Greenspace with Overweight and Obesity: A Systematic Review and Meta-analysis of Epidemiological Studies Up to 2020

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Abstract

Background: Several reviews have been conducted to assess the association between greenspace and overweight or obesity, but the conclusions were inconsistent. However, an updated comprehensive review and meta-analysis is warranted, because several high-quality papers have been published more recently.

Objectives: To systematically and quantitatively assess the evidence for a link between greenspace with overweight/obesity, and to make specific recommendations for further research.

Methods: We searched three English language databases, four Chinese language databases and the reference lists of previously published reviews for epidemiological studies on greenspace and overweight/obesity published before January 2020. We developed inclusion criteria, screened the literature, and extracted key data from selected papers. We assessed methodological quality and risk of bias, and we graded the credibility of the pooled evidence. We also performed sensitivity analyses.

Results: Fifty-seven records met our inclusion criteria and were included in the study. Most studies were cross-sectional designs (81%) and were from developed nations (88%). More than half (55%) of the included studies found beneficial associations between greenspace and overweight/obesity in overall or sub-populations. Our meta-analytical results showed that greater Normalized Difference Vegetation Index was associated with lower odds of overweight/obesity in a statistically significant fashion (OR: 0.88; 95% CI: 0.84, 0.91), but not residential proximity to greenspace (OR: 0.99; 95% CI: 0.99, 1.00), proportion of greenspace (OR: 0.96; 95% CI: 0.85, 1.08) or number of parks in an area (OR: 0.99; 95% CI: 0.97, 1.01).

However, we detected high between-study heterogeneity in two of the four meta-analyses, which reduced the credibility of the pooled evidence.

Conclusions: Current evidence indicates that there might be an association between greater access to greenspace and lower odds of overweight/obesity. However, additional high-quality studies are needed to more definitively assess the evidence for a causal association.

Keywords: Greenness, adiposity, body-mass-index, review

1. Introduction

Obesity is a leading contributor to the global burden of disease (e.g., diabetes, cardiovascular diseases and cancer) and early death (1, 2). The number of people with obesity worldwide grew from 150 million in 1975 to 641 million in 2014 (3). Although many studies demonstrate that genetic factors and individual behavior play prominent roles in obesity (4, 5), these are unlikely to explain the upsurge in obesity over the past few decades (6). Accumulating evidence suggests that features of the built environment, such as land use, might play a role in contributing to adiposity (7). Greenspace exposure (i.e., access to and/or availability of areas with vegetation, such as parks, gardens, and forests), in particular, has attracted growing interest in recent years, and it has been speculated that greenspace exposure may affect obesity (8-10). Mechanistically, greenspace could mitigate harmful environmental exposures (e.g. noise, air pollution), encourage health-related behaviors (e.g. physical activity), enhance psychophysiological recovery (e.g. stress alleviation) as well as facilitate social cohesion (11); these beneficial responses are correlated with the pathophysiologic pathways of obesity (12-14).

Numerous epidemiological studies have investigated associations between greenspace exposure and obesity and body mass index (BMI) in different populations, but the results have been heterogeneous. Six prior reviews synthesized epidemiological studies on this topic (15-19, 94), although none performed a meta-analysis. Three of the previous reviews focused on multiple features of the built environment, and greenspace was only considered as one of them (15, 17, 19). Two reviews (16, 18) focused on associations between greenspace exposure and human health endpoints, including obesity. However, several important studies were not included in those reviews. In addition, one review focused on greenspace and obesity, but included only 10 studies (94). Consequently, the six previous reviews included 25 studies, suggesting that important studies were not covered (20-26). The summarized findings of these recent reviews were inconsistent. For example, James et al. (16) concluded a lower risk of obesity associated with more greenspace, while Schulz et al. (15) reported no association. Further, these reviews included articles published before 2016, and so could not incorporate several more recent high-quality articles on this topic (9, 10, 27-47).

In the absence of an updated synthesis of the relevant literature on this topic, here we aim to systematically review epidemiological studies on associations between greenspace exposure and overweight/obesity. Our focused question of the present systematic review and meta-analysis was: Is greenspace exposure associated with overweight/obesity?

2. Methods

2.1. Search strategy

We conducted the study following standard protocols recommended by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (48) (Table S1).We systematically searched three English language databases (PubMed, Embase, and Web of Science) and four Chinese language databases (CBM, CQVIP, Wanfang Data, and CNKI) to find epidemiologic studies of greenspace and obesity. We used combinations of terms concerning greenspace (e.g., "greenspace," "green space," "greenness," "greenery," "open space," "greenbelt") and obesity (e.g., "obesity," "obese," "adiposity," "overweight," "bodyweight," "body weight," "body mass index," "body fat mass," "waist-to-hip ratio," and "waist circumference") for the search. We also manually searched the reference lists of the included studies as well as pertinent review articles (15-19) for additional citations. Our search was limited to studies written in English or Chinese. The detailed search strategy is presented in Table S2.

2.2. Inclusion criteria

We retained identified studies that: (I) explored the association between greenspace and overweight/obesity; (II) were cohort, case-control, cross-sectional or panel study designs; (III) assessed greenspace exposure using an objective measure (e.g., normalized difference vegetation index (NDVI), a vegetation index that assesses chlorophyll calculated as the ratio of near-infrared minus red light divided by near-infrared plus red light, and measured distance to the nearest green space) or subjective measures (e.g., self-reported proximity to the nearest park, frequency of visits to parks/greenspaces, etc.); (IV) obesity was assessed using BMI, waist circumference (WC), or whole body fat (WBF); (V) and was published in a peer-reviewed journal before Jan 16th, 2020. For duplicate publications from the same study, the paper that reported the more detailed methods was included. For example, two papers referring to the same study were published in 2011 (49) and 2012 (50). In our review, we included the more comprehensive and detailed 2011 publication (49).

