked the underexamined negative mediating channels. Based on a conditional indirect  
166 effect framework, we examine whether perceived environmental deterioration, insufficient  
167 public amenities, and poor neighborhood act as competitive suppressors that drive the  
168 diminishing marginal returns of green space. Third, by examining the moderating effect of  
169 provincial crime rates, this study demonstrates that the mental health benefits of green spaces  
170 are strongly contingent on local public security conditions. The findings highlight the necessity  
171 of aligning macro ecological interventions with refined micro-level community governance.

## 172 **Methods**

### 173 **Data**

#### 174 *Data Source*

175 This study constructs a matched micro-macro panel dataset by combining CFPS individual

longitudinal data, provincial procuratorial crime statistics, and official green space ecological indicators. Three categories of authoritative data are adopted to ensure empirical accuracy and representativeness.

First, individual-level microdata are derived from the 2016 and 2018 waves of the China Family Panel Studies (CFPS). Hosted by the Institute of Social Science Survey (ISSS) at Peking University, CFPS is a nationally representative longitudinal tracking survey. It adopts a three-stage implicit-stratified Probability Proportional to Size (PPS) sampling design: the primary sampling units (PSUs) are districts and counties, the secondary sampling units (SSUs) are administrative villages and urban communities, and the tertiary (ultimate) sampling units (TSUs) are resident households within selected communities. The baseline survey was launched in 2010, covering 25 provincial-level administrative regions across China, with 14,960 households and 42,590 individual respondents successfully interviewed in the baseline wave.

CFPS applies a unique gene-member tracking mechanism to maintain longitudinal consistency. Gene members identified in the 2010 baseline are permanently tracked regardless of residential relocation or household separation; non-gene family members are interviewed only as long as they maintain household ties with gene members. Each respondent is assigned a unique personal identification code (PID) to enable cross-year tracking of the same individual, ensuring the accuracy of panel data observations. This study uses publicly released anonymized secondary data; the CFPS project implements strict confidentiality protocols to protect respondent privacy, which complies with academic ethical requirements.

This paper specifically selects the 2016 (3rd round) and 2018 (4th round) CFPS waves.

The reason for choosing these two years is that only 2016 and 2018 have complete and non-missing matching data among CFPS individual information, provincial public prosecution statistics, and official green space indicators; subsequent years have variable missing and cannot be matched consistently. The sample is restricted to individuals aged 18 and above, focusing on the mental health of adult residents. The 2016 and 2018 adult questionnaires, subjective attitude modules, and health modules contain complete CESD-8 depressive symptom scores and a full set of demographic, socioeconomic and residential control variables, which perfectly match the research needs.

Second, provincial-level macro indicators are mainly obtained from the official database of the National Bureau of Statistics of China. This includes core explanatory variables and control variables such as per capita green space, per capita GDP, urbanization rate, total public fiscal expenditure, and per capita public safety expenditure. Strictly following national statistical standards: Urban green area refers to all types of land used for landscape and afforestation at the end of the reporting period, including park green space, production green space, protective green space, affiliated green space and other urban green lands. Forest area includes arbor forests and bamboo forests with a canopy closure above 0.2[37], specially designated shrub lands, farmland shelterbelts, as well as tree cover beside villages, roads, rivers and residential settlements. This study sums urban green area and forest area to construct total provincial green space, and further calculates per capita green space by dividing total green space by provincial population. The reason for integrating the two types of green space is solid and theoretically sufficient. First, the official statistical standard breaks the artificial boundary between urban community greening and suburban forest resources, forming a complete urban-

rural green continuum. Traditional research often only focuses on urban built-up green space while ignoring peripheral forest land, which cannot reflect residents' real natural exposure. The combined indicator covers both daily urban leisure greenery and suburban forest recreation spaces, which better reflects residents' actual living environment. Second, with the improvement of transportation and lifestyle mobility, urban and rural residents no longer live in isolated spatial boundaries. Urban residents often go to suburban forests for leisure and vacation, while rural residents also have daily contact with village roadside and farmland forest resources. All green resources jointly form a shared psychological exposure pool affecting individual mental health. Therefore, adopting the sum of urban and forest green spaces can more objectively and comprehensively measure the population's overall exposure to the natural environment.

Third, provincial-level crime rate data are manually compiled from official sources. Specifically, for each province-year, we calculate the provincial crime rate by dividing the number of people prosecuted by the age-specific resident population. For the numerator, we collect the total number of people prosecuted in each province for 2016 and 2018 from the annual work reports of provincial people's procuratorates. We adopt the number of people prosecuted as the proxy for criminal offenses because this indicator is highly correlated with standard criminal justice measures, maintains a uniform statistical caliber across provinces, and is a standard empirical measure in the existing literature[38]. For the denominator, we use age-specific resident population (aged 15+, 16+, or 18+) rather than total permanent population, to align the statistical scope with the legal age of criminal responsibility. All age-specific population data are sourced from provincial statistical yearbooks and official statistical bulletin.

Two caveats apply to the denominator data. First, official age-specific population statistics are unavailable for five provinces (Jilin, Hubei, Xinjiang, Sichuan, and Xizang), so these provinces are excluded from the crime rate-matched sample. Second, the age thresholds of population statistics are not fully consistent across provinces, covering 15+, 16+, and 18+ respectively, which introduces mild measurement heterogeneity. Accordingly, the crime rate variable covers 26 provincial-level administrative regions, while other provincial indicators remain available for all 31 provincial-level regions. Baseline and most supplementary analyses use the full 31-province sample, and only the crime rate moderation analysis is conducted on the 26-province matched sample.

### *Sample Selection*

The analytical sample was constructed according to the following criteria:

1. Adult participants: Respondents were required to be aged 18 years or older.
2. Valid province information: Participants were required to have valid province identifiers so that individual observations could be matched with province-level green space, crime rate, and other macro-level variables.
3. Complete analytical variables: Participants were required to have complete information on the CESD-8 outcome measure and all individual- and province-level covariates included in the empirical models.
4. Survey waves: Participants were drawn from the 2016 and 2018 waves of the China Family Panel Studies (CFPS).
5. Balanced panel observations: Only respondents who were successfully observed in both

survey waves were retained in the final analytical sample.

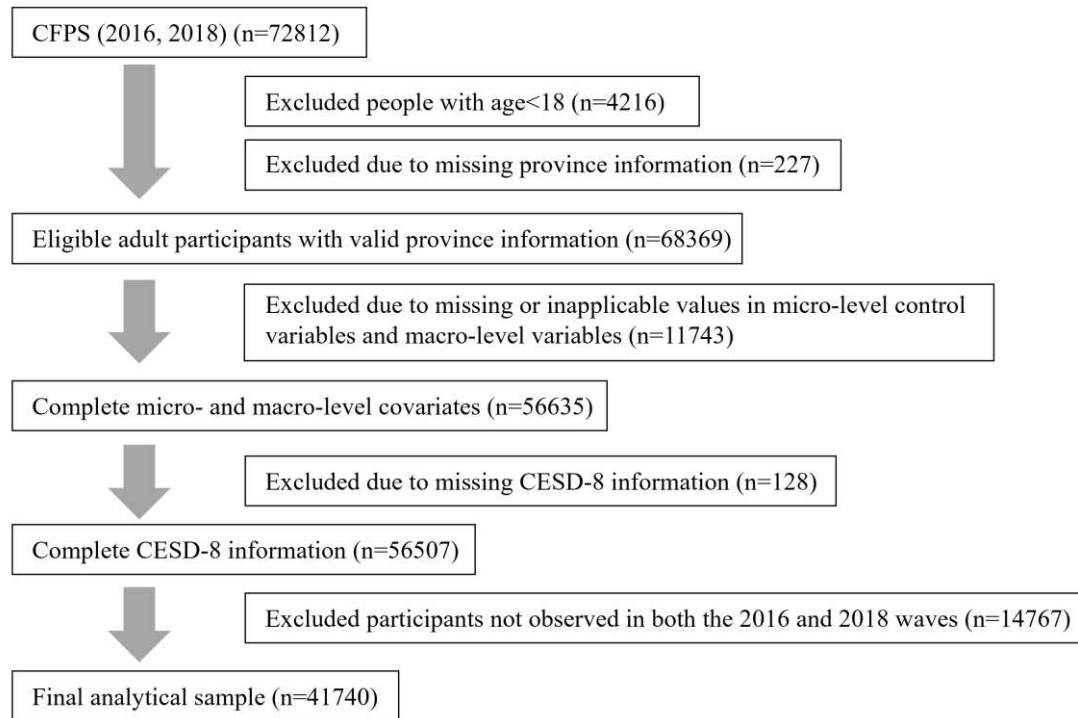


**Figure 1: Flowchart of the sample selection process**

Figure 1 illustrates the sample selection process. Starting from 72812 observations in the 2016 and 2018 CFPS waves, respondents younger than 18 years, those without valid province identifiers, and observations with missing analytical variables were sequentially excluded. To ensure consistency in the panel analysis, only participants observed in both survey waves were retained, yielding a final analytical sample of 41740 person-wave observations.

## **Variable Measurement**

### *Dependent Variables*

The dependent variable of this study is residents' depressive symptoms, measured based

on the 8-item Center for Epidemiologic Studies Depression Scale (CESD-8) from the China Family Panel Studies (CFPS). As a continuous indicator, the CESD-8 score captures respondents' depressive status over the past week, covering affective, somatic, and interpersonal dimensions of depression. Each item is rated on a 4-point scale from 0 (rarely or none of the time) to 3 (most or all of the time), with a total score ranging from 0 to 24. Higher scores indicate more severe depressive symptoms.

In addition, a binary dummy variable Depression is constructed for robustness analysis. Following the standard cutoff criterion for the CESD-8 scale, respondents with a total score of 8 or above are coded as 1 (with clinically significant depressive symptoms), while those with a score below 8 are coded as 0 (without significant depressive symptoms).

## **Independent Variables**

The core independent variable is per capita green space exposure at the provincial level. To ensure numerical stability and mitigate multicollinearity in the regression model, the raw per capita green space variable is scaled to the unit of  $10^{-2}$  ten thousand hectares per capita.

To test the hypothesized U-shaped nonlinear relationship between green space exposure and depressive symptoms, the quadratic term of per capita green space is included in the empirical model. Correspondingly, the quadratic term is scaled to the unit of  $10^{-4}$  ten thousand hectares squared per capita squared, which aligns with the dimension of the linear term and avoids estimation bias caused by differences in variable magnitude.

## *Control Variables*

Following established literature on the determinants of depressive symptoms, this study incorporates a comprehensive set of individual-level and provincial-level control variables to address confounding bias and accurately identify the net effect of green space exposure on depression.

At the individual level, control variables include: age and its quadratic term to account for the potential nonlinear association between age and mental health; gender (coded as 1 for male and 0 for female); educational attainment (coded as 1 for higher education, including associate's, bachelor's and master's degrees and above, and 0 for non-higher education of high school and below); marital status (coded as 1 for married and 0 for unmarried); self-rated health status (coded as 1 for having chronic diseases within the past six months and 0 otherwise); the natural logarithm of per capita household income to correct for the skewed distribution of income data; household size; total household assets measured in million yuan; and residential location (coded as 1 for urban residents and 0 for rural residents).

At the provincial level, control variables include: per capita GDP (ten thousand yuan per capita); urbanization rate (measured in percentage); and the natural logarithm of public fiscal expenditure.

### *Mediating Variables*

To explore the internal transmission mechanisms underlying the U-shaped relationship between green space exposure and depressive symptoms, three mediating variables are selected from the dimensions of environmental perception, community public infrastructure, and neighborhood social interaction. The first is perceived environmental problem severity,

measured by respondents' self-evaluation of local environmental conditions on an 11-point scale from 0 to 10, with higher values indicating more severe perceived environmental problems; this variable serves as the core mediator for the environmental buffering pathway and is also applied in subsequent heterogeneity analysis. The second is Public Facilities, constructed from the CFPS, which asks respondents to rate the overall condition of public facilities such as education, medical care, and transportation around their residential community on a 5-point scale ranging from 1 for very good to 5 for very poor, with higher values representing poorer public facility support. The third is Neighborhood Relations, derived from the CFPS, which investigates respondents' overall perception of neighborhood interpersonal atmosphere in the community, also scored on a 5-point scale from 1 for very good to 5 for very poor, with higher values indicating more strained neighborhood interactions. It should be noted that Neighborhood Relations as a mediator captures the overall community interpersonal environment, which is conceptually distinct from the neighborhood trust variable used for moderation analysis.

### *Moderating Variables*

This study includes four moderating variables to examine the boundary conditions of the green space-depression association from both objective regional context and subjective individual cognition perspectives. The core moderating variable is the provincial crime rate, calculated as the number of criminal cases per 10,000 residents, which objectively reflects the baseline public safety risk of each region and is used to test the moderating effect of public security on the U-shaped relationship. The remaining three moderating variables are applied to

contextual heterogeneity analysis through interaction terms. The first is perceived environmental problem severity, which captures differences in subjective environmental cognition. The second is neighborhood trust, measured by respondents' self-reported trust in neighbors on an 11-point scale from 0 to 10, reflecting the level of neighborhood social capital at the individual level. The third is per capita public safety expenditure, a provincial-level indicator measured in 100 million yuan per capita that reflects the intensity of local government investment in public security construction.

