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# The Influence of Green Space on Obesity in China: A Systematic Review

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**Keywords**
Green space · Body weight · Obesity · China · Review

**Abstract**
***Introduction:*** This study systematically reviewed scientific evidence concerning the influence of green space on obesity in China. ***Methods:*** Keyword and reference search was conducted in PubMed, Web of Science, Scopus, EBSCO, and CNKI. Predetermined selection criteria included study designs: experimental and observational studies; subjects: people of all ages; exposures: green space (i.e., any open land partly or entirely covered with grass, trees, shrubs, or other vegetation); outcomes: body weight status (e.g., body mass index [BMI], overweight, or obesity); and country: China. ***Results:*** Ten studies met the selection criteria and were included in the review. All studies adopted a cross-sectional design. Overall greenness measures were found to be inversely associated with BMI, overweight, and obesity in most included studies. Street greenness, which measures the perceived greenness at the eye level on streets, was found to be inversely associated with BMI and obesity. By contrast, mixed results were observed for the relationship between green space accessibility and weight outcomes. Air quality was found to mediate the relationship between greenness and obesity. The influence of green space on obesity tended to vary by residents' gender, age, and socioeconomic status. Boys, women, older residents, and those with lower education or household income were more likely to benefit from greenness exposure. ***Conclusion:*** The literature on green space exposure in relation to obesity in China remains limited. Longitudinal and quasi-experimental studies are warranted to assess the causal link between green space and obesity. Future measures should better capture the self-perception, quality, and attractiveness of green space. The underlying pathways through which green space affects residents' weight outcomes should be further elucidated.



## Introduction

Obesity is a leading risk factor for various chronic diseases and health conditions, such as hypertension, dyslipidemia, diabetes, cardiovascular disease, sleep apnea, and many types of cancer [1, 2]. Obesity has become a significant population health concern in China. In 2019, about half of Chinese adults and a fifth of children were overweight or obese [3]. It was projected that the prevalence of overweight and obesity in China would reach 15.6% in preschoolers, 31.8% in school-age children and adoles-

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cents, and 65.3% in adults by 2030 [4]. The prevalence of various chronic diseases caused by obesity imposes a long-term burden on both patients and society and results in an increase in health expenditures [5, 6]. In emerging economies such as China, how to balance the need to promote public health, control noncommunicable diseases, and improve the health of the population remains a major challenge [6, 7].

Green space is any open land partly or entirely covered with grass, trees, shrubs, or other vegetation [8]. Many potential benefits of green spaces have been studied, including mitigating air and noise pollution, reducing heat island effects, promoting local ecosystems, and improving health and overall well-being [9–12]. Green space is also thought of as an essential environmental determinant of obesity [13–16]. Conceptually, green space may prevent obesity by promoting physical activity, reducing stress and negative emotions, improving neighborhood cohesion and residential satisfaction, mitigating air pollution, and moderating temperature and humidity [17, 18].

A growing body of studies has reported mixed findings concerning the associations between obesity and spatial characteristics of green space, such as accessibility, frequency of use, and vegetation coverage [10, 15]. While some studies reported an inverse relationship between green space and obesity [17, 19], others only identified a relationship for some subgroups [20, 21], a null or nonlinear (e.g., U-shaped) association [22–24], or even a positive association between green space exposure and obesity [25]. Potential reasons for the inconsistencies may involve different approaches used to measure green space features, varied spatial scales, and different geographical environments [26–28]. It is noteworthy that most studies were conducted in high-income countries such as the USA, the UK, Australia, and Canada [20, 29–31]. Differences in urbanization, residential density, transportation systems, and socioeconomic status may contribute to the differential relationships reported for green space and obesity [32]. Therefore, the evidence found in those developed countries may not be generalizable to developing nations.