2.3. Study selection

All potentially relevant articles were downloaded into reference manager software [EndNote X9.2 (Clarivate Analytics, Philadelphia, PA, USA)]. One investigator (YNL) deleted duplicates using the function of the software, and two investigators (YNL and WZH) then screened the titles and abstracts to eliminate obviously irrelevant articles from the remaining citations. Finally, two independent investigators (YNL and WZH) screened the full text of relevant articles, and any disagreement was resolved in a discussion with a third investigator (BYY).

2.4. Data extraction

For each eligible study, the following information was extracted: authors, publication year, participants' age, study design, study setting, assessment of greenspace exposure, obesity measurement methods, covariates, sample size, and effect estimates [e.g., odds ratio (OR), risk ratio (RR), or regression coefficient (β)] and their corresponding 95% confidence intervals (CI) or standard errors. For articles reporting multiple exposures and/or outcomes, each was considered as an independent analysis. Two investigators (YNL and WZH) extracted the data independently, and discrepancies were resolved by a third investigator (BYY).

2.5. Assessment of studies

2.5.1. Quality assessment

We employed the Newcastle-Ottawa Scale (NOS) (51) to evaluate the quality of cohort, case-control, and panel studies. The NOS contains eight items grouped into three dimensions. Each item is scored with 0 or 1 star, except for one item ("control confounders") that is scored with 0–2 stars, resulting in a maximum score of 9 stars. We classified a score greater than 7 as a "high quality," otherwise the study was categorized as "low quality." We used the Joanna Briggs Institute (JBI), Practical Application of Clinical Evidence System (JBI PACES) (http://www.joannabriggs.edu.au/) to rate the quality of cross-sectional studies. Each study was evaluated as a JBI score from 0 to 20, and a score greater than 16 was categorized as a "high quality" study.

2.5.2. Risk of bias assessment

We assessed the risk of bias (ROB) for each study, defined as characteristics of a study that can introduce systematic errors into the magnitude or direction of effect estimates (52). We further applied the U.S. National Institutes of Environmental Health Sciences National Toxicology Program Office of Health Assessment and Translation (OHAT) (53) and University of California at San Francisco (UCSF) Navigation Guide (52, 54) to assess the ROB. The included studies were assessed for key criteria (i.e., exposure assessment, outcome assessment, and confounding bias) and other methodologic criteria (i.e., selection bias, attrition/exclusion bias, selective reporting bias, conflict of interest, and "other" sources of bias). Each criterion was assessed as "low," "probably low," "probably high," or "high" risk for bias according to specific guidelines (Table S3). Following OHAT tool recommendations, we excluded studies from the systematic review that were classified as ‘‘high” or ‘‘probably high” risk of bias for key criteria and for most of the other criteria.

Two investigators (YNL and WZH) independently rated the quality and ROB of the included studies, and any conflict was adjudicated by a third investigator (BYY).

2.6. Statistical analysis

Considering that the included studies assessed greenspace exposure using multiple metrics, we classified greenspace exposure assessment strategies into five groups: (I) NDVI; (II) residential proximity to the nearest green space; (III) proportion of greenspace within 30m-1600m buffer around residential address; (IV) number of parks in a certain area; and (V)“other” (e.g., greenery, shrub density, etc.). In addition, we performed meta-analyses for overweight/obesity with NDVI, residential proximity to the nearest greenspace, proportion of greenspace, and number of parks in a certain area. Most studies reported ORs and only a few studies reported other effect measures like RRs (4 studies) or prevalence ratios (PR; 2 studies). Since the prevalence of overweight was always high (i.e., 39%) (55), OR were likely to be different from other effect measures, such RRs (56). Therefore, we only extracted and pooled ORs from individual studies using the inverse variance method. To compare effect sizes from different studies, we standardized all effect estimates unit to a 0.1 difference in NDVI, per 500 meters difference in residential distance to the nearest greenspace, per 1 % difference in proportion of greenspace, and per 1 park difference in the number of parks, according to the following formula:

$$\mathrm{OR}_{\mathrm{Standardized}} = \mathrm{e}^{\left(\frac{\ln(\mathrm{OR}_{\mathrm{Origin}})}{\mathrm{Increment}_{\mathrm{Origin}}} \times \mathrm{Increment}_{\mathrm{Standardized}}\right)}$$

We assessed between-study heterogeneity using I^2 statistics (I^2 = 0-25%: no heterogeneity; (I^2 = 25-50%: moderate heterogeneity; I^2 = 50-75%: large heterogeneity; I^2=75-100%: extreme heterogeneity). Where $I^2 > 50\%$, the inverse variance heterogeneity model (57, 58) was used to pool effect estimates; otherwise, the Mantel- Haenszel fixed effect model was used to pool effect estimates. We also performed sensitivity analyses by excluding each study and repeating the analysis to estimate the impact. Finally, we graded the credibility of the pooled evidence based on the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) working Group guidelines (60).

All statistical analyses were performed using the STATA software package version 11.0 (StataCorp, College Station, TX, USA) and MetaXL v.5.3 software (EpiGear International Pty Ltd, Sunrise Beach, Queensland, Australia, www.epigear.com). $P<0.05$ for a two-tailed test was regarded as statistically significant.

3. Results

3.1. Literature retrieval and study characteristics

Figure 1 summarizes the selection of studies for our review. The initial search of seven electronic databases yielded 27,698 articles, and 30 additional articles were retrieved from reference lists of review articles. There were 4,328 duplicates removed. The titles and abstracts of the remaining 23,400 articles were screened, and irrelevant articles were eliminated. A total of 104 papers underwent full text evaluation. After full text review, we excluded 40 additional articles that were irrelevant, six review articles, and one articles that repeated data (Table S9). Finally, we retained 57 articles (67 analyses) that met our inclusion criteria in the review.