### *Heterogeneity Analysis Variables*

This study conducts heterogeneity analysis through two complementary approaches to comprehensively examine the differential effects of green space exposure across groups and contexts. For subgroup heterogeneity analysis, the full sample is partitioned by three individual characteristics: age cohort, gender, and housing quality. Housing quality is constructed as a binary variable coded as 1 for good quality and 0 for poor quality: unit apartments, villas, and townhouses are categorized as good housing quality, whereas bungalows, traditional courtyard houses, and small low-rise residential buildings are categorized as poor housing quality. Observations of other unspecified housing types are excluded from this subgroup analysis. For contextual heterogeneity analysis, the three aforementioned moderating variables—perceived environmental problem severity, neighborhood trust, and per capita public safety expenditure—are incorporated into interaction term models to explore how the mental health effect of green space varies under different contextual conditions. This two-dimensional analytical framework helps clarify the applicable scope of the core findings and enhances the

practical reference value of the study.

Detailed definitions and assignment rules of all variables used in this study are presented in Table 1.

**Table 1: Definitions of variables**

| Variable                | Definition                                                                                                            |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------|
| CESD-8                  | 8-item depression scale (0-24), higher values mean more severe depression                                             |
| Depression              | Dummy: 1=depressed ( $CESD8 \geq 8$ ), 0=non-depressed                                                                |
| Greenspace              | Per capita green space ( $\times 10^{-2}$ hectares per capita)                                                        |
| Greenspace <sup>2</sup> | Quadratic term of per capita green space ( $\times 10^{-4}$ hectares squared per capita squared)                      |
| Individual Variables    |                                                                                                                       |
| Age                     | Age of respondent ( $\geq 18$ years old)                                                                              |
| Age Squared             | Quadratic term of age                                                                                                 |
| Gender                  | Dummy: 1=male, 0=female                                                                                               |
| Education               | Dummy: 1=Higher Education (Associate's/Bachelor's/Master's+), 0 = Non-higher education (high school and below)        |
| Marital Status          | Dummy: 1=married, 0=unmarried                                                                                         |
| Health Status           | Dummy: 1=Having chronic diseases within the past six months, 0=Not having chronic diseases within the past six months |
| Ln(Income)              | Logarithm of per capita household income                                                                              |
| Family Size             | Household size                                                                                                        |
| Urban                   | Dummy: 1 = urban resident, 0 = rural resident                                                                         |
| Total Asset             | Total household assets (million yuan)                                                                                 |
| Neighborhood Relations  | Community neighborhood relations (1-5), higher values mean poorer neighborhood ties                                   |
| Public Facilities       | Community public facilities (1-5), higher values mean worse facility conditions                                       |
| Environment Perception  | Perceived environmental problems severity (0-10), higher values mean more severe perception                           |
| Neighborhood Trust      | Neighborhood trust level (0-10), higher values mean more trust                                                        |
| Housing Types           | Dummy: 1 = good housing quality, 0 = poor housing quality                                                             |
| Provincial Variables    |                                                                                                                       |
| GDP per capita          | Per capita GDP (ten thousand yuan per capita)                                                                         |
| Urbanization Rate       | Urbanization rate (%)                                                                                                 |

|                                         |                                                                       |
|-----------------------------------------|-----------------------------------------------------------------------|
| Ln(Public Expenditure)                  | Logarithm of public fiscal expenditure                                |
| Crime Rate                              | Province crime rate (per 10,000 residents)                            |
| Public Safety Expenditure<br>per capita | Per capita public safety expenditure (100 million yuan<br>per capita) |

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## Empirical Strategy

To address the research questions and examine the potential non-linear relationship between greenspace and residents' depression, we estimate a series of high-dimensional two-way fixed-effects (TWFE) models. This approach mitigates potential omitted variable bias arising from time-invariant regional heterogeneity and macroeconomic shocks. The baseline econometric specification takes the following quadratic form:

$$\text{Depression}_{ipt} = \beta_0 + \beta_1 \text{Greenspace}_{pt} + \beta_2 \text{Greenspace}_{pt}^2 + \gamma X_{ipt} + \mu_p + \lambda_t + \epsilon_{ipt} \quad (1)$$

Where subscripts  $i$ ,  $p$ , and  $t$  denote individual, province, and year, respectively.  $\text{Depression}_{ipt}$  represents the depressive symptoms score measured by the CES-D 8 scale.  $\text{Greenspace}_{pt}$  and its squared term  $\text{Greenspace}_{pt}^2$  are the key explanatory variables capturing the U-shaped effect of green coverage.  $X_{ipt}$  represents a vector of individual-level and macro-level control variables (e.g., age, sex, education, household income, urban residence, and GDP per capita).  $\mu_p$  denotes province fixed effects to absorb time-invariant regional characteristics, and  $\lambda_t$  denotes year fixed effects to control for nationwide temporal shocks.  $\beta_0$  is the intercept, and  $\epsilon_{ipt}$  is the idiosyncratic error term. To formally validate the U-shaped relationship, we supplement the regression with the exact U-test proposed by Lind and Mehlum[39].

To further unpack the underlying mechanism, we adopt the conditional indirect effect framework[40]. To prevent multicollinearity between the linear and squared terms, the

greenspace variable is first mean-centered ( $Green\_c_{pt}$ ). The mediation models are specified as follows:

$$M_{ipt} = \alpha_0 + \alpha_1 Green\_c_{pt} + \alpha_2 Green\_c_{pt}^2 + \gamma X_{ipt} + \mu_p + \lambda_t + \epsilon_{ipt} \quad (2)$$

$$Depression_{ipt} = \eta_0 + \eta_1 M_{ipt} + \eta_2 Green\_c_{pt} + \eta_3 Green\_c_{pt}^2 + \gamma X_{ipt} + \mu_p + \lambda_t + \epsilon_{ipt} \quad (3)$$

In Eq. (2) and Eq. (3),  $M_{ipt}$  represents the mediating variable (the perceived severity of environmental problems). Because the effect of greenspace on the mediator is non-linear ( $\alpha_1 + 2\alpha_2 Green\_c_{pt}$ ), the indirect effect of greenspace on depression through environmental perception is conditional on the specific level of greenspace. The conditional indirect effect is calculated as  $(\alpha_1 + 2\alpha_2 Green\_c_{pt}) \times \eta_1$ .

To test the statistical significance of the mediation pathway, this paper uses both the Sobel test and the cluster-robust bootstrap method for dual validation:

1. The Sobel test assesses the significance of the baseline linear mediation effect as a preliminary check;
2. The cluster-robust bootstrap with 1,000 replications (clustered at the individual ID level) generates bias-corrected and accelerated (BCa) 95% confidence intervals at three greenspace levels (−1 SD, mean, and +1 SD) to verify the nonlinear conditional indirect effects.

## Statistical Analysis

All statistical analyses were performed using Stata 18.0 (StataCorp LLC, College Station, TX, USA). Descriptive statistics were first computed to summarize the distribution of all study

variables. Categorical variables are presented as frequencies and percentages, while continuous variables are reported as means and standard deviations. To examine the non-linear relationship between greenspace and residents' depression, we employed high-dimensional two-way fixed-effects (TWFE) models estimated using the `reghdfe` command. This approach efficiently absorbs province and year fixed effects to mitigate potential omitted variable bias arising from time-invariant regional heterogeneity and macroeconomic temporal shocks. To formally validate the presence of the non-linear curve, the exact U-test proposed by Lind and Mehlum[39] was applied. Standard errors in the baseline model were clustered at the individual level to account for within-person autocorrelation and heteroskedasticity across survey waves.

Furthermore, given the quadratic specification of the baseline model, the traditional Baron and Kenny framework is inadequate for mechanism analysis. "Instead, mediation effects were tested using the conditional indirect effect framework[40,41], supplemented by manual Sobel tests and cluster-robust bootstrap resampling methods (with 1000 replications at the individual level) to rigorously assess the statistical significance of non-linear indirect effects." Heterogeneity analyses were conducted through two complementary approaches to explore how the greenspace-depression relationship varies across population subgroups and contextual conditions. First, subgroup heterogeneity analysis was performed by stratifying the sample by age groups (18–45, 45–70, and 70+ years old), gender, and housing quality (good vs. poor housing) to examine differences in the U-shaped association across distinct population segments. Second, moderation analysis using interaction terms was implemented to test how three contextual factors, including environment perception, neighborhood trust, and public safety expenditure, moderate the relationship between greenspace exposure and depressive

symptoms. Statistical significance was set at  $p < 0.05$  (two-tailed).

## Results

### Descriptive Statistics

Table 2 presents the descriptive statistics of all variables included in this study, based on the final analytical sample of 41,740 individual-year observations.

**Table 2: Statistical description**

| Variable               | Obs                    | Min      | Max        |
|------------------------|------------------------|----------|------------|
| Categorical Variables  |                        | N(%)     |            |
| Depression             | 41740 (26.7%)          | 0        | 1          |
| Gender                 | 41740 (49.6%)          | 0        | 1          |
| Urban                  | 41740 (48.7%)          | 0        | 1          |
| Housing Types          | 35354 (21.0%)          | 0        | 1          |
| Education              | 41740 (10.7%)          | 0        | 1          |
| Marital Status         | 41740 (83.7%)          | 0        | 1          |
| Health Status          | 41740 (17.7%)          | 0        | 1          |
| Continuous Variables   |                        | Mean(SD) |            |
| CESD-8                 | 5.370(4.025)           | 0        | 24         |
| Greenspace             | 14.835 (13.974)        | 0.883    | 438.709    |
| Greenspace^2           | 415.358<br>(2630.554)  | 0.779    | 192465.587 |
| Age                    | 48.190 (15.484)        | 18       | 95         |
| Age Squared            | 2562.003<br>(1517.342) | 324      | 9025       |
| Ln(Income)             | 9.545 (1.006)          | 0        | 15.243     |
| Family Size            | 4.199 (2.003)          | 1        | 21         |
| Total Asset            | 0.643 (1.607)          | -1.350   | 80.130     |
| GDP per capita         | 5.606 (2.785)          | 2.858    | 16.034     |
| Urbanization Rate      | 59.430 (11.430)        | 31.471   | 89.131     |
| Ln(Public Expenditure) | 8.727 (0.425)          | 7.135    | 9.663      |
| Crime Rate             | 12.387 (3.996)         | 4.949    | 29.761     |
| Public Facilities      | 2.715 (0.918)          | 1        | 5          |
| Neighborhood Relations | 2.159 (0.817)          | 1        | 5          |
| Environment Perception | 6.548 (2.696)          | 0        | 10         |
| Neighborhood trust     | 6.685 (2.135)          | 0        | 10         |

|                                      |               |       |       |
|--------------------------------------|---------------|-------|-------|
| Public Safety Expenditure per capita | 0.725 (0.300) | 0.367 | 3.092 |
|--------------------------------------|---------------|-------|-------|

Approximately 26.7% of the participants met the clinical cutoff for significant depressive symptoms (the binary indicator is defined as CESD-8 score  $\geq 8$ ), indicating a non-negligible prevalence of depressive burden among Chinese adults in the sample. The continuous CESD-8 score had a mean of 5.37 (SD = 4.03), ranging from 0 to 24, reflecting moderate overall symptom severity with substantial variation across respondents.

In terms of sociodemographic and health characteristics, male respondents accounted for 49.6% of the sample, and 48.7% were urban residents. 83.7% of respondents were married, and only 10.7% had received higher education (associate degree or above). Residents living in good-quality housing made up 21.0% of the sample. Regarding physical health, 17.7% of respondents reported having chronic diseases within the past six months.

For the core independent variable, the average per capita green space exposure was 14.84 units (SD = 13.97), with a wide range from 0.88 to 438.71. This large dispersion reflects pronounced regional disparities in green space resource endowment across China. The squared term of per capita green space, which is incorporated to test the hypothesized U-shaped nonlinear relationship, had a mean value of 415.36 (SD = 2630.55).

For individual-level control variables, respondents had a mean age of 48.19 years (SD = 15.48), with ages ranging from 18 to 95. The average household size was 4.20 persons (SD = 2.00). The natural logarithm of per capita household income averaged 9.55 (SD = 1.01). Total household assets showed notable heterogeneity, with a mean of 0.64 million yuan (SD = 1.61) and a range from -1.35 to 80.13 million yuan. At the provincial level, the average urbanization

rate stood at 59.43% (SD = 11.43), per capita GDP averaged 5.61 ten thousand yuan per capita (SD = 2.79), and the natural logarithm of public fiscal expenditure had a mean of 8.73 (SD = 0.43).