China has experienced rapid urbanization and industrialization over the past several decades – the Chinese urban population increased from 17.9% in 1978 to 63.9% in 2020 [33]. Increasing attention has been paid to health behavior promotion in urban areas, where green space may play a critical role [34]. The Chinese National Development and Reform Commission has recently launched a plan to build a thousand recreational parks nationwide [35]. Building green cities has also been proposed by many Chinese local governments [36]. This public health agenda, which promotes physical activity and healthy lifestyles, forms part of the national public health policy to improve the health of the population and reduce the burden of noncommunicable diseases [6].

This study, to our knowledge, is the first that systematically reviews the scientific literature regarding the influence of green space on obesity among Chinese residents. Findings from this review could help policymakers and stakeholders make informed decisions in incorporating green space in urban design to promote physical activity and prevent obesity.

## Methods

### *Search Strategy*

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [37], relevant articles were identified by searching five electronic bibliographic databases: PubMed, Web of Science, Scopus, EBSCO, and CNKI. The search algorithm included all possible combinations of two keyword groups concerning green space and obesity. The Medical Subject Headings terms "overweight," "obesity," "China," and "human" were used in the PubMed search. The search algorithm in PubMed is provided as an example in online supplementary Material 1 (see www.karger.com/doi/10.1159/000524857 for all online suppl. material). Titles and abstracts of the articles identified through the keyword search were screened against the study selection criteria. Potentially eligible articles were retrieved, and their full texts were evaluated. Two co-authors independently performed title and abstract screening. Cohen's kappa ($\kappa = 0.75$) was used to assess inter-rater agreement. Discrepancies were resolved through discussion under the participation of a third co-author. Besides the keyword search, a reference list search and a cited reference search were conducted.

### *Study Selection Criteria*

Studies that met all of the following criteria were included in the review: (1) study designs – experimental (e.g., randomized controlled trials or pre-post-studies) and observational studies (e.g., longitudinal or cross-sectional studies); (2) study subjects – people of all ages; (3) exposures – green space (e.g., parks, vegetation areas, or open green fields); (4) outcomes – body weight status (e.g., body mass index [BMI], overweight, or obesity); (5) article type – peer-reviewed journal publications; (6) time window of search – from the inception of an electronic bibliographic database to September 2021; (7) country – China; and (8) language – articles written in English or Chinese. Studies that met any of the following criteria were excluded from the review: (1) studies that examined either green space or body weight status but not both; and (2) letters, editorials, study/review protocols, case reports, or review articles.

### *Data Extraction and Synthesis*

A standardized data extraction form was used to collect the following methodological and outcome variables from each included study: author(s), year of publication, city, study design, sample