The basic characteristics of the 57 included articles (67 analyses) are shown in Table 1. Most (80%) of the studies were published during the past 10 years, underscoring the growing interest in greenspace and obesity. We included studies from 17 different countries, of which 15 are considered to be "developed" nations, and two are "developing" countries, including China and Egypt. Forty-six studies were cross-sectional designs and 11 were cohort studies. 17 studies assessed greenspace exposure using residential proximity to green spaces, 15 studies adopted NDVI, 21 studies employed proportion of greenspace, nine studies used number of parks in a certain area, and five studies used other metrics. Body mass index was used to measure and/or define overweight or obesity in 66 analyses, and four studies employed WC or WBF. Sample size varied widely across studies, ranging from 108 children to more than 97 million adults. We rated nine cohort studies and 30 cross-sectional studies as "high quality" according to the NOS or JBI, respectively, and the remaining 18 as "low quality" (Table S4). With respect to the ROB assessment, none of the included studies was excluded because of high ROB (Table S4).

3.2. NDVI and overweight/obesity

Eleven studies, including two cohort studies (9, 21) and nine cross-sectional studies (23, 27, 36, 37, 39, 41, 47, 61, 62), examined the association between NDVI and dichotomous overweight/obesity (Figure 2). Among them, six studies (23, 27, 36, 39, 47, 61) detected a statistically significant protective association (e.g., the estimated ORs ranged from 0.67 to 0.99) in the overall sample. Two studies (9, 45) detected statistically significant associations between NDVI and dichotomous overweight/obesity in sub-samples. For example, a cohort study by Persson et al. (9) explored associations between obesity and NDVI in buffers (bounded areas of a specific dimension surrounding each residential location in which NDVI was quantified) of 100m, 250m, and 500m among 5,126 Swedes. They found that each 0.07 increase in NDVI 500m was significantly associated with 12% decreased odds of obesity in females (OR: 0.88; 95% CI:0.79, 0.99), but not in males. No statistically significant association was found in the remaining three studies.

We also found seven studies, including two cohort studies (8, 30) and five cross-sectional studies (27, 44, 47, 61, 63), that focused on associations between NDVI and continuous BMI. Six of them (8, 27, 44, 47, 61, 63) reported statistically significant associations between greater NDVI levels and lower BMI (i.e., estimated β values ranged from -0.18 to -0.05). Three studies also used WC or WBF to define overweight/obesity (9, 27, 47). Sarkar and colleagues (43) found that, among 333,183 UK participants aged 38–73 years, each interquartile (0.24) increment in NDVI 500m was associated with a reduction of 0.551 cm (95% CI: -0.61, -0.50) in WC as well as a reduction of 0.138 kg in WBF (95% CI: -0.18, -0.10). Persson et al. (9) reported that each 0.07 increase in NDVI-500m was associated with a 0.110 cm smaller WC increase per year in 5126 Swedish women (95% CI: −0.144, −0.076). However, Huang et al. (38) reported no statistically significant association for greenspace and WC.

In our meta-analysis, the pooled effects of six studies showed that NDVI was significantly associated with overweight/obesity (OR: 0.88; 95% CI: 0.84, 0.91; $I^2 = 39\%$) (Table 2, Fig.S1). In sensitivity analyses, when any single study was excluded, the pooled estimates were not materially changed (Table S5). Based on the GRADE system, confidence in the cumulative evidence was “Low” (Table 2).

3.3. Residential proximity to the nearest greenspace and overweight/obesity

Five studies examined the association of residential proximity to the nearest greenspace with BMI (Figure 3), including one cohort study (28) and four cross-sectional studies (24, 64-66). Only one study detected a statistically significant association. Specifically, Rundle et al. (24) reported that closer proximity to a large park space was significantly associated with a lower BMI (β: -1.69; 95% CI: -2.76, -0.63) in 13102 adults from New York City. However, Zhang et al. (28) investigated the association between network distance to the nearest parks and BMI levels in 8,365 Mexican American women and found that a 1-km increase in distance to the nearest parks was associated with 0.29 kg/m^2 (95% CI: -0.47, -0.1) decrease in BMI levels.

Fourteen studies, including one cohort study (28) and 13 cross sectional studies (20, 25, 26, 31, 36, 39, 45, 65, 67-71), investigated associations between proximity to the nearest greenspace and dichotomous overweight/obesity. Five studies reported statistically significant and beneficial associations between greenspace and overweight/obesity (25, 31, 67, 68, 71) For example, in a study of 21,832 Danish adults, Toftager et al. (67) reported that persons living more than 1 km from greenspace had higher odds of obesity (BMI≥30) than those living less than 300 m from greenspace (OR: 1.36; 95% CI: 1.08, 1.71). However, two studies (26, 28) reported contradictory associations. Zhang et al. (28) found that greater distance to the nearest park was associated with lower odds of obesity (OR: 1.01; 95% CI: 1.00, 1.01) in 41,283 American children. In another study (26), distance to the nearest park becomes significant and inversely associated with obesity for women, (OR: 0.96; 95% CI: 0.94, 0.99), but not for men (OR: 0.99 95% CI: 0.97, 1.01). The remaining seven studies did not report a statistically significant association between proximity to the nearest greenspace and overweight/obesity.

We performed a meta-analysis of four studies investigating overweight/obesity and proximity to the nearest greenspace, and found that the pooled association was not statistically significant (OR: 0.99; 95% CI: 0.99, 1.00) (Table 2, Fig.S2). Sensitivity analyses excluding each study one by one did not change the overall estimates (Table S6). Confidence in the pooled estimate was "Very low" based on the GRADE system (Table 2).