For mediating variables used in mechanism analysis, three indicators are included to capture environmental, infrastructural and social transmission paths. The overall rating of community public facilities, scored on a 5-point scale where higher values indicate worse facility conditions, has a mean of 2.715 with a standard deviation of 0.918. The overall rating of community neighborhood relations, also measured on a 5-point scale with higher values representing a poorer interpersonal atmosphere, averages 2.159 with a standard deviation of 0.817. In addition, perceived environmental problem severity, scored on a 0-10 scale, has a mean of 6.548 with a standard deviation of 2.696; this variable serves both as a mediator for the environmental buffering pathway and as a contextual moderator in subsequent heterogeneity analysis.

For moderating and heterogeneity-related variables, the provincial crime rate, which acts as the core moderating variable, averages 12.387 cases per 10,000 residents with a standard deviation of 3.996, objectively capturing cross-regional differences in baseline public safety risks. For contextual heterogeneity analysis conducted via interaction terms, two additional variables are included besides environment perception. Neighborhood trust level, measured on a 0-10 scale where higher values mean more trust, averages 6.685 with a standard deviation of 2.135. Per capita public safety expenditure has a mean of 0.725 hundred million yuan per capita with a standard deviation of 0.300, reflecting the intensity of local government investment in public security.

Overall, the descriptive statistics demonstrate that the sample covers sufficient variation across demographic, socioeconomic, and regional dimensions, as well as key mechanism and moderating variables. This provides a solid empirical foundation for subsequent econometric analysis of the nonlinear association between green space exposure and depressive symptoms, its underlying mechanisms, and heterogeneous patterns.

### **Main Regression Result**

To determine the optimal level for clustering standard errors, we conducted rigorous pre-estimation diagnostic tests on the error structure. First, to account for potential serial correlation within the panel data, we extracted the idiosyncratic residuals from the baseline two-way fixed-effects model and calculated the Pearson correlation coefficient between the 2016 and 2018 residuals for the same individuals. The result indicated a highly significant positive serial correlation ( $r=0.422$ ,  $p < 0.001$ , demonstrating stickiness in individuals' mental health states over time. Consequently, we clustered the standard errors at the individual level (PID) in all baseline models to correct for this within-person autocorrelation and prevent the underestimation of standard errors.

Furthermore, considering the hierarchical structure of our data, where individuals are nested within 31 provinces, we constructed an unconditional random-intercept model (null model) with depressive symptoms as the dependent variable. This model strictly partitions the total variance of depressive symptoms into between-province variance (captured by the province-level random intercept) and within-province variance (captured by individual-level residuals). The results yielded a provincial-level Intraclass Correlation Coefficient (ICC) of

0.0241 (95% CI: [0.0137, 0.0420]), indicating that approximately 2.41% of the total variation in residents' depressive symptoms is attributable to unobserved province-level factors. Given this non-negligible spatial clustering effect, we clustered the standard errors at the provincial level in our robustness checks to ensure the validity and robustness of our statistical inferences.

Table 3 presents the core findings from our empirical analysis, examining the impact of greenspace on residents' depression. Consistent with H1, across all specifications, the coefficients for the linear term of greenspace remain statistically significant and negative, whereas the squared term remains significant and positive. This confirms a U-shaped non-linear relationship between greenspace provision and depressive symptoms.

In our most parsimonious specification, controlling only for province and year fixed effects (Column 1), the linear and squared terms of greenspace are significantly negative and positive, respectively. This non-linear effect persists when accounting for a comprehensive set of individual and macroeconomic controls (Column 2;  $\beta = -0.2407$ ,  $p < 0.01$ ;  $\beta = 0.0006$ ,  $p < 0.01$ ). To verify whether this pattern holds under alternative outcome definitions, Column 3 employs a Linear Probability Model (LPM) using a binary depression indicator. The U-shaped trajectory remains structurally unchanged and statistically significant ( $\beta = -0.0195$ ,  $p < 0.05$ ;  $\beta = 0.0001$ ,  $p < 0.01$ ).

To formally validate this U-shaped relationship, we conducted the exact U-test proposed by Lind and Mehlum (2010) based on the primary specification (Column 2). The test confirms an extreme point at 198.95. Within the valid data range, the marginal effect is significantly negative at the lower bound (Slope = -0.2397,  $p < 0.01$ ) and significantly positive at the upper bound (Slope = 0.2901,  $p < 0.01$ ). The overall test strictly rejects the null hypothesis of a

526 monotonic or inverse-U relationship ( $p = 0.002$ ), confirming the presence of a U-shaped impact.

527

528 **Table 3: Baseline Regression Results (Clustered at Individual Level)**

|                        | (1)<br>CESD-8<br>Fixed Effect | (2)<br>CESD-8<br>Fixed Effect | (3)<br>Depression (LPM)<br>Fixed Effect |
|------------------------|-------------------------------|-------------------------------|-----------------------------------------|
| Greenspace             | -0.1292*<br>(0.0709)          | -0.2407***<br>(0.0844)        | -0.0195**<br>(0.0098)                   |
| Greenspace^2           | 0.0004***<br>(0.0001)         | 0.0006***<br>(0.0002)         | 0.0001***<br>(0.0000)                   |
| Age                    |                               | 0.1145***<br>(0.0099)         | 0.0124***<br>(0.0010)                   |
| Age squared            |                               | -0.0011***<br>(0.0001)        | -0.0001***<br>(0.0000)                  |
| Female                 |                               | -0.8665***<br>(0.0445)        | -0.0736***<br>(0.0048)                  |
| High education         |                               | -0.1776**<br>(0.0692)         | -0.0174**<br>(0.0078)                   |
| Married                |                               | -1.1911***<br>(0.0753)        | -0.1071***<br>(0.0078)                  |
| Health status          |                               | 1.8046***<br>(0.0600)         | 0.1641***<br>(0.0065)                   |
| Ln(Income per capita)  |                               | -0.5226***<br>(0.0269)        | -0.0430***<br>(0.0028)                  |
| Family size            |                               | -0.1238***<br>(0.0121)        | -0.0106***<br>(0.0013)                  |
| Total asset            |                               | -0.0439***<br>(0.0160)        | -0.0045***<br>(0.0017)                  |
| GDP per capita         |                               | -0.0224<br>(0.0735)           | -0.0072<br>(0.0089)                     |
| Urbanization rate      |                               | -0.0090<br>(0.0434)           | -0.0016<br>(0.0053)                     |
| Ln(Public expenditure) |                               | -1.1219<br>(0.7102)           | -0.0535<br>(0.0867)                     |
| Urban                  |                               | -0.2724***<br>(0.0482)        | -0.0246***<br>(0.0052)                  |
| Constant               | 7.0951***<br>(1.0011)         | 23.3006***<br>(6.3146)        | 1.3922*<br>(0.7654)                     |
| R2                     | 0.029                         | 0.108                         | 0.074                                   |
| Controls               | NO                            | YES                           | YES                                     |
| Year fixed effect      | YES                           | YES                           | YES                                     |
| Province fixed effect  | YES                           | YES                           | YES                                     |
| N                      | 47140                         | 41740                         | 41740                                   |

Note: Standard errors clustered at the individual level are in parentheses.

\* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.01

## Mediation Analysis Results

This section examines the mediating mechanisms of environmental perception, public facilities, and neighborhood relations in the nonlinear relationship between greenspace and depressive symptoms. This study adopts the conditional indirect effect framework proposed by Hayes and Preacher[41]. Notably, the greenspace variable is mean-centered to effectively eliminate the multicollinearity between the linear and squared terms and to allow the linear coefficient to represent the marginal effect at the sample's average greenspace level. Due to data availability, the environmental perception pathway is estimated using the full panel dataset with two-way fixed effects, whereas the pathways for public facilities and neighborhood relations are estimated using pooled OLS without province fixed effects to prevent perfect multicollinearity. Regression results for the mediation models are reported in Table 4.

For the environmental perception pathway, Column (1) shows that greenspace is positively associated with environmental perception problems ( $\beta = 0.2243$ ,  $p < 0.01$ ), and the squared term is significantly negative ( $\beta = -0.0003$ ,  $p < 0.1$ ). Column (2) indicates that worse environmental perception significantly increases depressive symptoms ( $\beta = -0.2292$ ,  $p < 0.01$ ). Similarly, greenspace exhibits a significant U-shaped effect on the inadequacy of public facilities (Column 3: linear  $\beta = 0.0041$ ,  $p < 0.01$ ; squared  $\beta = -0.000008$ ,  $p < 0.01$ ) and the deterioration of neighborhood relations (Column 5: linear  $\beta = 0.0016$ ,  $p < 0.01$ ; squared  $\beta = -0.000005$ ,  $p < 0.05$ ). Both inadequate public facilities (Column 4:  $\beta = 0.4930$ ,  $p < 0.01$ ) and poor neighborhood relations (Column 6:  $\beta = 0.7810$ ,  $p < 0.01$ ) are positively associated with depressive symptoms.

**Table 4: Regression Results for Mediation Pathways**

|                             | (1)                    | (2)                        | (3)                         | (4)                        | (5)                       | (6)                        |
|-----------------------------|------------------------|----------------------------|-----------------------------|----------------------------|---------------------------|----------------------------|
|                             | Env.<br>Percepti<br>on | Depressi<br>on             | Public<br>Facilities        | Depressi<br>on             | Neighborho<br>od          | Depressio<br>n             |
| Greenspace<br>(Centered)    | 0.2243*<br>**          | -<br>0.2292**<br>*         | 0.0041***                   | 0.0001                     | 0.0016***                 | 0.0010                     |
|                             | (0.0650)               | (0.0811)                   | (0.0007)                    | (0.0026)                   | (0.0006)                  | (0.0026)                   |
| Greenspace^<br>2 (Centered) | -0.0003*<br>(0.0001)   | 0.0006**<br>(0.0002)       | 0.000008*<br>(0.000002<br>) | 0.000011<br>(0.00000<br>9) | -0.000005**<br>(0.000003) | 0.000012<br>(0.00000<br>8) |
| Env.<br>Perception          |                        | 0.0258**<br>*<br>(0.0079)  |                             |                            |                           |                            |
| Public<br>Facilities        |                        |                            |                             | 0.4930**<br>*<br>(0.0305)  |                           |                            |
| Neighborhood<br>Relations   |                        |                            |                             |                            |                           | 0.7810**<br>*<br>(0.0335)  |
| Constant                    | -4.4280<br>(4.4022)    | 19.9526*<br>**<br>(5.6879) | 3.3190***<br>(0.1899)       | 13.5493*<br>**<br>(0.8163) | 3.1704***<br>(0.1696)     | 12.6882*<br>**<br>(0.8089) |
| R2                          | 0.095                  | 0.108                      | 0.032                       | 0.110                      | 0.011                     | 0.123                      |
| Control<br>Variables        | YES                    | YES                        | YES                         | YES                        | YES                       | YES                        |
| Year Fixed<br>Effect        | YES                    | YES                        | NO                          | NO                         | NO                        | NO                         |
| Province<br>Fixed Effect    | YES                    | YES                        | NO                          | NO                         | NO                        | NO                         |
| N                           | 41559                  | 41559                      | 20861                       | 20861                      | 20857                     | 20857                      |

555 Note: Standard errors clustered at the individual level are reported in parentheses. Models (1)  
556 and (2) utilize two-way fixed effects. Considering that the indicators of public facility  
557 conditions and neighborhood relationships are only available in the 2016 wave of the China  
558 Family Panel Studies (CFPS), we only adopt the cross-sectional data of 2016 for the empirical  
559 analysis of the above mediating variables. Models (3) through (6) utilize pooled OLS without  
560 two-way fixed effects to avoid perfect multicollinearity due to the single-wave availability of  
561 the mediators. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

562

563 To test the significance of these nonlinear conditional indirect effects, a cluster-robust

bootstrap analysis with 1,000 replications (clustered at the individual PID level) is conducted at three levels of greenspace: low (-1 SD), average (mean), and high (+1 SD). The results are summarized in Table 5. The conditional indirect effects of environmental perception, public facilities, and neighborhood relations are consistently positive and statistically significant across all three levels, as all 95% bias-corrected confidence intervals exclude zero.

**Table 5: Conditional Indirect Effects of Environmental Perception, Public Facilities and Neighborhood Relations**

| Mediator                           | Greenspace Level        | Point Estimate | Boot SE | Sobel p-value | 95%Bootstrap CI  |
|------------------------------------|-------------------------|----------------|---------|---------------|------------------|
| Env. Perception<br>(95% CI)        | Low (-1 SD, X=-15.025)  | 0.0060**       | 0.0043  | 0.0183        | [0.0018, 0.0198] |
|                                    | Average (Mean, X=0.000) | 0.0058**       | 0.0036  | 0.0180        | [0.0017, 0.0160] |
|                                    | High (+1 SD, X=15.025)  | 0.0056**       | 0.0029  | 0.0176        | [0.0017, 0.0131] |
| Public Facilities<br>(95% CI)      | Low (-1 SD, X=-15.025)  | 0.0021***      | 0.0004  | < 0.001       | [0.0013, 0.0029] |
|                                    | Average (Mean, X=0.000) | 0.0020***      | 0.0004  | < 0.001       | [0.0014, 0.0028] |
|                                    | High (+1 SD, X=15.025)  | 0.0019***      | 0.0003  | < 0.001       | [0.0013, 0.0026] |
| Neighborhood Relations<br>(95% CI) | Low (-1 SD, X=-15.025)  | 0.0014***      | 0.0018  | 0.0049        | [0.0004, 0.0096] |
|                                    | Average (Mean, X=0.000) | 0.0013***      | 0.0010  | 0.0063        | [0.0003, 0.0053] |
|                                    | High (+1 SD, X=15.025)  | 0.0011***      | 0.0004  | 0.0079        | [0.0003, 0.0020] |

Note: Clustered at individual level (pid); 1,000 bootstrap replications. Bias-corrected 95% confidence intervals are reported. \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.01.