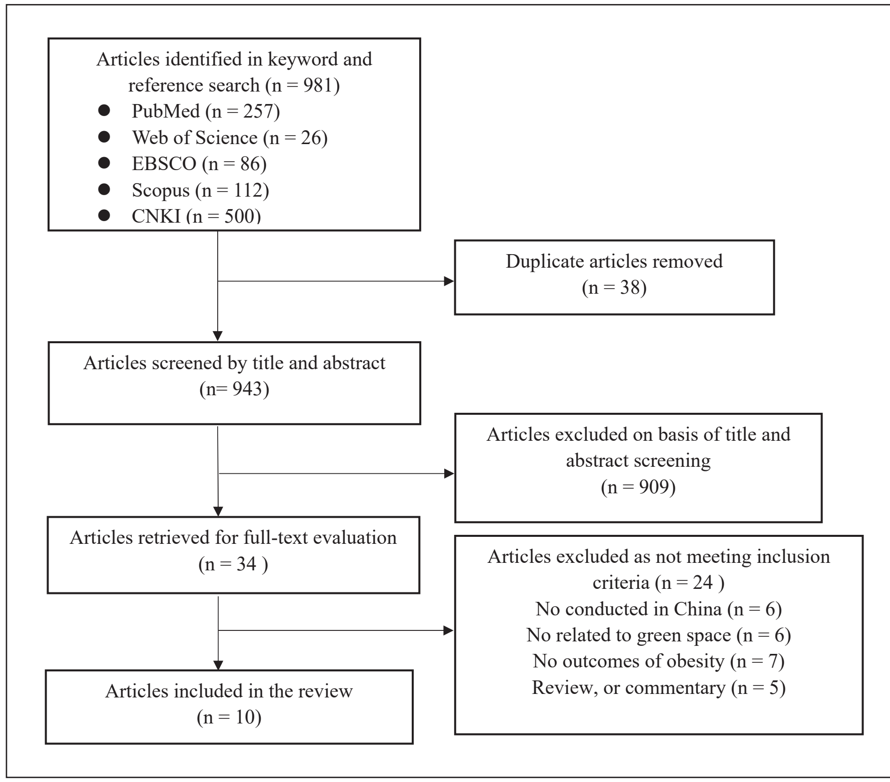


**Fig. 1.** Study selection flowchart.

size, age range, the proportion of females, sample characteristics, statistical model, nonresponse rate, geographical coverage, study setting, green space measure(s), body weight measure(s), estimated effects of green space on weight outcomes, and main findings of the study. Two co-authors independently conducted the data extraction, and discrepancies were resolved through discussion with a third co-author. Heterogeneous exposure and outcome measures prevented meta-analysis, so we summarized the common themes and findings of the included studies narratively.

*Study Quality Assessment*

We used the National Institutes of Health's Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies to assess the quality of each included study [38]. For each criterion, a score of one was assigned if "yes" was the response, whereas a score of zero was assigned otherwise. A study-specific global score, ranging from 0 to 14, was calculated by summing up scores across all criteria. Study quality assessment helped measure the strength of scientific evidence but was not used to determine the inclusion of studies.

## Results

*Study Selection*

Figure 1 shows the study selection flowchart. We identified 981 articles through keyword and reference search, including 257 from PubMed, 26 from Web of Science, 112 from Scopus, 86 from EBSCO, and 500 from CNKI. After removing duplicates, 943 articles underwent title and abstract screening, in which 909 were excluded. The remaining 34 articles were reviewed in the full text against the study selection criteria. Of these, 24 were excluded – six were not conducted in China, six reported no green space measure, seven reported no body weight status, and the remaining five were reviews or commentaries instead of original studies. Therefore, a final pool of ten articles was included in the review [18, 21, 26–28, 39–43].

*Characteristics of the Included Studies*

Table 1 summarizes the characteristics of the ten studies included in the review. All studies were published within the past 5 years (one in 2015, eight in 2020, and one in 2020). Three exclusively focused on residents in Shanghai [39, 42, 43], two in Guangzhou [26, 40], one in Shenyang, Anshan, and Jinzhou [21], one in seven provinces or municipalities including Liaoning, Tianjin, Ningxia, Shanghai, Chongqing, Hunan, and Guangdong [28], one in 64 townships or neighborhoods [18], and one each in Harbin [41] and Hong Kong [27]. All studies adopted a cross-sectional study design. The sample sizes were generally large but varied substantially across studies. Three studies had a sample size of over 10,000 par-