3.4. Proportion of greenspace and overweight/obesity

Sixteen studies, including two cohort studies (10, 35) and 14 cross-sectional studies (22, 26, 32, 40-42, 49, 69, 70, 72-76), investigated the association between proportion of greenspace in a certain area and dichotomous overweight/obesity (Figure 4). Six studies reported statistically significant lower risks of obesity in association with greenspace (10, 22, 26, 32, 35, 41). For instance, a study (41) conducted among 97,574,613 adults found that greater percent tree canopy cover was significantly associated with lower obesity (OR = 0.974, $p < 0.05$). Schalkwijk et al. (35) observed that percentages of greenspace less than 30% were associated with greater odds of childhood overweight/obesity (OR: 1.14; 95% CI: 1.02, 1.27) in 6,467 children from the UK Millennium Cohort Study. In addition, Dempsey et al. (40) found a U-shaped relationship between urban areas greenspace and obesity within a 1.6km buffer zone; those living in areas with the lowest and highest shares of greenspace had the highest probabilities of being obese (BMI⩾30). However, two studies (42, 75) reported counterintuitive associations between greenspace and obesity. Cummins and Fagg (75) found that residing in areas with the highest proportion of greenspace was significantly associated with greater odds of overweight (12%) and obesity (23%) from 2000-2003, but not from 2004-2007. Wilhelmsen (42) reported that the odds for overweight was 1.38 (95% CI: 1.02, 1.85) times larger in the greenest areas compared to the least green areas, within a 1km buffer. The remaining five cross-sectional studies found no statistically significant association between percentage of greenspace and overweight/obesity.

Six studies, including two cohort studies (77, 78) and four cross-sectional studies (34, 43, 64, 72), investigated the association between percentage of greenspace in a certain area and BMI level; three of them (43, 72, 78) detected a statistically significant association. For example, Sander et al. (43) showed that recreational park percentage was negatively related to mean BMI in middle-aged females residing in 546 Cleveland, Ohio U.S. Census block groups ($\beta = -0.015$, $p < 0.05$).

In our pooled meta-analysis, effect estimates of six studies concerning proportions of greenspace and overweight/obesity (Table 2, Fig.S3), showed that a higher proportion of greenspace was associated with lower odds of overweight/obesity, although the association did not reach statistical significance (OR: 0.96; 95% CI: 0.85, 1.08; $I^2 = 97\%$). Sensitivity analyses indicated that the pooled results were robust to the impact of individual studies (Table S7). Our confidence in the cumulative evidence was "Very low" based on the GRADE system (Table 2).

3.5. Number of parks in a certain area and overweight/obesity

Nine epidemiologic studies, including two cohort studies (29, 33) and seven cross-sectional studies (64, 69, 70, 79-82), investigated the association between the number of parks in an area and BMI or overweight/obesity (Figure 5). Two of them (33, 79) reported a statistically significant association between number of parks and overweight/obesity. For example, Scott et al. (79) found that higher park numbers were associated with lower BMI in a sub-population of non-Hispanic whites ($\beta = -0.01$, $p = 0.04$). In a meta-analysis of five studies, the pooled OR for overweight/obesity was 0.99 (95% CI: 0.97, 1.01) per 1 park increase (Table 2, Fig.S4). No heterogeneity was detected for the five studies ($I^2 = 0\%$). Sensitivity analyses indicated that the pooled estimates were robust to the results of individual studies (Table S8). Based on the GRADE system, the credibility of the pooled evidence was "Very low" (Table 2).

3.6. Other greenspace exposures and overweight/obesity

Five cross-sectional studies (38, 46, 83-85) investigated the correlation between "other" measures of greenspace exposure (e.g., density of street trees, greenery, etc.) and overweight/obesity (Figure 6). All of them detected a statistically association. For example, Lovasi et al. (83) found that the density of street trees was significantly associated with the prevalence of obesity (PR: 0.88; 95% CI: 0.79, 0.99), in 11,562 children (3-5 years of age).In addition, Li et al. (38) measured green space exposure using a green view index (GVI) and found that a higher GVI was associated with lower BMI in a sub-population of middle-aged men. However, due to the limited number of studies, we did not perform a meta-analysis of the results from "other" greenspace metrics and measures of overweight/obesity.

4. Discussion

4.1. Key findings

In this systematic review and meta-analysis, we comprehensively summarized the published epidemiologic evidence on greenspace exposure and overweight/obesity to date. We included 57 epidemiologic studies covering 17 countries, 88% of which were performed in developed countries. Forty-six studies (81%) were published in the past 10 years, indicating the rapid growth of epidemiological interest in this field since 2005, when the first included study was published. More than half (55%) of the reviewed studies reported beneficial associations between greenspace and overweight/obesity in the overall sample or in sub-populations. The results of a meta-analysis showed that greater NDVI was significantly associated with lower odds of overweight/obesity, but not residential proximity to greenspace, proportion of greenspace, or number of parks in an area. However, high between-study heterogeneity was detected in two of the four meta-analyses, limiting the credibility of the pooled evidence. Statistically significant associations were also reported by studies investigating other greenspace metrics and obesity outcomes, but the number of those studies was too few to facilitate a meta-analysis.

4.2. Comparison with prior reviews and interpretations

Six previously published reviews summarized the associations of greenspace with overweight/obesity (15-19, 94). In 2009, Dunton et al. (17) included three studies published before 2007 and found that the number of and/or distance to parks and the presence of parks was not correlated with BMI. In 2010, Lachowycz and Jones (18) reviewed 13 studies from three developed countries and reported that most found a beneficial association between greenspace and BMI, but the results remained mixed across population sub-groups and different greenspace measures. In 2014, Mackenbach and colleagues (19) included seven studies and found that greenspace exposure was consistently and beneficially associated with overweight/obesity. In 2015, James et al. (16) reviewed the relationships of greenspace with overweight/obesity among 11 studies from six developed countries and one developing nation. They concluded that there may be an inverse association between greenspace and overweight/obesity. In 2016, Schulz and colleagues (15) included four German studies focused on greenspace and obesity and concluded that there was no association between greenspace and obesity. A more recent systematic review (94) included 10 studies related to greenspace and obesity, and found that eight of them demonstrated a positive correlation between the two. By comparison, the results from previously published reviews were differed from our results in some respects, which may be due in part to differences in the number and characteristics of the studies included. In addition, our review incorporated the most recent literature, through January 16th, 2020. Consequently, we captured 57 studies reporting on more than 100 million study participants in total, much more than the six previously published reviews. Further, we evaluated individual study quality and risk of bias using recommended assessment tools, which provided a more objective evaluation of the existing evidence. Importantly, we focused on multiple metrics of greenspace and performed meta-analyses to quantify the current evidence. Therefore, we believe that our review provides greater insight into the nature of epidemiologic associations between greenspace and overweight/obesity than previously available.