Consequently, environmental perception, community public facilities, and neighborhood relations are identified as suppressor variables. The positive indirect effects of these three pathways partially offset the direct protective effect of greenspace on depressive symptoms. The conditional indirect effects remain stable across different levels of greenspace, confirming the robustness of the nonlinear competitive mediating mechanisms.

### **Moderation Analysis of Crime Rate**

We further investigate how objective regional safety, measured by provincial crime rates, moderates the nonlinear association between green space exposure and depressive symptoms. As reported in Table 6, both the linear and quadratic interaction terms of green space with crime rate are statistically significant.

The linear interaction term (Greenspace  $\times$  Crime Rate) is positive and significant at the 1% level ( $\beta = 0.0068$ ), while the main effect of greenspace remains negative and significant at the 1% level ( $\beta = -0.8165$ ). This pattern indicates that higher regional crime rates attenuate the protective mental health benefits of green space exposure. The quadratic interaction term is negative and significant at the 1% level ( $\beta = -0.0002$ ), showing that elevated crime rates flatten the curvature of the identified U-shaped relationship. The main effect of crime rate is positive and statistically significant ( $\beta = 0.0540$ ,  $p < 0.05$ ), suggesting that higher regional crime exposure is independently correlated with increased depressive symptoms among residents.

All models control for a comprehensive set of individual-level socioeconomic and demographic covariates, as well as province and year fixed effects. The final moderating model yields an  $R^2$  of 0.1092 with a valid analytical sample of 38,134 observations.

| Table 6: Moderating Effect of Objective Crime Rate |                        |
|----------------------------------------------------|------------------------|
| Variables                                          | CESD-8                 |
| Greenspace (Centered)                              | -0.8165***<br>(0.2287) |
| Greenspace <sup>2</sup> (Centered)                 | 0.0154*<br>(0.0081)    |
| Crime Rate                                         | 0.0540**<br>(0.0256)   |
| Greenspace×Crime Rate                              | 0.0068***<br>(0.0022)  |
| Greenspace <sup>2</sup> ×Crime Rate                | -0.0002***<br>(0.0001) |
| Constant                                           | 20.5597***<br>(6.0190) |
| N                                                  | 38134                  |

Note: Standard errors clustered at the individual (PID) level are reported in parentheses. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

## Heterogeneity Analysis

This section examines the heterogeneous effects of green space exposure on depressive symptoms across individual characteristics and contextual factors. For each variable, we employ both subgroup regression and interaction term regression: the former characterizes within-group U-shaped patterns, and the latter formally tests the statistical significance of between-group differences.

## Individual Characteristics

We first stratify the sample by age cohort, gender, and housing quality to examine differences in the U-shaped relationship. Subgroup results are presented in Table 7, and interaction term regressions are used as a complementary robustness check (Table 8).

**Table 7: Heterogeneity Analysis by Subgroup**

| Panel A:<br>Individual<br>Characteristics | 18-45                | 45-70                | 70+                 | Female               | Male                 | Good<br>Housing     | Bad<br>Housing      |
|-------------------------------------------|----------------------|----------------------|---------------------|----------------------|----------------------|---------------------|---------------------|
| Greenspace                                | -0.1745<br>(0.1326)  | -0.7721*<br>(0.3594) | -0.7950<br>(1.0685) | -0.6452*<br>(0.3619) | -0.2196*<br>(0.1161) | 0.7915<br>(0.6573)  | -0.0795<br>(0.1300) |
| Greenspace^2                              | 0.0005**<br>(0.0002) | 0.0059*<br>(0.0033)  | 0.0004<br>(0.0099)  | 0.0042<br>(0.0033)   | 0.0007**<br>(0.0002) | -0.0086<br>(0.0056) | 0.0004*<br>(0.0002) |
| Constant                                  | 15.29*<br>(9.147)    | 35.40**<br>(11.14)   | 19.39<br>(36.08)    | 27.09**<br>(10.27)   | 24.41***<br>(8.771)  | 20.07<br>(15.58)    | 12.24<br>(9.239)    |
| R2                                        | 0.0683               | 0.1406               | 0.1688              | 0.1047               | 0.0938               | 0.0878              | 0.1184              |
| Controls                                  | YES                  | YES                  | YES                 | YES                  | YES                  | YES                 | YES                 |
| Year &<br>Province<br>Fixed Effect        | YES                  | YES                  | YES                 | YES                  | YES                  | YES                 | YES                 |
| N                                         | 16619                | 21593                | 3528                | 21025                | 20715                | 7436                | 27918               |

| Panel B:<br>Contextual<br>Factors | Low Env.<br>Perception | High Env.<br>Perception | Low Trust              | High<br>Trust         | Low<br>Safety<br>Exp.  | High<br>Safety<br>Exp. |
|-----------------------------------|------------------------|-------------------------|------------------------|-----------------------|------------------------|------------------------|
| Greenspace                        | -0.3398**<br>(0.1434)  | -0.1720<br>(0.1219)     | -0.1432<br>(0.1414)    | -0.2949<br>(0.3641)   | 0.0465***<br>(0.0076)  | 0.0012<br>(0.0033)     |
| Greenspace^2                      | 0.0010***<br>(0.0003)  | 0.0004**<br>(0.0002)    | 0.0005***<br>(0.0002)  | 0.0003<br>(0.0033)    | -0.0009***<br>(0.0001) | -0.000002<br>(0.00001) |
| Constant                          | 16.5582<br>(11.4166)   | 27.6957**<br>(9.2796)   | 24.2677**<br>(11.0692) | 24.1512*<br>(10.1780) | 9.1666***<br>(0.6112)  | 13.0496**<br>(0.5259)  |
| R2                                | 0.1280                 | 0.0925                  | 0.1114                 | 0.1019                | 0.0880                 | 0.1116                 |
| Controls                          | YES                    | YES                     | YES                    | YES                   | YES                    | YES                    |
| Year Fixed<br>Effect              | YES                    | YES                     | YES                    | YES                   | YES                    | YES                    |
| Province<br>Fixed Effect          | YES                    | YES                     | YES                    | YES                   | NO                     | NO                     |

| N | 19899 | 21660 | 19366 | 22341 | 19996 | 21744 |
|---|-------|-------|-------|-------|-------|-------|
|---|-------|-------|-------|-------|-------|-------|

Note: The dependent variable is the CESD-8 depression score. Standard errors clustered at the individual level are in parentheses. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

#### *Age Heterogeneity*

Significant age differences are observed in the association between green space exposure and depressive symptoms. Among adults aged 18–45, the linear term of green space is negative but not statistically significant, while the squared term is positive and significant at the 1% level (coefficient = 0.000508,  $p < 0.01$ ). This indicates that the initial protective effect of green space against depressive symptoms is not pronounced among young adults, but the diminishing marginal return of green space is highly significant: the mental health benefit gradually weakens and may even reverse as green space exposure rises to high levels.

For adults aged 45–70, a clear U-shaped relationship is identified. The linear term of green space is significantly negative (coefficient = -0.772,  $p < 0.05$ ), and the positive squared term reaches marginal significance (coefficient = 0.00600,  $p < 0.10$ ), suggesting that green space alleviates depressive symptoms at moderate levels but its protective effect diminishes as exposure increases. No statistically significant association is detected among adults aged 70 and above, which may be explained by the smaller sample size and age-specific patterns of daily activity and mental health formation in the elderly population.

This age heterogeneity reflects differences in daily activity patterns and green space usage across life stages. For young adults aged 18–45, green space is often integrated into social and recreational activities rather than serving as a dedicated stress-relief channel, so its baseline protective effect is less distinct. However, excessive green space with high visitor density may bring about crowding and noise, which erode the mental health benefits and result in a

significant diminishing marginal effect. For middle-aged adults aged 45–70, who typically face peak work and family pressures, moderate green space acts as a highly effective stress buffer, generating a strong initial protective effect. Meanwhile, the high opportunity cost of time for this group makes remote, large-scale green spaces less accessible and less rewarding, leading to a notable U-shaped pattern.

Interaction analysis further confirms that the moderating effect of age on the U-shaped relationship is statistically significant at the 1% level (Table 8), lending formal statistical support to the age heterogeneity pattern observed in subgroup regressions.

#### *Gender Heterogeneity*

The effect of green space exposure on depressive symptoms differs notably between males and females. For females, green space exposure exerts a significant linear protective effect (coefficient = -0.645,  $p < 0.10$ ), while the quadratic term does not reach statistical significance. This indicates that higher green space exposure is consistently associated with lower depressive symptoms among female respondents, with no evident diminishing marginal effect within the observed range.

In contrast, males exhibit a significant U-shaped relationship between green space and depressive symptoms. The linear term is negative and marginally significant (coefficient = -0.220,  $p < 0.10$ ), and the squared term is positive and significant at the 1% level (coefficient = 0.000655,  $p < 0.01$ ), confirming that the protective effect of green space weakens gradually at higher exposure levels.

This gender difference may stem from variations in green space usage patterns and mental

health needs. Females tend to use green spaces for emotional regulation, casual socializing and relaxation, which delivers steady and sustained mental health benefits and forms a linear protective pattern. Males, by contrast, engage in more diverse green space activities including competitive sports and solitary recreation. When green space exposure exceeds a certain level, issues such as overcrowding and reduced perceived safety become more prominent, diminishing the mental health returns and forming a U-shaped association.

The interaction term for the quadratic term is marginally significant (Table 8), indicating that the difference in curve curvature between males and females is weakly statistically significant, consistent with the subgroup findings.

#### *Housing Quality Heterogeneity*

Marked differences are found between residents in good-quality and poor-quality housing. No significant association between green space exposure and depressive symptoms is observed among residents living in good-quality housing, with neither the linear nor the quadratic term reaching conventional significance levels.

For residents in poor-quality housing, the linear term of green space is negative but statistically insignificant, while the squared term is positive and marginally significant (coefficient = 0.000387,  $p < 0.10$ ). This suggests that low-level green space exposure has no significant alleviating effect on depressive symptoms, while excessive green space is marginally associated with elevated depressive symptoms.

This heterogeneity may reflect disparities in neighborhood governance, green space maintenance and perceived safety across housing groups. Residents in poor-quality housing

often reside in socioeconomically disadvantaged neighborhoods, where large-scale green spaces may be accompanied by inadequate maintenance, poor lighting, higher perceived safety risks and social isolation, which may offset or even outweigh the health benefits of green space. In contrast, residents in good-quality housing generally live in well-managed neighborhoods with comprehensive supporting facilities, and their mental health is shaped by multiple favorable living conditions, making the independent effect of green space less detectable.

Interaction analysis further shows that the moderating effect of housing quality is statistically significant at the 5% level (Table 8), verifying that the gap in green space mental health returns between the two groups is not driven by sample randomness.