**Table 1.** Basic characteristics of the studies included in the review

| Study ID | First author, year | Region | Study design | Sample size | Age, years | Female, % | Sample characteristics | Statistical model | Non-response rate, % | Geographical coverage | Setting |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Zhang et al. [39] | Shanghai | Cross-sectional | 1,100 | 46–80 | | Middle-aged and older residents | Hierarchical linear models and hierarchical nonlinear models | 6 | Green and open spaces | Urban, rural |
| 2 | Chen et al. [40] | Guangzhou | Cross-sectional | 938 | 18–70 | 58 | Adult residents | Multivariate analysis Logistic regression | 6.9 | Urban green space | Urban |
| 3 | Huang et al. [18] | China | Cross-sectional | 12,112 | 50+ | 53.17 | Middle-aged and older residents | Multilevel structural equation models | | Neighborhood greenness | Urban, rural |
| 4 | Huang et al. [21] | Shenyang, Anshan, and Jinzhou | Cross-sectional | 24,845 | 18–74 | 49 | Adult residents | Two-level logistic and generalized linear mixed regression models | 13.8 | Community greenness | Urban |
| 5 | Leng et al. [41] | Harbin | Cross-sectional | 4,155 | 20–98 | 47.7 | Adult residents | Logistic regression | | Green space of neighborhood | Urban |
| 6 | Lu et al. [42] | Shanghai | Cross-sectional | 403 | 18–80 | 51.4 | Adult residents | Structural equation modeling | 5.6 | Main green space in the survey area | Urban |
| 7 | Xiao et al. [43] | Shanghai | Cross-sectional | 8,988 | All ages | 54.08 | Residents | Two-level multilevel mixed-effects ordered logistic regression | 5.6 | Neighborhood greenness | Urban |
| 8 | Yang et al. [26] | Guangzhou | Cross-sectional | 418 | 16–60 | 55.5 | Residents | Ordered logit model | 7.1 | Neighborhood environments | Urban, suburban |
| 9 | Yang et al. [27] | Hong Kong | Cross-sectional | 1,148 | 11–13 | 48.6 | Primary school students | Multilevel regression analysis and structural equation modeling | | Urban greenery | Urban |
| 10 | Bao et al. [28] | Seven provinces/ municipalities | Cross-sectional | 56,401 | 6–18 | 48.7 | Children and adolescents | Generalized linear mixed regression models | 4.5 | Greenness surrounding schools | Urban, rural |

Seven provinces/municipalities include Liaoning, Tianjin, Ningxia, Shanghai, Chongqing, Hunan, and Guangdong.

ticipants [18, 21, 28], but other three had less than 1,000 [26, 40, 42]. Two studies focused on middle-aged and older adults [18, 39], four on adults 18 years old and above [21, 40–42], two on children and adolescents under 18 years old [27, 28], and two on people of all ages [26, 43]. The percentage of females across studies ranged from 48% to 58%. Various statistical models were applied, including multivariate logistic regression [40], ordered logistic regression [26], multilevel regression [27], structural equation model [18, 42], and generalized linear regression [21, 28].

Table 2 summarizes the measures for green space and body weight status among the included studies. The majority ($n$ = 7) of studies adopted objective green space measures [18, 21, 26–28, 39, 43], two used subjective measures [40, 42], and one used both objective and subjective measures [41]. Objective green space measures included satellite-based remote sensing images from Google or Baidu street view [26, 27, 43], geographical data collected by the Lands Department of Hong Kong or Landsat 5 Thematic Mapper satellites [18, 21, 27], and measures constructed using geographical information system (GIS) [28, 39]. Subjective green space measures were collected by field surveys [41] or questionnaires administered to study participants [40]. Four studies examined the accessibility of green space [26, 39, 40, 43], five examined normalized difference vegetation index (NDVI) [18, 21, 27, 28, 43], three examined street greenness or green view index [27, 41, 43], and two examined the perceptions of green space or green space ratio [41, 42]. Measures for body weight status included BMI ($n$ = 9), BMI $z$-score ($n$ = 1), overweight ($n$ = 8), obesity ($n$ = 9), and waist circumference ($n$ = 3). Body weight status was objectively measured in half of the studies [18, 21, 28, 39, 41].

Table 3 summarizes the key findings of the included studies concerning the estimated influences of green space on body weight status in Chinese residents. We grouped the results into four categories.