4.3. Potential mechanisms

The exact biopsychosocial pathways underlying the association between greenspace and overweight/obesity are as of yet unclear. However, several hypotheses have been suggested for mechanisms that drive the associations reported for greenspace and general health status or other health outcomes. First, living close to greenspace, such as parks, may increase opportunities and motivation for physical activity (86), which is an important protective factor for obesity (87). Additionally, access to greenspace may offer opportunities for social interaction. A review by Glonti et al. (13) found significant associations for higher levels of social cohesion or strong social bonds with a lower risk of obesity. Evidence also indicates that high levels of stress could contribute to obesity (12). Greenspace has been indicated as an environmental resource for psychological restoration, which could help to alleviate stress (86). Moreover, vegetation may reduce exposure to ambient air pollution and noise (11). A recent review linked higher noise exposure to greater waist circumference (88), and evidence indicates that air pollution may contribute to obesity (14). Finally, recent research suggests that obesity is an inflammatory disease (89), and Rook et al. (90) found that exposure to multiple bacteria present in greenspace may transmit immunoregulatory benefits and reduce inflammation.

4.4. Limitations and strengths

Several limitations should be noted for proper interpretation of our results. First, we pooled results from studies that used different exposure (e.g., ecological geographic information system data versus individual self-report) and outcome assessment strategies (e.g., clinical medical records vs. self-report), which might bias the effect estimates. Second, approximately 32% (18/57) of the included studies were categorized as "low quality" according to GRADE criteria, and had high between-study heterogeneity, which might have compromised the robustness of the overall evidence. We did not detect any source of heterogeneity as there are not enough articles to do a meta-regression. Third, although there were a few studies from developing countries, such as China and Egypt, most of the included studies came from developed countries. Many factors, such as the proportion and rate of urbanization, may introduce differences in the association of greenspace with overweight/obesity between developed and developing nations. Thus, the current evidence may not be generalizable to populations in developing countries. Fourth, statistical modeling strategies varied greatly, with different confounding factors assessed by different studies. For example, Liu, et al. (62) adjusted for age, race/ethnicity, and gender in their statistical models, while Wilhelmsen, et al. (42) adjusted for age, gender, ethnicity, physical activity, transportation mode, use of nature, social support from friends and family, family situation, diet, smoking habits, county, moving history, and climatic confounders. Thus, some studies might have over- or under-adjusted for confounding factors, leading to biased effect estimates. Fifth, most of the included studies explored modification of effects according to several factors (e.g., age, gender, etc.) in subgroup analyses. In the interests of space, given the rich set of greenspace exposure metrics and obesity outcome metrics included in this review, we focused on the overall sample results in the selected studies. Thus, our results may not be relevant for vulnerable population subgroups. Sixth, studies with statistically null results are less likely to be published than studies with statistically significant, so publication bias is possible. Unfortunately, we did not perform any formal publication bias test, due to the small number of pooled studies (59). Seventh, most of the studies selected for this study used cross-sectional designs, so we cannot evaluate the temporality of the reported relationships between greenspace and overweight/obesity or draw inference on causality, and cannot exclude "reverse causation" (e.g., more active people select to live in greener neighborhoods). In addition, we only included studies published in peer-reviewed journals, so we may have missed important papers published in the "grey" literature. Finally, we only included studies published in English and Chinese, thus it is possible that studies written in other languages, with results systematically different from those we selected, were missed.

Nevertheless, we provided the most comprehensive and systematic assessment of the current epidemiological evidence on greenspace and overweight/obesity to date; a rich set of greenspace and overweight/obesity metrics were covered. Additionally, we employed the inverse variance heterogeneity model to pool effect estimates, which outperforms the more traditional random effects model. The inverse variance heterogeneity model favors larger studies, retains a correct coverage probability, and exhibits a lower observed variance, regardless of study heterogeneity (57). Furthermore, we assessed the quality and risk of bias of each of the studies, graded the credibility of the pooled evidence, as well as pointed out the limitations and gaps of current literature. Therefore, our results may be helpful for researchers in this field to further investigate the greenspace-overweight/obesity association and to improve the design of future studies, as well as for policy makers to design strategies to mitigate the obesity burden.

4.5. Recommendations for future studies

Future high-quality studies using a standardized design should be implemented to improve our understanding of this association. In particular, we recommend that future studies should focus on longitudinal and quasi-experimental study designs to ensure temporality of the exposure-outcome association, to provide robust evidence of a causal relationship, and to rule out neighborhood self-selection or reverse causation. In addition, each greenspace metric has its own advantages and disadvantages, so the comprehensive use of multiple greenspace exposure metrics in parallel may better reflect the true exposure. Furthermore, a dynamic greenspace exposure assessment strategy (91), which accounts for changes in greenspace over time, can also be used to capture more accurate greenspace exposure. For obesity assessment, in addition to BMI, other indicators like waist circumferences or waist-to-height ratio, which are strongly related to adverse metabolic outcomes (92), should also be included in future studies. Due to the unclear nature of mechanisms underlying the association between greenspace and overweight/obesity, mediators (e.g., physical activity and air pollution) of the association between greenspace and overweight/obesity should be considered, and mediation analyses are warranted to clarify the potential mechanisms that underpin the associations. In addition, confounder selection should be based on advanced methods, such as directed acyclic graphs (DAGs) (93) to ensure proper adjustment and to minimize bias in statistical models. Finally, future studies should also shed more light on the association between greenness and overweight/obesity in developing countries, where the urbanization rate is high, deconstruction of the natural environment is severe, and the prevalence of obesity prevalence is growing.