**Table 8: Heterogeneity Analysis by Interaction Effects**

| Panel A: Individual Characteristics    | Age                         | Gender                 | Housing Quality           |
|----------------------------------------|-----------------------------|------------------------|---------------------------|
| Greenspace                             | -0.3044***<br>(0.0856)      | -0.2498***<br>(0.0843) | -0.1705*<br>(0.0959)      |
| Greenspace^2                           | 0.0008***<br>(0.0002)       | 0.0007***<br>(0.0002)  | 0.0005**<br>(0.0002)      |
| Greenspace × Age                       | 0.0009***<br>(0.0001)       |                        |                           |
| Greenspace^2 × Age                     | -0.000002***<br>(0.0000007) |                        |                           |
| Greenspace × Gender                    |                             | -0.0008<br>(0.0039)    |                           |
| Greenspace^2 × Gender                  |                             | -0.00003*<br>(0.00001) |                           |
| Greenspace × Housing Quality           |                             |                        | -0.0309**<br>(0.0121)     |
| Greenspace^2 × Housing Quality         |                             |                        | 0.0005**<br>(0.0002)      |
| R2                                     | 0.1091                      | 0.1078                 | 0.1158                    |
| Controls                               | YES                         | YES                    | YES                       |
| Year & Province Fixed Effects          | YES                         | YES                    | YES                       |
| N                                      | 41740                       | 41740                  | 35353                     |
| Panel B: Contextual Factors            | Perceived Env. Problems     | Neighborhood Trust     | Public Safety Expenditure |
| Greenspace                             | -0.2134**<br>(0.0857)       | -0.2535***<br>(0.0839) | 0.0244**<br>(0.0111)      |
| Greenspace^2                           | 0.0005***<br>(0.0002)       | 0.0006***<br>(0.0001)  | -0.0004***<br>(0.0001)    |
| Greenspace × Env. Perception           | -0.0021***<br>(0.0007)      |                        |                           |
| Greenspace^2 × Env. Perception         | 0.000009**<br>(0.000003)    |                        |                           |
| Greenspace × Neighborhood Trust        |                             | -0.0010<br>(0.0009)    |                           |
| Greenspace^2 × Neighborhood Trust      |                             | 0.000008<br>(0.000005) |                           |
| Greenspace × Public Safety Expenditure |                             |                        | -0.0128<br>(0.0127)       |

Greenspace<sup>2</sup> × Public Safety  
Expenditure 0.0001\*\*\*

|                        |        |        | (0.0001) |
|------------------------|--------|--------|----------|
| R2                     | 0.1081 | 0.1271 | 0.0992   |
| Controls               | YES    | YES    | YES      |
| Year Fixed Effects     | YES    | YES    | YES      |
| Province Fixed Effects | YES    | YES    | NO       |
| N                      | 41559  | 41707  | 41740    |

Note: The dependent variable is the CESD-8 depression score. Standard errors clustered at the individual level are in parentheses. \*p < 0.1, \*\*p < 0.05, \*\*\*p < 0.01

### Contextual Factors

Beyond the core structural moderation of the objective crime rate discussed in Section 3.4, we further investigate how environmental perception, neighborhood trust, and public safety expenditure moderate the U-shaped association. We take interaction term models as the primary analytical approach, supplemented by median-split subgroup regressions. Full results are reported in Table 8 and Table 7.

#### *Environment perception*

Environment perception significantly moderates the U-shaped relationship between green space exposure and depressive symptoms. The linear interaction term between green space exposure and perceived environmental problems is negative and significant at the 1% level (coefficient = -0.0021, p < 0.01), indicating that the initial protective effect of green space against depressive symptoms is stronger among individuals who perceive more severe environmental problems. The quadratic interaction term is also positive and significant at the 5% level (coefficient = 0.000009, p < 0.05), suggesting that the diminishing marginal return of green space is more pronounced for respondents with higher environmental problem perception,

and the adverse effect of excessive green space emerges more clearly.

This moderation pattern implies that green space acts as a buffer against the negative mental health impacts of poor environmental conditions. For individuals living with high perceived environmental stress such as pollution and noise, access to green spaces provides a critical restorative refuge that effectively alleviates psychological stress. However, when green space exceeds a reasonable scale, issues such as insufficient maintenance, poor accessibility, and overcrowding may exacerbate mental health burden more noticeably for groups that are already sensitive to environmental quality.

When dichotomized by the sample median, the U-shaped curve appears steeper in the low-perception group (Table 7). This discrepancy partly stems from systematic differences in green space endowment between the two groups; the continuous interaction model, which isolates the net moderating effect, provides a more rigorous identification.

### *Neighborhood Trust*

Existing literature generally posits that neighborhood trust strengthens the mental health benefits of green space, as higher social cohesion facilitates positive social interactions in public green spaces and amplifies their restorative effects[42]. Contrary to this theoretical expectation, however, this study finds no statistically significant moderating effect of neighborhood trust on the U-shaped relationship between green space exposure and depressive symptoms. Neither the linear nor the quadratic interaction term reaches conventional significance levels, indicating that the mental health returns of green space do not systematically differ between residents with high and low neighborhood trust.

This finding suggests that the depressive-alleviating effect of green space in China is primarily driven by its natural restorative properties, rather than its role in fostering neighborhood social interaction. For Chinese urban residents, green space use is typically oriented toward individual leisure, exercise, or stress relief, rather than informal neighborhood socializing. As a result, the level of neighborhood trust does not significantly alter how residents experience and benefit from green environments. This result complements the existing literature by identifying the boundary condition of the social capital pathway in the green space–health relationship, and highlights the dominance of the environmental restoration mechanism in the Chinese context.

Subgroup analysis stratified by median neighborhood trust yields consistent results: there is no substantive difference in the U-shaped pattern between high- and low-trust groups (Table 7), further confirming that neighborhood trust does not significantly moderate the mental health returns of green space.

#### *Public Safety Expenditure*

Public safety expenditure significantly moderates the nonlinear association between green space exposure and depressive symptoms, with its moderating effect mainly reflected in the curvature of the U-shaped relationship. The linear interaction term between green space and per capita public safety expenditure is not statistically significant (coefficient = -0.0128,  $p > 0.10$ ), indicating that the initial protective intensity of green space does not vary significantly with the level of public safety investment. In contrast, the quadratic interaction term is positive and significant at the 1% level (coefficient = 0.0001,  $p < 0.01$ ), slows down diminishing

marginal returns and delays the arrival of the inflection point.

This finding suggests that public safety measures shape the green space–mental health relationship mainly by extending the effective benefit range of green spaces rather than amplifying the basic health benefits of green space. In areas with high public safety expenditure, residents have a stronger willingness to use public green spaces and higher usage frequency, which postpones the saturation point of mental health benefits. That is, improved public safety unlocks the accessibility of green space, but it also makes the law of diminishing marginal returns more obvious, rather than simply strengthening the protective effect of green space in a linear manner.

Subgroup regression results are fully consistent with the interaction findings: the inverted-U curve is steep in the low-expenditure group and nearly flat in the high-expenditure group (Table 7), verifying that higher public safety expenditure weakens the nonlinear curvature.

## **Robustness Test**

To verify the reliability and validity of the baseline U-shaped relationship between green space exposure and depressive symptoms, a set of systematic robustness tests are conducted, and the corresponding results are presented in Table 9.

First, we address the potential bias caused by extreme outliers by winsorizing the core green space variable at the 1st and 99th percentiles. As shown in Column (2), after adjusting for extreme values, the linear term of green space remains significantly negative (coefficient = -0.627,  $p < 0.05$ ), confirming that the protective effect of green space against depressive symptoms is not driven by abnormal observations. The quadratic term retains a positive sign

but is no longer statistically significant, indicating that extreme values partly amplify the nonlinear U-shaped pattern. Even so, the core negative association between green space and depressive symptoms remains stable.

Second, we adopt an alternative clustering strategy to test the stability of statistical inference. The baseline specification clusters robust standard errors at the individual level to account for serial correlation of residuals in the panel data structure. As a robustness check, we re-estimate the model with standard errors clustered at the provincial level. The results in Column (3) show that the magnitudes of both the linear and quadratic coefficients are identical to the baseline estimates, and both remain statistically significant at the 1% level. This confirms that the main findings are not sensitive to the choice of clustering level.

Overall, the core U-shaped association between green space exposure and depressive symptoms remains largely stable across the two robustness strategies. While the nonlinear curvature weakens after excluding extreme values, the direction and significance of the main protective effect, as well as the U-shaped pattern under alternative clustering, consistently support the credibility of the baseline findings.

**Table 9: Robustness Checks**

|                              | (1) Baseline<br>OLS  | (2) Winsor 1%       | (3) Cluster<br>Province |
|------------------------------|----------------------|---------------------|-------------------------|
| Greenspace                   | -0.241***<br>(0.084) | -0.627**<br>(0.249) | -0.241***<br>(0.079)    |
| Greenspace^2                 | 0.001***<br>(0.0002) | 0.004<br>(0.002)    | 0.001***<br>(0.0001)    |
| R2                           | 0.108                | 0.108               | 0.108                   |
| Controls                     | YES                  | YES                 | YES                     |
| Year & Province Fixed Effect | YES                  | YES                 | YES                     |

|     | N                                                                                                 | 41740 | 41740 | 41740 |
|-----|---------------------------------------------------------------------------------------------------|-------|-------|-------|
| 796 | Note: *p<0.01, **p<0.05, ***p<0.10. Robust standard errors are in parentheses. Column             |       |       |       |
| 797 | (1) presents the baseline OLS results with individual-level clustered standard errors. Column     |       |       |       |
| 798 | (2) uses the 1%-99% winsorized green space variable to address extreme value bias. Column         |       |       |       |
| 799 | (3) reports results with province-clustered standard errors. All specifications include province- |       |       |       |
| 800 | year fixed effects and a full set of control variables.                                           |       |       |       |

## Discussion

## Findings

Using matched micro–macro CFPS datasets, this study departs from the conventional linear specification of environmental well-being effects[43] and delivers refined evidence regarding the nonlinear impacts of greenspace on mental health and its underlying mechanisms from environmental, infrastructural and social dimensions. Three key empirical results emerge as follows:

First, the baseline results strongly support a robust U-shaped non-linear relationship between per capita greenspace exposure and residents’ mental health condition. Moderate greenspace provision effectively alleviates depression, serving as a vital restorative environment. However, this protective effect diminishes and eventually reverses as greenspace expands to excessive levels. This finding challenges the prevalent “more is better” notion in urban greening policies[44,45], and is consistent with emerging research suggesting that the negative externalities of ecological gentrification, public safety hazards, and spatial mismatch can structurally offset the initial psychological relief provided by nature.

Second, the analysis identifies three competitive suppressor mediators that drive the nonlinear pattern, namely environmental perception, public facilities, and neighborhood relations. The environmental perception pathway reveals that higher green space coverage is

associated with greater perceived severity of environmental problems, which may stem from the expectation-reality gap between macro ecological endowments and micro community sanitation deficits[46]. In terms of the infrastructural pathway, high per capita green space may also reflect regional disparities in economic development and infrastructure provision, where abundant natural resources coexist with limited community public facilities[47-49]. For the social pathway, urban sociology and built environment research consistently indicate that the spatial dispersion and lower population density inherently associated with high per capita open space can significantly reduce the probability of incidental daily encounters, thereby eroding routine neighborhood interactions and social cohesion[26,27,50]. The negative indirect effects generated through these three pathways partially offset the direct protective benefits of green space, and jointly contribute to the upward slope of the U-shaped curve at high exposure levels.

Third, moderation analyses demonstrate that the mental health benefits of green space are further conditioned by objective neighborhood safety. Specifically, higher crime rates significantly weaken the initial protective effect of green space on depressive symptoms, suggesting that favorable natural environments alone are insufficient to generate psychological benefits when accompanied by unsafe social conditions[30]. This finding supports previous research showing that the restorative value of green space depends not only on ecological characteristics but also on the surrounding social environment [1,8,30]. Interestingly, higher crime rates also flatten the upward slope of the U-shaped relationship, indicating that crime moderates both the initial benefits and the subsequent nonlinear trajectory of green space exposure. From the perspective of Crime Prevention Through Environmental Design (CPTED), unsafe neighborhood environments reduce natural surveillance and discourage residents from

actively using public spaces[24], while Prospect–Refuge Theory further suggests that environments characterized by limited visibility and increased concealment influence individuals' safety perceptions and behavioral responses[25]. Consequently, elevated crime may suppress residents' interactions with nearby green spaces across all exposure levels, thereby reducing both the psychological benefits of moderate greenness and the nonlinear rebound observed at higher levels of green space exposure. Together, these findings identify objective public safety as an important contextual boundary condition shaping the nonlinear relationship between green space and mental health[30].

Fourth, heterogeneity analyses demonstrate that the mental health effects of green space are highly context-dependent[51]. We examine this heterogeneity across individual factors and contextual factors, with both subgroup regressions and interaction term models adopted for cross-validation. For individual factors, the U-shaped dynamic is most prominent among middle-aged adults (45–70), while young adults (18–45) only show significant diminishing marginal returns, and no significant association is observed among adults aged 70 and above. Males present a significant U-shaped relationship, whereas females exhibit a consistent linear protective effect. For housing quality subgroups, the adverse marginal effect of excessive green space is marginally significant among residents in poor-quality housing, while no significant link is detected among those in good-quality housing. Interaction term regressions further confirm that the between-group differences in age and housing quality are statistically significant, and the gender difference in curve curvature reaches marginal significance, formally supporting the subgroup findings. For contextual factors, first, interaction analyses reveal that stronger perceived environmental problems amplify both the initial protective effect

and the diminishing marginal returns of green space. Subgroup regressions based on median splits yield consistent core conclusions, with minor differences in estimated curvature driven by systematic variations in green space endowment across groups. Second, neighborhood trust shows no statistically significant moderating effect. Subgroup analysis stratified by median trust level corroborates this finding, with no substantive difference in the nonlinear pattern between high- and low-trust groups. Third, higher public safety expenditure flattens the inverted-U curve and delays the onset of diminishing marginal returns, without significantly altering its baseline protective intensity. Subgroup results are fully consistent with the interaction findings: the inverted-U pattern is pronounced in the low-expenditure group and nearly flat in the high-expenditure group. This underscores the complementary relationship between formal public safety measures and the mental health benefits of green spaces, especially in disadvantaged living environments.