**Table 2.** Measures of green space and body weight status in the studies included in the review

| Study ID | Type of green space measure | Detailed measure of green space | Type of body weight status measure | Detailed measure of body weight status |
|---|---|---|---|---|
| 1 | Objective measure: GIS | Parkland proximity, green, and open spaces | Objective measure | BMI, overweight, obesity |
| 2 | Self-report questionnaire | The distance and time from homes to green space | Self-report questionnaire | BMI, overweight, obesity |
| 3 | Objective measure: Landsat 5 Thematic Mapper images | 1. Neighborhood greenness<br>2. NDVI | Objective measure | Height, weight, waist circumference, BMI, general obesity, and abdominal obesity |
| 4 | Objective measure: Landsat 5 Thematic Mapper satellite images, GIS | 1. NDVI<br>2. SAVI | Objective measure | Height, weight, waist circumference, BMI, peripheral obesity, central obesity |
| 5 | Objective measure: land use data, the field survey | Green space ratio, green view index, and type of evergreen tree configuration | Objective measure | Height, weight, BMI, overweight, obesity |
| 6 | Self-report questionnaire | Perceptions of green space | Self-report questionnaire | BMI |
| 7 | Objective measure: GIS, the novel technique of deep convolutional neural network architecture, Baidu street view images | Green access, green exposure index, NDVI, and view-based green index | Self-report questionnaire | Height, weight, BMI, overweight, obesity |
| 8 | Objective measure: GIS, Baidu map application | Green coverage rate and distance to the park | Self-report questionnaire | Height, weight, BMI, overweight, obesity |
| 9 | Objective measure: Land Department of Hong Kong SAR, Google street view images | The number of parks, NDVI, and street greenness | Self-report questionnaire | Height, weight, BMI, overweight, obesity |
| 10 | Objective measure: ArcGIS, Landsat 8 Operational Land Imager (OLI) satellite images | 1. NDVI<br>2. SAVI | Objective measure | BMI *z*-scores, waist circumference, and overweight/obesity |

GIS, geographic information system; BMI, body mass index; NDVI, normalized difference vegetation index; SAVI, soil-adjusted vegetation index.

First, overall greenness measures were found to be inversely associated with BMI, overweight, and obesity in the majority of the included studies. Higher school-based greenness levels were associated with lower BMI *z*-score, lower odds of overweight and obesity, and lower waist circumferences in Chinese children and adolescents [28]. Greater greenness levels were associated with lower BMI and peripheral or central obesity prevalence in adults [21], lower abdominal obesity in middle-aged and older adults [18], and lower odds of overweight and obesity [18, 26]. In neighborhoods with a green space ratio lower than 28%, residents had a higher risk of being overweight or obese [41]. By contrast, greenness surrounding residence has no significant effect on body weight [27] or waist circumference [21]. Two studies found that NDVI was inversely associated with BMI and obesity within a 500 m or 1,000 m circular buffer [21, 28]. By contrast, Xiao et al. [43] reported no correlation between the NDVI within a 1,000 m buffer and residents' BMI.

Second, street greenness, typically measured by the green view index, reflects the perceived greenness at the eye level on streets and is an essential indicator for urban residents' daily green space exposure. Street greenness was found to be inversely associated with BMI within a 400 m buffer [27]. In neighborhoods with a green view index lower than 15%, residents had a higher risk of being overweight or obese [41]. An increase in the green view index within a 1,000 m buffer was inversely associated with obesity [43].

Third, accessibility to green space was found to be inversely associated with BMI and overweight or obesity in some but not all studies. Living within 1 km to urban green space was correlated with lower odds of being overweight or obese [40]. Distance to parkland was positively associated with overweight and obesity [39]. By contrast,


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**Table 3.** Estimated effects of green space on body weight status in the studies included in the review