5. Conclusions

The results of this review and meta-analysis indicate that there might be an association between greater access to greenspace and lower odds of overweight/obesity. However, because of high between-study heterogeneity and a limited number of available studies, a robust conclusion cannot be drawn.

Conflicts of interest

None

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Figure legends

Figure 1. Flowchart of study selection.

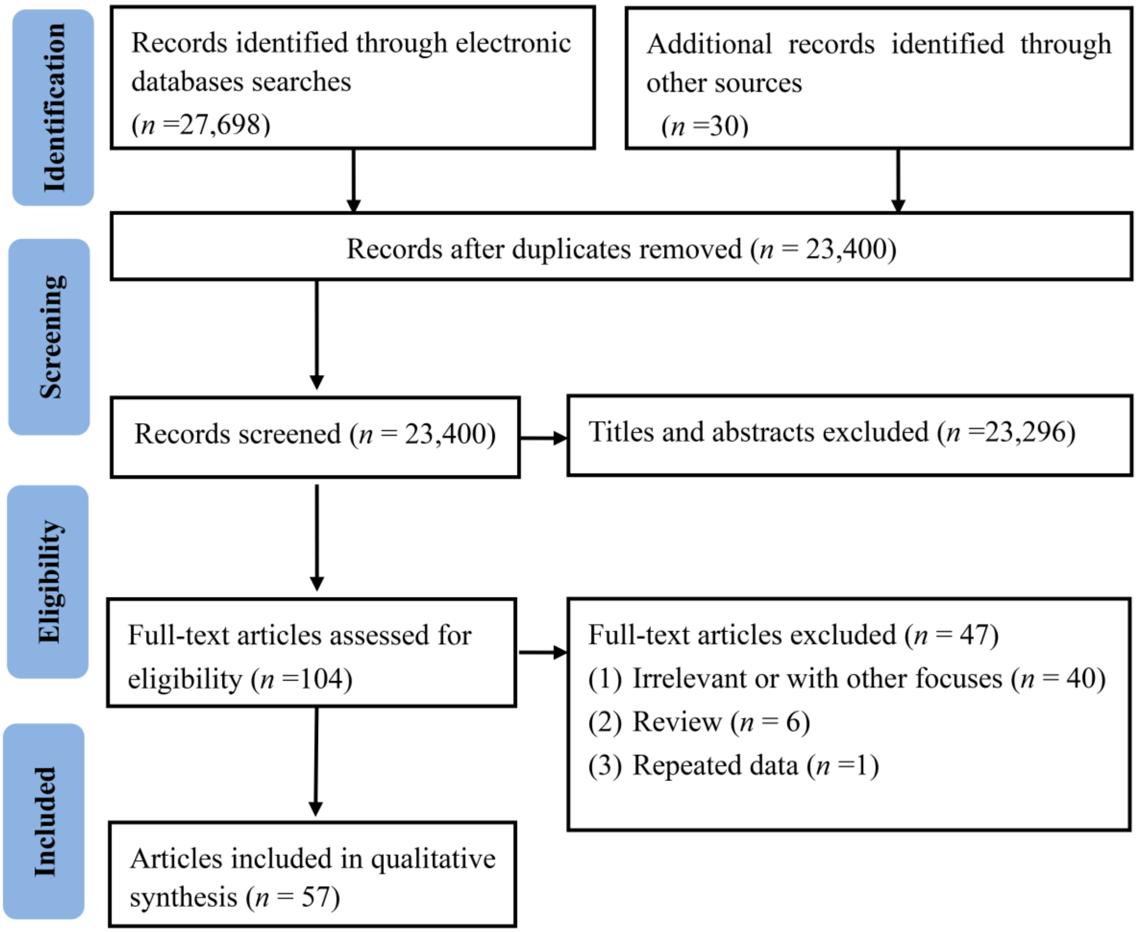

Figure 2. Overview of studies examining associations between NDVI and overweight/obesity. The direction of the effect is denoted by "+" for a positive association; "0" for no association; and "(+)" for non-significant associations in the overall sample, but significant associations that are restricted to subgroups. BMI: Body Mass Index; NDVI: Normalized Difference Vegetation Index; WC: Waist Circumference; WBF: Whole Body Fat;

Author (year)	BMI	Overweight/obesity	WC /WBF
Huang et al. (2020)	+	+	0
Benjamin-Neelon et al. (2019)	0		
Browning & Rigolon (2018)		0	
Klompmaker et al. (2018)		+	
Ortega Hinojosa et al. (2018)		0	
Persson et al. (2018)		(+)	(+)
Petraviciene et al. (2018)		+	
James et al. (2017)	(+)		
Sarkar et al. (2017)	+	+	+
Dadvand et al. (2014)	+	+	
Paquet et al. (2014)		0	
Pereira et al. (2013)		+	
Bell et al. (2008)	+		
Liu et al. (2007)		(+)	
Tilt et al. (2007)	+		

Figure 3. Overview of studies examining associations between residential proximity to the nearest greenspace and overweight/obesity. The direction of the effect is denoted by "+" for a positive association; "0" for no association; "-" for a negative association; and "(+)" for non-significant associations in the overall sample, but significant associations that are restricted to subgroups. BMI: Body Mass Index.