However, although all estimated coefficients are statistically significant, the model yields modest effect magnitudes and limited explanatory power, with an R-squared of approximately 0.11. This finding suggests greenspace exposure is merely one determinant of adults' depressive conditions. Low  $R^2$  statistics are typical within large-sample microeconomic and epidemiological studies, as mental health outcomes are jointly determined by a broad set of observable and unobservable individual, genetic and socioeconomic covariates. Even with modest effect sizes, the results identify a statistically robust, replicable non-linear linkage between green space and mental health across the sampled population.

## **Limitations and Future Research**

First, from the spatial measurement perspective, integrating urban greenspace and forest area enables innovative characterization of the urban-rural green continuum, yet this macro-level aggregated indicator remains overly coarse[52]. Official forest statistics include not only easily accessible suburban forest parks and rural recreational green land but also extensive remote wilderness unavailable for daily or weekend leisure activities. Accordingly, the existing measure fails to capture actual interactions between urban residents and peripheral natural resources[53]. Future research can refine crude administrative aggregation by categorizing cross-boundary green infrastructure into detailed types such as suburban parks, national forest parks and rural-specific green spaces. Meanwhile, introducing granular accessibility indicators—including real travel distance, commute time and transportation connectivity between downtown areas and rural green fields—can achieve more precise quantification of residents' actual cross-regional nature exposure[54].

Second, this study identifies environmental perception, public facilities, and neighborhood relations as key suppressor mediators, whereas core socioeconomic and environmental drivers of such mechanisms are only indirectly inferred. The theoretical framework attributes the suppressor effects to compromised natural surveillance, expectation disconfirmation, and spatial mismatch. Restricted by data availability, however, the current analysis relies on provincial-level public prosecution statistics and respondents' self-reported perception, lacking matched neighborhood-specific objective metrics. Additionally, the provincial crime rate indicator adopted in this study suffers from inherent measurement limitations in official demographic statistics. Ideally, crime ratio indicators should be standardized based on the resident population aged 15 and above, as individuals in this age group bear full legal

responsibility for criminal behavior. However, several provincial administrative regions fail to release age-stratified population data for specific years, resulting in incomplete provincial samples. Furthermore, official statistical caliber varies across provinces, with inconsistent age thresholds of 15, 16, and 18 years adopted for legal population statistics, which introduces systematic measurement heterogeneity and potential bias to the provincial crime rate calculation. Besides, future research may combine individual micro-survey data with fine-grained block-level statistics—such as local PM2.5 concentration and sanitation conditions—to empirically validate the complex socio-physical interactive pathways behind the documented non-linear pattern[55].

Finally, limitations derive from the observational nature of the dataset. Although the high-dimensional two-way fixed-effects specification applied to 2016–2018 panel data greatly mitigates omitted variable bias from time-constant individual and regional traits, rigorous causal identification cannot be fully secured. Unobserved time-varying confounders, including unexpected municipal planning adjustments and idiosyncratic personal life shocks, may still bias regression outcomes[56]. Future research can leverage exogenous policy shocks and quasi-natural experiments such as staggered National Forest City implementation and targeted urban afforestation programs, alongside longer-run panel data, to establish more credible causal evidence on the non-linear health impacts of greenspace expansion[21].

## **Conclusion**

Overall, using matched CFPS micro-data and provincial green space statistics, this paper empirically identifies a robust U-shaped relationship between per capita green space and

residents' depression based on two-way fixed effect models. Moderate green space alleviates depressive symptoms, but excessive green expansion leads to diminishing mental health returns, with environmental perception, public facilities, and neighborhood relations acting as competing suppressor mediators. Provincial crime rates significantly moderate this nonlinear green space–depression association through both linear and quadratic interactive pathways. Higher regional crime rates weaken the initial psychological protective effects of green space and simultaneously flatten the curvature of the U-shaped trajectory, suggesting that public safety functions as a critical contextual boundary condition that shapes the magnitude and nonlinear pattern of green space mental health benefits. Heterogeneity exists across age, gender, and housing quality groups. Green space exerts a stronger psychological buffering effect among people with more serious perceived environmental problems. Public safety expenditure plays a complementary moderating role, while neighborhood trust shows no statistically significant moderating effect.

This study contributes to the literature in both conceptual and methodological ways. Conceptually, it establishes the nonlinear nature of the green space–mental health relationship, explains the mechanisms underlying this relationship through three competing suppressor pathways, and identifies objective provincial crime rates as a critical contextual moderator that reshapes the nonlinear green space health gradient. Together, these contributions provide a more comprehensive understanding of the complex relationship between green space and mental health. Methodologically, the study adopts a unified urban–rural green space indicator and integrates objective macro-level ecological statistics with longitudinal micro-level survey data, enabling a more comprehensive representation of residents' ecological environments

while reducing common method bias associated with single-source studies.

For urban governance, the findings provide targeted practical implications. Blind large-scale green expansion is insufficient and may even trigger adverse psychological effects at high exposure levels. Urban greening policies should therefore be closely coordinated with public safety governance strategies, as the mental health dividends of green environments depend not only on ecological provision but also on local safety conditions. Macro ecological initiatives should be coordinated with micro community investments, including public facility upgrading and environmental sanitation improvement, with priority given to holistic environmental upgrading in disadvantaged neighborhoods to ensure equitable health benefits.

#### **List of abbreviations:**

BCa: Bias-corrected and accelerated

CFPS: China Family Panel Studies

CESD-8: 8-item Center for Epidemiologic Studies Depression Scale

CPTED: Crime Prevention Through Environmental Design

974    FAO: Food and Agriculture Organization of the United Nations

975    GS: Green space

976    ICC: Intraclass Correlation Coefficient

977    ISSS: Institute of Social Science Survey

978    LPM: Linear Probability Model

979    OLS: Ordinary Least Squares

980    PID: Personal identification code

981    PPS: Probability Proportional to Size

982    PSUs: Primary sampling units

983    SSUs: Secondary sampling units

984    TSUs: Tertiary sampling units

985    TWFE: Two-way fixed-effects

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991    **Declarations:**

992    **Ethics approval and consent to participate**

993        The China Family Panel Studies (CFPS) data used in this study is hosted by the Institute

994    of Social Science Survey (ISSS) at Peking University. The CFPS project has obtained formal

995    ethical approval and written informed consent from all respondents. This study only uses

publicly available anonymized secondary data and involves no additional intervention to human participants, which complies with all relevant ethical research guidelines.

#### **Consent for publication**

All individual-level data applied in this study are fully anonymized by the original survey project, with no identifiable personal information of respondents. The CFPS project has already obtained consent for research use and public release of the data from all participants. No additional consent for publication is required for this manuscript.

#### **Availability of data and materials**

The CFPS data that support the findings of this study are openly available on the official website of the China Family Panel Studies at <https://cfpsdata.pku.edu.cn/#/home>.

Provincial macroeconomic statistics are publicly accessible on the official website of the National Bureau of Statistics of China at <http://www.stats.gov.cn/>

Crime rate data are calculated from the number of people prosecuted in annual work reports of provincial people's procuratorates, with corresponding age-specific population data sourced from provincial statistical yearbooks and official bulletin. Detailed data sources for each province are listed in the Appendix.

#### **Competing interests**

The authors declare that they have no competing interests

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#### **Authors' contributions**

The authors confirm contribution to the paper as follows: Conceptualization, CCH;

Methodology, CCH; Validation, CCH; Software, XM and XZ; Formal analysis, CCH, XM and XZ; Investigation, XM and XZ; Data curation, XM and XZ; Writing – original draft preparation, XM and XZ; Writing – review and editing, CCH; Visualization, XM and XZ; Supervision, CCH; Project administration, CCH. All authors reviewed and approved the final version of the manuscript.

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### **Authors' information (optional)**

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## Appendix:

**Table A1: Number of People Prosecuted by Province and Data Sources**

| Province       | Year | Prosecution | Data Source                                                                                                                                                                             |
|----------------|------|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Shanghai       | 2016 | 38030       | <a href="https://www.sh.jcy.gov.cn/gzbg/2013/rdhgzb/27965.jhtml">https://www.sh.jcy.gov.cn/gzbg/2013/rdhgzb/27965.jhtml</a>                                                             |
| Shanghai       | 2018 | 38287       | <a href="https://www.shobserver.cn/wx/detail.do?id=129921">https://www.shobserver.cn/wx/detail.do?id=129921</a>                                                                         |
| Yunnan         | 2016 | 50916       | <a href="http://www.yn.jcy.gov.cn/upload/uploadimages/articleimage/20170930104004269.pdf">http://www.yn.jcy.gov.cn/upload/uploadimages/articleimage/20170930104004269.pdf</a>           |
| Yunnan         | 2018 | 55162       | <a href="https://m.yunnan.cn/system/2019/02/02/030194346.shtml">https://m.yunnan.cn/system/2019/02/02/030194346.shtml</a>                                                               |
| Inner Mongolia | 2016 | 29812       | <a href="https://www.nm.jcy.gov.cn/ygjw/gzbg/201701/t20170117_1927319.shtml">https://www.nm.jcy.gov.cn/ygjw/gzbg/201701/t20170117_1927319.shtml</a>                                     |
| Inner Mongolia | 2018 | 34479       | <a href="http://www.nmgrd.gov.cn/rdhy/zzq13jie/dechy13/zyfb/ggbg/201902/t20190225_338551.html">http://www.nmgrd.gov.cn/rdhy/zzq13jie/dechy13/zyfb/ggbg/201902/t20190225_338551.html</a> |