| Study ID | Estimated effects of green space on body weight status | Main findings of study |
|---|---|---|
| 1 | 1. A 1-SD increase in proximity of parkland ($t$ = 2.238, $p$ = 0.026) was associated with a 10% increase of BMI, respectively<br>2. A 1-unit (10%) decrease in proximity of parkland ($t$ = 3.308, $p$ = 0.002) will increase 18% in overweight/obesity, respectively<br>3. A 1-unit (10%) increase in green and open space areas ($t$ = –0.118, $p$ = 0.008) was accompanied with a 12% BMI reduction | 1. Parkland proximity related to BMI: +<br>2. Parkland proximity related to overweight/obesity: –<br>3. Green and open space area related to BMI: – |
| 2 | Easier access to urban green space was related to lower odds of overweight or obesity when an urban green space was within 1 km (β = –0.320, $p$ < 0.01) | Accessibility of green space related to obesity: – |
| 3 | 1. A significant negative association between residential greenness and overweight/obesity (odds = 0.73, 95% CI = 0.58, 0.92)<br>2. A significant negative association between residential greenness and abdominal obesity (odds = 0.55, 95% CI = 0.33, 0.91) | 1. Residential greenness related to overweight/obesity: –<br>2. Residential greenness related to abdominal obesity: – |
| 4 | Each interquartile range (0.17 unit) increase in NDVI500-m was associated with 0.18 kg/m$^2$ (95% CI = 0.24, 0.11) lower BMI, 20% (95% CI = 26%, 13%) lower odds for peripheral obesity, and 12% (95% CI = 17%, 7%) lower odds for central obesity | 1. Community greenness related to BMI: –<br>2. Community greenness related to odds for peripheral obesity: –<br>3. Community greenness related to odds for central obesity: –<br>4. Community greenness related to odds for waist circumference: 0 |
| 5 | 1. In neighborhoods with a green space ratio lower than 28%, residents had a higher risk of overweight or obesity (OR = 1.22, 95% CI = 1.01, 1.46)<br>2. In neighborhoods with a green view index lower than 15%, residents had a higher risk of overweight/obesity (OR = 1.28, 95% CI = 1.09, 1.52)<br>3. Evergreen tree configuration was found to be associated with overweight/obesity (OR = 1.44, 95% CI = 1.09, 1.91) | 1. Green space ratio equal to or lower than 28% related to overweight/obesity: +<br>2. Green view index equal to or lower than 15% related to overweight/obesity: +<br>3. Evergreen trees configuration related to overweight/obese: + |
| 6 | Perception of large parks positively correlates to BMI (β = 0.169, SE = 0.087, $p$ = 0.053), while the perception of small parks has a negative association with BMI (β = –0.174, SE = 0.100, $p$ = 0.082) | 1. Perception of large parks related to BMI: +<br>2. Perception of small parks related to BMI: – |
| 7 | 1. Longer distance from parks relieves the risk of obesity or overweightness (β = –0.004, $p$ < 0.01)<br>2. No direct correlation between the NDVI and residents' BMI was found<br>3. View-based green index had an adverse effect on weight and obesity | 1. View-based green index related to obesity: –<br>2. NDVI related to BMI: 0<br>3. Distance from parks related to obesity/overweight: – |
| 8 | 1. Green coverage rate was an important factor affecting residents' BMI and has a significant negative impact on the risk of overweight or obesity ($p$ < 0.05)<br>2. Distance to park had a negative effect on individual BMI, which was significant at 10.0% and 5.0% levels at the scale of neighborhood and 1-km buffer, respectively | 1. Green coverage rate related to BMI, overweight, or obesity: –<br>2. Distance to the park related to BMI: – |
| 9 | 1. Street greenness (β = –0.132, 95% CI = 0.019, 0.257) and the number of parks surrounding schools (β = –0.118, 95% CI = 0.006, 0.204) were significantly negatively associated with BMI with the 400 m buffer<br>2. NDVI has no significant effect on body weight ($p$ > 0.05) | 1. Street greenness related to BMI: –<br>2. The number of parks surrounding schools related to BMI: –<br>3. NDVI related to body weight: 0 |
| 10 | 1. An interquartile range increase in NDVI-1,000 m was associated with lower zBMI (β = –0.11, 95% CI = –0.13, –0.09) and waist circumference (β = –0.64, 95% CI = –0.78, –0.50)<br>2. An interquartile range increase in NDVI-100 m, NDVI-500 m, and NDVI-1,000 m was associated with 7–20% lower odds of overweight/obesity | 1. NDVI-1,000 m related to zBMI: –<br>2. NDVI-1,000 m related to waist circumference: –<br>3. NDVI-100 m, NDVI-500 m, and NDVI-1,000 m related to odds of overweight/obesity: – |

Correlation: + positively, – negatively, 0 insignificantly. BMI, body mass index; NDVI, normalized difference vegetation index.

distance from parks was reported to be inversely associated with BMI in two studies [26, 43].