Author (year)	BMI	Overweight/obesity
Zhang et al. (2019)	+	-
Klompmaker et al. (2018)		0
Petraviciene et al. (2018)		0
Yang et al. (2018)		+
Akpinar et al. (2017)		0
Alexander et al. (2013)		0
Rundle et al. (2013)	+	
Hoehner et al. (2012)	0	
Wen & Kowaleski-Jones (2012)		+
Toftager et al. (2011)		+
Wen & Maloney (2011)		-
Coombes et al. (2010)		+
Brown et al. (2009)	0	0
Potestio et al. et al. (2009)		0
Witten et al. (2009)	0	
Potwarka et al. (2008)		0
Nielsen & Hansen (2007)		+

Figure 4. Overview of studies examining associations between the proportion of greenspace in a certain area and overweight/obesity. The direction of the effect is denoted by "+" for a positive association; "0" for no association; "-" for a negative association; as well as "(-)" and "(+)" for non-significant associations in the overall sample but significant associations that are restricted to subgroups. BMI: Body Mass Index.

Author (year)	BMI	Overweight/obesity
Feng et al. (2018)		+
Schalkwijk et al. (2018)		+
Dempsey et al. (2018)		(+)
Browning & Rigolon (2018)		+
Villeneuve et al. (2018)		+
Sun et al. (2018)	0	
Sander et al. (2017)	(+)	
Wilhelmsen et al. (2017)		-
Ying et al. (2015)	+	0
Sanders et al. (2015)	0	
Pearson et al. (2014)		+
Astell-Burt et al. (2014)		(+)
Richardson et al. (2014)		0
Hoehner et al. (2012)	0	
Cummins & Fagg (2012)		(-)
Prince et al. (2011)		(+)
Wen & Maloney (2011)		+
Wolch et al. (2010)	+	
Potestio et al. (2009)		0
Li et al. (2008)		0
Potwarka et al. (2008)		0

Figure 5. Overview of studies examining associations between the number of parks in a certain area and overweight/obesity. The direction of the effect is denoted by "+" for a positive association; "0" for no association; and "(+)" for non-significant associations in the overall sample, but significant associations that are restricted to subgroups. BMI: Body Mass Index.

Author (year)	BMI	Overweight/obesity
Hobbs et al. (2019)	0	0
van der Zwaard et al. (2018)	+	
Hoehner et al. (2012)	0	
Mowafi et al. (2012)	0	
Scott et al. (2009)	(+)	
Potestio et al. (2009)		0
Oreskovic et al. (2009)		0
Potwarka et al. (2008)		0
Norman et al. (2006)	0	

Figure 6. Overview of studies examining associations between "other" greenspace metrics and overweight/obesity. The direction of the effect is denoted by "+" for a positive association; "0" for no association; and "(+)" for non-significant associations in the overall sample, but significant associations that are restricted to subgroups. BMI: Body Mass Index, GVI: Green View Index.

Author (year)	"Others"	BMI	Overweight/obesity
Li et al. (2018)	GVI	(+)	
Tsai et al. (2016)	Density of shrub land	+	
Lovasi et al. (2013)	Density of street trees		+
Bjork et al. (2008)	Mean natural values		+
Ellaway et al. (2005)	Visible greenery		+

Table 1. Characteristics of the included studies.

Authors (year)	Population	Study design	Country	Sample size	Exposures	Outcomes	Results	Covariate adjustment
Akpinar et al. (2017)	General	Cross-sectional	Turkey	422 children	Distance to urban green spaces by seven levels	Overweight （BMI）	Distance to urban greenspaces from home did not show significant relationships with children's overweight β(SE): -0.001(0.01); p>0.05.	Children's sex, age, and parents' monthly income.
Alexander et al. (2013)	General	Cross-sectional	USA	42,278 children	Access to recreational parks (yes or no)	Obesity (BMI)	No significantly association between access to recreational parks and obesity, PR (95% CI): 0.77(0.55, 1.07). PR=prevalence ratios.	Age, race/ethnicity, maternal and paternal education, socioeconomic status, geographic location, and living status.
Astell-Burt et al. (2014)	General	Cross-sectional	Australia	246,920 adults (⩾45 years)	Percentage of green space within a 1-km buffer by five levels	Overweight/obesity（BMI）	Women with over 80% to green space had relative risk ratios of 0.90 (95% CI: 0.83, 0.97) for overweight and 0.83 (0.74, 0.94) for obese. No similarly protective association was found for men.	Age, gender, couple status, ethnicity, country of birth, language spoken at home, smoking status, alcohol consumption, sleep duration, social interactions, experience of falls within the last 12 months and the Kessler Psychological Distress Scale.
Bell et al. (2008)	General	Cohort	USA	3,831 children (3-16 years)	Per 0.01-unit increment in NDVI-1km	BMI z-scores	Per 0.01-unit increment in the NDVI-1km was significantly associated with baseline BMI z-scores OR (95% CI): 0.87(0.79, 0.97).	Racial/ethnicity, gender, age at baseline, and health insurance status.
Benjamin-Neelon et al. (2019)	General	Cohort	Mexico	102 children (3-5 years)	Define greenspace as NDVI values ≥0.2 and non-greenspace as<0.2	BMI-z scores	Greater time in greenspace was not associated with BMI z-score for children in Tijuana β (95% CI): −0.009(−0.02, 0.004) or Ensenadaβ (95% CI):0.001(−0.008, 0.01).	Child age, child gender, family income, assessment, and accelerometer wear time.
Bjork et al. (2008)	General	Cross-sectional	Sweden	24,819 (18-80 years)	natural recreational values	Overweight/obesity（BMI）	The beneficial effect of the number of recreational values on obese was apparent among tenants OR (95% CI): 1.22 (1.06 to 1.41), but not among house-owners.	Gender, age, born abroad, educational level, employment status, problems with paying bills, smoking status, and type of residence