|           |      |        |                                                                                                                                                                                                                         |
|-----------|------|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Beijing   | 2016 | 19505  | <a href="https://www.bjrd.gov.cn/zyfb/bg/202012/t20201222_2180318.html">https://www.bjrd.gov.cn/zyfb/bg/202012/t20201222_2180318.html</a>                                                                               |
| Beijing   | 2018 | 21073  | <a href="https://www.beijing.gov.cn/gongkai/jihua/bg/201903/t20190320_1838586.html">https://www.beijing.gov.cn/gongkai/jihua/bg/201903/t20190320_1838586.html</a>                                                       |
| Sichuan   | 2016 | 67247  | <a href="https://www.sc.jcy.gov.cn/ygjw/gzbg/201805/t20180509_2201112.shtml">https://www.sc.jcy.gov.cn/ygjw/gzbg/201805/t20180509_2201112.shtml</a>                                                                     |
| Sichuan   | 2018 | 71208  | <a href="https://www.sc.gov.cn/10462/bgzy/2019/1/24/0931461f140f4d38bd4b0858955356aa.shtml">https://www.sc.gov.cn/10462/bgzy/2019/1/24/0931461f140f4d38bd4b0858955356aa.shtml</a>                                       |
| Tianjin   | 2016 | 14620  | <a href="https://www.tj.jcy.gov.cn/jwgk/gzbg/201702/t20170214_1938629.shtml">https://www.tj.jcy.gov.cn/jwgk/gzbg/201702/t20170214_1938629.shtml</a>                                                                     |
| Tianjin   | 2018 | 18140  | <a href="https://www.tj.jcy.gov.cn/jwgk/gzbg/201901/t20190123_2474770.shtml">https://www.tj.jcy.gov.cn/jwgk/gzbg/201901/t20190123_2474770.shtml</a>                                                                     |
| Ningxia   | 2016 | 7804   | <a href="https://www.nx.jcy.gov.cn/ldxy/ldjjwgk/ldgzbg/201807/t20180724_611335.html">https://www.nx.jcy.gov.cn/ldxy/ldjjwgk/ldgzbg/201807/t20180724_611335.html</a>                                                     |
| Ningxia   | 2018 | 7338   | <a href="https://nx.jcy.gov.cn/ldxy/ldjjwgk/ldgzbg/201903/t20190327_611351.html">https://nx.jcy.gov.cn/ldxy/ldjjwgk/ldgzbg/201903/t20190327_611351.html</a>                                                             |
| Guangxi   | 2016 | 47128  | <a href="https://www.gxrd.gov.cn/html/art154609.html">https://www.gxrd.gov.cn/html/art154609.html</a>                                                                                                                   |
| Guangxi   | 2018 | 53411  | <a href="http://www.gx.jcy.gov.cn/jwgk/gzbg25/202011/t20201119_3044011.shtml">http://www.gx.jcy.gov.cn/jwgk/gzbg25/202011/t20201119_3044011.shtml</a>                                                                   |
| Xinjiang  | 2016 | 41305  | <a href="http://www.xjaletai.jcy.gov.cn/gzbg/201811/t20181114_2411535.shtml">http://www.xjaletai.jcy.gov.cn/gzbg/201811/t20181114_2411535.shtml</a>                                                                     |
| Xinjiang  | 2018 | 135546 | <a href="https://www.xjpcsc.gov.cn/article/2347539c626d49698b0853d4a17c0570">https://www.xjpcsc.gov.cn/article/2347539c626d49698b0853d4a17c0570</a>                                                                     |
| Gansu     | 2016 | 28498  | <a href="http://big5.cctv.com/gate/big5/news.cctv.com/2017/01/11/ARTIPEyUvmgnCMPeQTnIVfDy170111.shtml">http://big5.cctv.com/gate/big5/news.cctv.com/2017/01/11/ARTIPEyUvmgnCMPeQTnIVfDy170111.shtml</a>                 |
| Gansu     | 2018 | 26932  | <a href="https://gansu.gscn.com.cn/system/2019/01/28/012108573.shtml">https://gansu.gscn.com.cn/system/2019/01/28/012108573.shtml</a>                                                                                   |
| Xizang    | 2016 | 1793   | <a href="http://www.xztzb.gov.cn/lianzheng/1484188501932.shtml">http://www.xztzb.gov.cn/lianzheng/1484188501932.shtml</a>                                                                                               |
| Xizang    | 2018 | 1752   | <a href="http://www.xz.jcy.gov.cn/jwgk/gzbg/201903/t20190301_2501903.shtml">http://www.xz.jcy.gov.cn/jwgk/gzbg/201903/t20190301_2501903.shtml</a>                                                                       |
| Guizhou   | 2016 | 47731  | <a href="http://www.gz.jcy.gov.cn/jwgk/gzbg/201807/t20180710_2279174.shtml">http://www.gz.jcy.gov.cn/jwgk/gzbg/201807/t20180710_2279174.shtml</a>                                                                       |
| Guizhou   | 2018 | 38651  | <a href="https://www.gzrd.gov.cn/gzdt/jdgz/tqsybg/201902/t20190220_77653557.html">https://www.gzrd.gov.cn/gzdt/jdgz/tqsybg/201902/t20190220_77653557.html</a>                                                           |
| Chongqing | 2016 | 33212  | <a href="http://www.cq.jcy.gov.cn/jwgk/jcgzbg/202111/t20211129_3447077.shtml">http://www.cq.jcy.gov.cn/jwgk/jcgzbg/202111/t20211129_3447077.shtml</a>                                                                   |
| Chongqing | 2018 | 33774  | <a href="http://www.cq.jcy.gov.cn/jwgk/jcgzbg/202111/t20211129_3447063.shtml">http://www.cq.jcy.gov.cn/jwgk/jcgzbg/202111/t20211129_3447063.shtml</a>                                                                   |
| Shaanxi   | 2016 | 28972  | <a href="http://tgzf.wnzwf.gov.cn/c/2017/0118/574442.shtml">http://tgzf.wnzwf.gov.cn/c/2017/0118/574442.shtml</a>                                                                                                       |
| Shaanxi   | 2018 | 31519  | <a href="http://www.sxzf.gov.cn/html/12/85504.html">http://www.sxzf.gov.cn/html/12/85504.html</a>                                                                                                                       |
| Qinghai   | 2016 | 6122   | <a href="https://www.qhrd.gov.cn/qhsrd/zyfb/rdhkhk/ljrdhkhk/sejrdhkhk/sejlerdhkhk/201706/t20170619_38900.html">https://www.qhrd.gov.cn/qhsrd/zyfb/rdhkhk/ljrdhkhk/sejrdhkhk/sejlerdhkhk/201706/t20170619_38900.html</a> |
| Qinghai   | 2018 | 6446   | <a href="https://www.qhrd.gov.cn/rdhhy/qhsdssjrmdbdhdschy/hywj_1806/201902/t20190218_74664.html">https://www.qhrd.gov.cn/rdhhy/qhsdssjrmdbdhdschy/hywj_1806/201902/t20190218_74664.html</a>                             |

|              |      |        |                                                                                                                                                                                               |
|--------------|------|--------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hebei        | 2016 | 51137  | <a href="https://m.hebnews.cn/hebei/2017-01/11/content_6221794.htm">https://m.hebnews.cn/hebei/2017-01/11/content_6221794.htm</a>                                                             |
| Hebei        | 2018 | 64583  | <a href="https://oldszbz.hbfzb.com/html/2019-01/16/content_128774.htm?div=-1">https://oldszbz.hbfzb.com/html/2019-01/16/content_128774.htm?div=-1</a>                                         |
| Shanxi       | 2016 | 26996  | <a href="https://www.sx.jcy.gov.cn/jwgk/gzbg/201703/t20170316_1962859.shtml">https://www.sx.jcy.gov.cn/jwgk/gzbg/201703/t20170316_1962859.shtml</a>                                           |
| Shanxi       | 2018 | 32566  | <a href="http://www.sx.jcy.gov.cn/jwgk/gzbg/202008/t20200821_2918430.shtml">http://www.sx.jcy.gov.cn/jwgk/gzbg/202008/t20200821_2918430.shtml</a>                                             |
| Liaoning     | 2016 | 44207  | <a href="http://www.lnfz.cn/news/5511.html">http://www.lnfz.cn/news/5511.html</a>                                                                                                             |
| Liaoning     | 2018 | 48855  | <a href="https://epaper.lnd.com.cn/lrbepaper/pc/con/201902/02/content_17266.html">https://epaper.lnd.com.cn/lrbepaper/pc/con/201902/02/content_17266.html</a>                                 |
| Jilin        | 2016 | 32126  | <a href="https://www.jlrd.gov.cn/ztl/ljhy/jlsdsyjrdschy_69427/wjbg/201701/t20170117_5411698.html">https://www.jlrd.gov.cn/ztl/ljhy/jlsdsyjrdschy_69427/wjbg/201701/t20170117_5411698.html</a> |
| Jilin        | 2018 | 33881  | <a href="https://www.jl.jcy.gov.cn/tjzj/gzbg/202011/t20201123_3051459.shtml">https://www.jl.jcy.gov.cn/tjzj/gzbg/202011/t20201123_3051459.shtml</a>                                           |
| Heilongjiang | 2016 | 31336  | <a href="http://epaper.hljnews.cn/hljrb/20170210/03.pdf">http://epaper.hljnews.cn/hljrb/20170210/03.pdf</a>                                                                                   |
| Heilongjiang | 2018 | 100390 | <a href="https://www.toutiao.com/article/6637421138207048206/?&amp;source=m_redirect">https://www.toutiao.com/article/6637421138207048206/?&amp;source=m_redirect</a>                         |
| Jiangsu      | 2016 | 100180 | <a href="https://jsnews.jschina.com.cn/jsyw/201702/t20170221_90818.shtml">https://jsnews.jschina.com.cn/jsyw/201702/t20170221_90818.shtml</a>                                                 |
| Jiangsu      | 2018 | 100390 | <a href="https://www.toutiao.com/article/6637421138207048206/?&amp;source=m_redirect">https://www.toutiao.com/article/6637421138207048206/?&amp;source=m_redirect</a>                         |
| Zhejiang     | 2016 | 119788 | <a href="https://www.zjjcy.gov.cn/art/2017/1/24/art_23_34529.html">https://www.zjjcy.gov.cn/art/2017/1/24/art_23_34529.html</a>                                                               |
| Zhejiang     | 2018 | 105055 | <a href="https://www.zjjcy.gov.cn/art/2019/2/11/art_23_67444.html">https://www.zjjcy.gov.cn/art/2019/2/11/art_23_67444.html</a>                                                               |
| Anhui        | 2016 | 48275  | <a href="https://www.ah.jcy.gov.cn/jwgk/gzbg/201702/t20170204_1933451.shtml">https://www.ah.jcy.gov.cn/jwgk/gzbg/201702/t20170204_1933451.shtml</a>                                           |
| Anhui        | 2018 | 58382  | <a href="https://www.ah.jcy.gov.cn/jwgk/gzbg/201901/t20190122_2474077.shtml">https://www.ah.jcy.gov.cn/jwgk/gzbg/201901/t20190122_2474077.shtml</a>                                           |
| Fujian       | 2016 | 67082  | <a href="http://www.fj.jcy.gov.cn/jwgk/jcgzbg/201804/t20180417_2182789.shtml">http://www.fj.jcy.gov.cn/jwgk/jcgzbg/201804/t20180417_2182789.shtml</a>                                         |
| Fujian       | 2018 | 62464  | <a href="https://www.spp.gov.cn/spp/dfjcdt/201902/t20190222_408899.shtml">https://www.spp.gov.cn/spp/dfjcdt/201902/t20190222_408899.shtml</a>                                                 |
| Jiangxi      | 2016 | 34572  | <a href="https://www.jx.jcy.gov.cn/jcxc/xcbd/201806/t20180622_2241745.shtml">https://www.jx.jcy.gov.cn/jcxc/xcbd/201806/t20180622_2241745.shtml</a>                                           |
| Jiangxi      | 2018 | 44279  | <a href="https://news.qq.com/rain/a/PJX2019013000495200">https://news.qq.com/rain/a/PJX2019013000495200</a>                                                                                   |
| Shandong     | 2016 | 73653  | <a href="http://www.sdjcy.gov.cn/sygg/gzbg/201703/t20170330_3933553.html">http://www.sdjcy.gov.cn/sygg/gzbg/201703/t20170330_3933553.html</a>                                                 |
| Shandong     | 2018 | 93150  | <a href="http://www.sdjcy.gov.cn/sygg/gzbg/201902/t20190216_3933555.html">http://www.sdjcy.gov.cn/sygg/gzbg/201902/t20190216_3933555.html</a>                                                 |
| Henan        | 2016 | 85058  | <a href="http://www.hnr.cn/news/djn/201701/t20170118_2885063.html">http://www.hnr.cn/news/djn/201701/t20170118_2885063.html</a>                                                               |
| Henan        | 2018 | 115684 | <a href="http://www.ha.jcy.gov.cn/jwgk/jctj/202009/t20200902_2940691.shtml">http://www.ha.jcy.gov.cn/jwgk/jctj/202009/t20200902_2940691.shtml</a>                                             |

|           |      |        |                                                                                                                                                                                                                   |
|-----------|------|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hubei     | 2016 | 46454  | <a href="https://tl.hbjc.gov.cn/jwgk_68501/gzbg_68502/202204/t20220422_1683168_mob.shtml">https://tl.hbjc.gov.cn/jwgk_68501/gzbg_68502/202204/t20220422_1683168_mob.shtml</a>                                     |
| Hubei     | 2018 | 52633  | <a href="http://news.cnhubei.com/zhengwu/p/10222957.html">http://news.cnhubei.com/zhengwu/p/10222957.html</a>                                                                                                     |
| Guangdong | 2016 | 144872 | <a href="http://www.gd.jcy.gov.cn/tjbg/jcbg/201701/t20170122_1930215.shtml">http://www.gd.jcy.gov.cn/tjbg/jcbg/201701/t20170122_1930215.shtml</a>                                                                 |
| Guangdong | 2018 | 164731 | <a href="http://www.gd.jcy.gov.cn/xwzx/mtbb/201901/t20190131_2481910.shtml">http://www.gd.jcy.gov.cn/xwzx/mtbb/201901/t20190131_2481910.shtml</a>                                                                 |
| Hainan    | 2016 | 10679  | <a href="https://hainanpc.gov.cn/hainanpc/ztl/ssjyc/lcsrdhzt/swjrdwchy/bgjd/2021110520564373354/index.html">https://hainanpc.gov.cn/hainanpc/ztl/ssjyc/lcsrdhzt/swjrdwchy/bgjd/2021110520564373354/index.html</a> |
| Hainan    | 2018 | 13221  | <a href="https://www.spp.gov.cn/spp/zd gz/201902/t20190202_407305.shtml">https://www.spp.gov.cn/spp/zd gz/201902/t20190202_407305.shtml</a>                                                                       |
| Hunan     | 2016 | 71694  | <a href="https://www.hn.jcy.gov.cn/xwfb/gzbg/jcgzbg/201902/1464909166349910018.html">https://www.hn.jcy.gov.cn/xwfb/gzbg/jcgzbg/201902/1464909166349910018.html</a>                                               |
| Hunan     | 2018 | 56029  | <a href="https://www.yylq.gov.cn/21487/21488/21499/content_674822.html">https://www.yylq.gov.cn/21487/21488/21499/content_674822.html</a>                                                                         |