Fourth, a few studies reported a dose-response relationship between green space exposure and BMI. A one-unit (10%) increase in green space areas was estimated to be associated with a 12% reduction in BMI [39]. Self-perceived of small park size was inversely associated with BMI [42].

**Table 4.** Study quality assessment

| Study ID criterion | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Was the research question or objective in this paper clearly stated? | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2. Was the study population clearly specified and defined? | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3. Was the participation rate of eligible persons at least 50%? | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study pre-specified and applied uniformly to all participants? | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5. Was a sample size justification, power description, or variance and effect estimates provided? | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured? | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed? | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure or exposure measured as continuous variable)? | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| 9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants? | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| 10. Was the exposure(s) assessed more than once over time? | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants? | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| 12. Were the outcome assessors blinded to the exposure status of participants? | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13. Was loss to follow-up after baseline 20% or less? | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)? | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Total score | 7 | 5 | 7 | 8 | 7 | 5 | 6 | 7 | 6 | 8 |

This study quality assessment tool was adopted from the National Institutes of Health's Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies. For each criterion, a score of one was assigned if "Y" was the response, whereas a score of zero was assigned otherwise. A study-specific global score, ranging from 0 to 14, was calculated by summing up scores across all 14 criteria. Study quality assessment helped measure strength of scientific evidence, but was not used to determine the inclusion of studies.

*Pathways Linking Green Space to Obesity*

Several studies explored the pathways linking green space to obesity, such as air pollution, physical activity, and temperature. Among those studies, ambient $NO_2$ and $PM_{2.5}$ were found to mediate the estimated associations between greenness and weight outcomes [18, 21, 28]. Moreover, active commute to and from school was found to partially mediate the influence of urban greenness on BMI [27]. By contrast, three studies found no evidence that physical activity or sedentary behaviors mediated the greenness-adiposity associations [18, 21, 28]. Also, no mediation effect of perennial mean temperature was found for greenness and adiposity [18].

*Study Quality Assessment*

Table 4 reports criterion-specific and global ratings of the study quality assessment. The included studies, on average, scored seven out of 14 (ranging from five to eight). All studies included in the review clearly stated the research question or objective, defined the study population, had a participation rate of over 50%, recruited subjects from the same or similar populations during the same period, and pre-specified and uniformly applied inclusion and exclusion criteria to all potential participants. Nine studies measured and statistically adjusted potential confounding variables for the associations between exposures and outcomes. Eight studies implemented valid and reliable exposure measures. Five studies implemented valid and reliable outcome measures. Four studies examined different levels of exposure in relation to the outcome. By contrast, none of the studies adopted a longitudinal study design, had the outcome assessors blinded to the exposure status of the participants, provided a sample size justification using power analysis, measured exposures of interest before the outcomes, had a reasonably long follow-up period that was sufficient for changes in the outcomes to be observed, or assessed the exposures more than once during the study period.

## Discussion

This study reviewed the scientific literature linking green space to body weight status in China. Ten studies met the selection criteria and were included in the review. Overall greenness measures were found to be inversely associated with BMI, overweight, and obesity in most included studies. Street greenness, which measures the perceived greenness at the eye level on streets, was found to be inversely associated with BMI and obesity. By contrast, mixed results were observed for the relationship between green space accessibility and weight outcomes.

Coinciding with the reviews focusing on developed countries [12], we found mixed results on the relationship between green space and weight outcomes. Several reasons may explain the discrepancies. First, given the lack of randomization, self-selection might lead to opposite findings on the association between accessibility to green space and obesity. For example, China's urbanization has increased the risk of overweight among residents with higher-than-average income levels [44, 45], and those people might choose to live closer to green spaces [43]. In addition, studies measured greenness using different scales (e.g., 500 m or 1,000 m buffer), which may differentially relate to weight outcomes [46]. Yang et al. [26] recommended a walking distance of 1,000 m to green space to define a "walkable" neighborhood, whereas 300–400 m was used as the threshold because green space usage was found to decline rapidly above that [47]. The relationship between green space and obesity varies by green space measures [10]. For example, perceived street greenness tends to predict weight outcomes better than NDVI. Street greenness could more accurately capture residents' daily exposure to green space than NDVI since it represents eye-level perception.