**Table A2: Age-Specific Resident Population by Province and Data Sources**

| Province       | Year | Age-Specific Population | Data Source                                                                                                                                                                                       |
|----------------|------|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Shanghai       | 2016 | 13124300                | <a href="https://tjj.sh.gov.cn/tjnj/nj17.htm?d1=2017tjnj/C0206.htm">https://tjj.sh.gov.cn/tjnj/nj17.htm?d1=2017tjnj/C0206.htm</a>                                                                 |
| Shanghai       | 2018 | 12816300                | <a href="https://tjj.sh.gov.cn/tjnj/nj19.htm?d1=2019tjnj/C0206.htm">https://tjj.sh.gov.cn/tjnj/nj19.htm?d1=2019tjnj/C0206.htm</a>                                                                 |
| Yunnan         | 2016 | 39385000                | <a href="https://www.yn.gov.cn/sjfb/tjgb/202103/t20210326_219251.html">https://www.yn.gov.cn/sjfb/tjgb/202103/t20210326_219251.html</a>                                                           |
| Yunnan         | 2018 | 39488000                | <a href="https://www.yn.gov.cn/zwgk/zfxgkpt/fdzdgknr/tjxx/tjsj/201906/t20190627_179363.html">https://www.yn.gov.cn/zwgk/zfxgkpt/fdzdgknr/tjxx/tjsj/201906/t20190627_179363.html</a>               |
| Inner Mongolia | 2016 | 21847000                | <a href="https://data.chinabaogao.com/hgshj/2017/12i061612017.html">https://data.chinabaogao.com/hgshj/2017/12i061612017.html</a>                                                                 |
| Inner Mongolia | 2018 | 21957000                | <a href="https://tj.nmg.gov.cn/tjyw/tjgb/ndtjgb/202102/t2021020210209_886014.html">https://tj.nmg.gov.cn/tjyw/tjgb/ndtjgb/202102/t2021020210209_886014.html</a>                                   |
| Beijing        | 2016 | 19491000                | <a href="https://tjj.beijing.gov.cn/zxfbu/202002/t20200216_1634839.html">https://tjj.beijing.gov.cn/zxfbu/202002/t20200216_1634839.html</a>                                                       |
| Beijing        | 2018 | 19276000                | <a href="https://tjj.beijing.gov.cn/tjsj_31433/tjgb_31445/ndgb_31446/202002/t20200216_1643263.html">https://tjj.beijing.gov.cn/tjsj_31433/tjgb_31445/ndgb_31446/202002/t20200216_1643263.html</a> |
| Tianjin        | 2016 | 13010200                | <a href="https://stats.tj.gov.cn/nianjian/2017nj/zk/indexch.htm">https://stats.tj.gov.cn/nianjian/2017nj/zk/indexch.htm</a>                                                                       |
| Tianjin        | 2018 | 12318500                | <a href="https://stats.tj.gov.cn/nianjian/2019nj/zk/indexch.htm">https://stats.tj.gov.cn/nianjian/2019nj/zk/indexch.htm</a>                                                                       |
| Ningxia        | 2016 | 5289200                 | <a href="https://tj.nx.gov.cn/tjsj_htr/tjgb_htr/201704/t20170418_1470249.html">https://tj.nx.gov.cn/tjsj_htr/tjgb_htr/201704/t20170418_1470249.html</a>                                           |

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| Ningxia      | 2018 | 5361100  | <a href="https://tj.nx.gov.cn/tjsj_htr/tjgb_htr/201904/t20190430_1470251.html">https://tj.nx.gov.cn/tjsj_htr/tjgb_htr/201904/t20190430_1470251.html</a>                                                                 |
| Guangxi      | 2016 | 37698000 | <a href="http://tjj.gxzf.gov.cn/tjsj/tjnj/material/tjnj20200415/2017/zk/html/fu.htm">http://tjj.gxzf.gov.cn/tjsj/tjnj/material/tjnj20200415/2017/zk/html/fu.htm</a>                                                     |
| Guangxi      | 2018 | 38393400 | <a href="http://tjj.gxzf.gov.cn/tjsj/tjgb/qqgb/t2382859.shtml">http://tjj.gxzf.gov.cn/tjsj/tjgb/qqgb/t2382859.shtml</a>                                                                                                 |
| Gansu        | 2016 | 21547700 | <a href="http://cn.chinagate.cn/reports/2018-03/16/content_50705111_2.htm">http://cn.chinagate.cn/reports/2018-03/16/content_50705111_2.htm</a>                                                                         |
| Gansu        | 2018 | 21760000 | <a href="https://tjj.gansu.gov.cn/tjj/c109457/201903/862168.shtml">https://tjj.gansu.gov.cn/tjj/c109457/201903/862168.shtml</a>                                                                                         |
| Guizhou      | 2016 | 27633000 | <a href="https://www.jiangkou.gov.cn/xxgk/xxgkml/jcgk/tjxx/sjfb/201707/t20170728_4660911.html">https://www.jiangkou.gov.cn/xxgk/xxgkml/jcgk/tjxx/sjfb/201707/t20170728_4660911.html</a>                                 |
| Guizhou      | 2018 | 27446200 | <a href="https://www.guizhou.gov.cn/zwgk/zfsj/tjgb/202109/t20210913_70088456.html">https://www.guizhou.gov.cn/zwgk/zfsj/tjgb/202109/t20210913_70088456.html</a>                                                         |
| Chongqing    | 2016 | 25101900 | <a href="https://tjj.cq.gov.cn/zwgk_233/fdzdgknr/tjxx/sjz1_55471/tjgb_55472/202002/t20200219_5274451_wap.html">https://tjj.cq.gov.cn/zwgk_233/fdzdgknr/tjxx/sjz1_55471/tjgb_55472/202002/t20200219_5274451_wap.html</a> |
| Chongqing    | 2018 | 25395000 | <a href="http://www.cq.gov.cn/zwgk/zfxxgkml/sjfb_120853/tjgb/201903/t20190319_8650130.html">http://www.cq.gov.cn/zwgk/zfxxgkml/sjfb_120853/tjgb/201903/t20190319_8650130.html</a>                                       |
| Shaanxi      | 2016 | 32738968 | <a href="http://snzd.stats.gov.cn/tjgb/2017/43142.shtml">http://snzd.stats.gov.cn/tjgb/2017/43142.shtml</a>                                                                                                             |
| Shaanxi      | 2018 | 33042100 | <a href="http://www.shaanxi.gov.cn/sj/zxfb/201905/t20190515_1475403.html">http://www.shaanxi.gov.cn/sj/zxfb/201905/t20190515_1475403.html</a>                                                                           |
| Qinghai      | 2016 | 4759600  | <a href="http://tjj.qinghai.gov.cn/nj/2026/indexch.htm">http://tjj.qinghai.gov.cn/nj/2026/indexch.htm</a>                                                                                                               |
| Qinghai      | 2018 | 4820300  | <a href="http://tjj.qinghai.gov.cn/nj/2027/indexch.htm">http://tjj.qinghai.gov.cn/nj/2027/indexch.htm</a>                                                                                                               |
| Hebei        | 2016 | 60782900 | <a href="http://tjj.hebei.gov.cn/hetj/ztbd/xy19da/101504169306833.html">http://tjj.hebei.gov.cn/hetj/ztbd/xy19da/101504169306833.html</a>                                                                               |
| Hebei        | 2018 | 62113000 | <a href="http://news.cnr.cn/native/city/20190130/t20190130_524498216.shtml">http://news.cnr.cn/native/city/20190130/t20190130_524498216.shtml</a>                                                                       |
| Shanxi       | 2016 | 31129300 | <a href="https://tjj.shanxi.gov.cn/tjsj/tjgb/qtpcgb/201706/t20170627_729103.shtml">https://tjj.shanxi.gov.cn/tjsj/tjgb/qtpcgb/201706/t20170627_729103.shtml</a>                                                         |
| Shanxi       | 2018 | 31304700 | <a href="https://tjj.shanxi.gov.cn/tjsj/tjgb/qtpcgb/201901/t20190129_9424786.shtml">https://tjj.shanxi.gov.cn/tjsj/tjgb/qtpcgb/201901/t20190129_9424786.shtml</a>                                                       |
| Liaoning     | 2016 | 36700000 | <a href="https://tjj.ln.gov.cn/tjj/tjsj/otherpages/2017/zk/indexch.htm">https://tjj.ln.gov.cn/tjj/tjsj/otherpages/2017/zk/indexch.htm</a>                                                                               |
| Liaoning     | 2018 | 36331000 | <a href="https://tjj.ln.gov.cn/tjj/tjsj/otherpages/2019/indexch.htm">https://tjj.ln.gov.cn/tjj/tjsj/otherpages/2019/indexch.htm</a>                                                                                     |
| Heilongjiang | 2016 | 33832000 | <a href="https://hlj.gov.cn/hlj/c108419/202101/c00_31186857.shtml">https://hlj.gov.cn/hlj/c108419/202101/c00_31186857.shtml</a>                                                                                         |
| Heilongjiang | 2018 | 33724000 | <a href="https://tjj.hlj.gov.cn/tjj/c106782/202001/c00_30326302.shtml">https://tjj.hlj.gov.cn/tjj/c106782/202001/c00_30326302.shtml</a>                                                                                 |
| Jiangsu      | 2016 | 69180200 | <a href="http://cn.chinagate.cn/reports/2018-03/11/content_50684144_9.htm">http://cn.chinagate.cn/reports/2018-03/11/content_50684144_9.htm</a>                                                                         |
| Jiangsu      | 2018 | 69348700 | <a href="https://tj.jiangsu.gov.cn/art/2019/3/8/art_87595_10688013.html">https://tj.jiangsu.gov.cn/art/2019/3/8/art_87595_10688013.html</a>                                                                             |

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| Zhejiang  | 2016 | 48409000 | <a href="https://tjj.zj.gov.cn/art/2019/1/30/art_1562195_30164486.html">https://tjj.zj.gov.cn/art/2019/1/30/art_1562195_30164486.html</a>                 |
| Zhejiang  | 2018 | 49051000 | <a href="https://gat.zj.gov.cn/art/2017/9/21/art_1229263037_2239995.html">https://gat.zj.gov.cn/art/2017/9/21/art_1229263037_2239995.html</a>             |
| Anhui     | 2016 | 50611000 | <a href="https://tjj.ah.gov.cn/ssah/qwfbjd/tjgb/sjtjgb/113724451.html">https://tjj.ah.gov.cn/ssah/qwfbjd/tjgb/sjtjgb/113724451.html</a>                   |
| Anhui     | 2018 | 51316000 | <a href="https://tj.bozhou.gov.cn/News/show/271223.html">https://tj.bozhou.gov.cn/News/show/271223.html</a>                                               |
| Fujian    | 2016 | 32360000 | <a href="https://fujian.gov.cn/zwgk/sjfb/tjgb/201702/t20170224_1134370.htm">https://fujian.gov.cn/zwgk/sjfb/tjgb/201702/t20170224_1134370.htm</a>         |
| Fujian    | 2018 | 32820000 | <a href="https://fj.gov.cn/zwgk/sjfb/tjgb/201902/t20190228_4775098.htm">https://fj.gov.cn/zwgk/sjfb/tjgb/201902/t20190228_4775098.htm</a>                 |
| Jiangxi   | 2016 | 36683000 | <a href="https://tjj.jiangxi.gov.cn/resource/nj/2017CD/index.htm">https://tjj.jiangxi.gov.cn/resource/nj/2017CD/index.htm</a>                             |
| Jiangxi   | 2018 | 37025700 | <a href="http://tjj.jiangxi.gov.cn/resource/nj/2019CD/index.htm">http://tjj.jiangxi.gov.cn/resource/nj/2019CD/index.htm</a>                               |
| Shandong  | 2016 | 83134000 | <a href="https://www.askci.com/news/finance/20170321/11154393865.shtml">https://www.askci.com/news/finance/20170321/11154393865.shtml</a>                 |
| Shandong  | 2018 | 82306900 | <a href="http://www.shandong.gov.cn/art/2019/3/2/art_98102_206938.html">http://www.shandong.gov.cn/art/2019/3/2/art_98102_206938.html</a>                 |
| Henan     | 2016 | 75001100 | <a href="https://tjj.henan.gov.cn/2017/03-01/1367743.html">https://tjj.henan.gov.cn/2017/03-01/1367743.html</a>                                           |
| Henan     | 2018 | 75450000 | <a href="https://tjj.henan.gov.cn/2019/06-14/1371953.html">https://tjj.henan.gov.cn/2019/06-14/1371953.html</a>                                           |
| Hunan     | 2016 | 55578000 | <a href="http://www.hunan.gov.cn/hnszf/zfsj/tjgb/201703/t20170309_4832923.html">http://www.hunan.gov.cn/hnszf/zfsj/tjgb/201703/t20170309_4832923.html</a> |
| Hunan     | 2018 | 55404300 | <a href="http://hunan.gov.cn/hnszf/zfsj/tjgb/201903/t20190313_5294248.html">http://hunan.gov.cn/hnszf/zfsj/tjgb/201903/t20190313_5294248.html</a>         |
| Guangdong | 2016 | 91043300 | <a href="http://stats.gd.gov.cn/tjkx185/content/post_1427883.html">http://stats.gd.gov.cn/tjkx185/content/post_1427883.html</a>                           |
| Guangdong | 2018 | 93967600 | <a href="https://gdzd.stats.gov.cn/ggl/202002/t20200227_154724.html">https://gdzd.stats.gov.cn/ggl/202002/t20200227_154724.html</a>                       |
| Hainan    | 2016 | 7707700  | <a href="https://www.hongheiku.com/lishishuju/1847.html">https://www.hongheiku.com/lishishuju/1847.html</a>                                               |
| Hainan    | 2018 | 7908900  | <a href="https://www.hongheiku.com/lishishuju/1849.html">https://www.hongheiku.com/lishishuju/1849.html</a>                                               |