In contrast, NDVI identifies greenness from the bird's-eye view. In addition, NDVI measurement does not provide detailed information about vegetation types of green space [48]. For example, NDVI extracted from remote sensing images includes farmland or forest unsuitable for physical activity [25, 28].

The influence of green space on obesity tends to vary by gender, age, and socioeconomic status. Boys, women, older residents, and those with lower education or household income were more likely to benefit from greenness [18, 21, 28]. The findings were largely consistent with prior studies conducted in developed countries, which found that women, older adults, and those with lower socioeconomic status benefited more from exposure to greenness [20, 29, 30, 48–50]. Such findings may inform future interventions targeting population subgroups and people with limited resources through increasing their proximity and accessibility to green space.

Many mediating factors (e.g., social cohesion, noise, stress) may be involved in the pathways linking green space to weight outcomes [18]. Physical activity was considered one of the main pathways [19], but several studies failed to identify relevant evidence [18, 21, 28, 39]. Differences in physical activity levels across age groups and diverse physical activity measures (e.g., intensity, duration, or metabolic equivalent task) might explain the mixed results [21].

Several limitations of this review and the included studies should be noted. First, we excluded most articles by performing title and abstract screening. It is suggested that future studies should screen articles according to the full texts and methodologies, which may be a more accurate method. Second, although this review compiled the results following systematic review guidelines, the relevant studies are scarce due to the scope of the review being limited to the sample of "studies conducted in China." This study could be an important review but may limit the level of evidence as a systematic review. Third, all studies adopted a cross-sectional study design, which could not infer causality between green space and obesity. Fourth, most studies were conducted in high population-density cities, and thus, the generalizability of study findings to smaller cities could be limited. Fifth, half of the studies used self-reported body weight measures prone to recall error and social desirability bias [51]. Finally, heterogeneous greenness exposure and outcome measures prevented meta-analysis.

Future research should investigate the role of affluence (e.g., social class, income level) in the relationship between green space and obesity. Longitudinal and quasi-experimental studies are warranted to assess the causal link between green space and obesity. Underlying mechanisms through which green space affects residents' weight outcomes should be further elucidated. With a deep understanding of the complex relationship between green space and obesity, at the proximal end, communities and individuals can prevent noncommunicable diseases by changing their lifestyles, living and working environments, and eating habits. In the long run, environments and behavior changes could potentially reduce health expenditure [52]. Future measures should better capture the self-perception, quality, and attractiveness of green space.

## Conclusion

This study systematically reviewed the scientific literature concerning the relationship between green space and weight outcomes among Chinese residents. Ten studies met the eligibility criteria and were included in the review. Overall greenness measures were found to be inversely associated with BMI, overweight, and obesity in most included studies, and street greenness was inversely associated with BMI and obesity. By contrast, mixed results were observed for the relationship between green space accessibility and weight outcomes. Air quality was found to mediate the relationship between greenness and obesity.

In conclusion, the literature on green space exposure in relation to obesity in China remains limited. Longitudinal and quasi-experimental studies are warranted to assess the causal link between green space and obesity. The underlying pathways through which green space affects residents' weight outcomes should be further elucidated.

## Statement of Ethics

An ethics statement is not applicable because this study is based exclusively on published literature.

## Conflict of Interest Statement

The authors have no conflicts of interest to declare.


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## Author Contributions

J.S. conceived and designed the study and wrote the manuscript. M.L. and Q.W. conducted the literature review and constructed the summary tables and figures. R.L. contributed to manuscript drafting. M.J. and R.A. contributed to manuscript revision. All authors have read and agreed to the published version of the manuscript.

## Data Availability Statement

A data availability statement is not applicable because this study is based exclusively on published literature.

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