Brown et al. (2009)	General	Cross-sectional	USA	5,000 (25-64 years)	Presence of parks (yes or no) within the 1-km buffer	Overweight/obesity （BMI）,BMI	The presence of parks within the 1-km street network buffer is unrelated to BMI or overweight/obesity, p>0.05.	Neighborhood income, proportions black, Hawaiian/Pacific Islander, Hispanic, Asian, median age of neighborhood residents, and individual age.
Browning & Rigolon (2018)	General	Cross-sectional	USA	97,574,613 adults (>18 years)	Per 0.01-unit increment in NDVI-250m & percent tree cover	Obesity (BMI)	No statistically significant relationships were found for the relationship between greenness (per 0.01-unit increment in NDVI-250m) and obesity, β(SE):0.00037 (0.009), p>0.1; Percent tree cover was significantly associated with obesity, β(SE): -0.026 (0.11), p<0.05.	Levels of income, race, and ethnicity, and sprawl.
Coombes et al. (2010)	General	Cross-sectional	UK	6,821 adults (>16 years)	Distance to nearest green space by quartile	Overweight/obesity（BMI）	Increase in odds of being overweight or obese associated with increasing distance to the nearest green space in highest quartile, OR (95% CI):1.27(1.09-1.47), compared to the lowest quartile.	Age, sex, socioeconomic status, self-rated health, and area deprivation.
Cummins & Fagg (2012)	General	Cross-sectional	UK	79,136 adults (>18 years)	Percentage of green space by quintiles	Overweight/obesity（BMI）	In 2000-2003, residence in the greenest areas was significantly associated with increases in overweight OR (95% CI): 1.12(1.03,1.22) and obesity 1.23(1.11,1.37), but not in 2004-2007.	Age, sex, social class, economic activity, neighborhood income deprivation, and urban/rural status.
Dadvand et al. (2014)	General	Cross-sectional	Spain	3,178 children (9-12 years)	An IQR increase in NDVI-100m, 300m, 500m, 1000m	Overweight/obesity, BMI z-scores	An IQR (0.12) increase in NDVI-500m was significantly associated with lower odds of overweight/obesity, OR (95% CI): 0.83 (0.72,0.95); An IQR (0.076) increase in NDVI-100m was also significantly associated with lower BMI β(95% CI): -0.05(-0.10, 0.00).	Child's sex and age, parental education, type of school, sport activity, and having siblings.
Dempsey et al. (2018)	General	Cross-sectional	Ireland	8,175 individuals aged 50 and over	Proportion of green space by quintiles	Overweight/obesity (BMI)	A u-shaped relationship between green space in urban areas and obesity; those living in areas with the lowest and highest shares of green space within a 1.6 km buffer zone have a higher probability of being classified as obese (BMI ⩾ 30).	Age, regional location, gender, income category, marital status, employment status, education level, type of medical coverage, smoking status.
Ellaway et al. (2005)	General	Cross-sectional	UK	6,919 adults	Visible greenery and vegetation	Overweight/obesity（BMI）	Greenery was significantly associated with overweight/obese in the highest level, OR (95% CI):0.63 (0.49, 0.82) compared to the lowest level.	Sex, age, socioeconomic status, and city of residence.
Feng et al. (2018)	General	Cohort	Australia	3,843 mothers	Percentage of land use by four levels	BMI	Compared with mothers in areas with ≤5% green space, adjusted BMI coefficients were −0.43 (SE 0.37), −0.69 (SE 0.32) −0.86 (SE 0.33) and −0.80 (SE 0.41) among mothers in	Highest educational qualification, economic status, and race.

							areas with 6%–10%, 11%–20%, 21%–40% and ≥41% green space, respectively.	
Hobbs et al. (2019)	General	Cohort	England	8,864 (18-86 years)	Number of physical activity facilities / parks	BMI/obesity (BMI)	Parks at baseline were not associated with change in BMI, β (95% CI): −0.001 (-0.015, 0.013). Change in obesity was unrelated to parks, OR (95% CI): 0.994 (0.975, 1.015).	Age, gender, ethnicity, education level, area-level deprivation score, and population density.
Hoehner et al. (2012)	General	Cross-sectional	USA	8,857 adults (20–88 years)	Distance to /proportion /number of parks within 800m buffer	BMI	No significantly association between distance to closest park and BMI, β(SE): 0.009 (0.046) p=0.85; No significantly association between number of parks and BMI, β(SE): 0.012 (0.011) p=0.24. No significantly association between proportion of vegetation and BMI, β(SE): -0.562(0.0467) p=0.23.	Sex, age, marital status, children in home, educational status, and smoking status.
Huang et al. (2020)	General	Cross-sectional	China	24,845 adults (18-74 years)	An IQR (0.17) increase in NDVI-500m	BMI/obesity/WC	An IQR (0.17) increase in NDVI500-m was significantly associated with lower odds of peripheral OR (95% CI): 0.80 (0.74, 0.87) and central obesity 0.88 (0.83, 0.93); Higher NDVI values were also significantly associated with lower BMI β(95% CI):-0.18 (-0.24, -0.11), but not for WC, β(95% CI): -0.14 (-0.32, 0.04).	Age, gender, ethnicity, and household income.
James et al. (2017)	General	Cross-sectional	USA	23,435 women (60–87 years)	NDVI-250m	BMI	At lower greenness levels, increases in greenness were associated with increased BMI, while at higher greenness levels, increases in greenness were associated with lower BMI.	Age, race, individual- and area-level socioeconomic status.
Klompmaker et al. (2018)	General	Cross-sectional	The Netherlands	3,87,195 adults (⩾19 years)	NDVI-100m,300m,500m, 1km, 3km & distance to park by quintiles	Overweight （BMI）	No significantly association between distance to nearest park and overweight, OR (95% CI):1.00(0.96,1.05). NDVI-300m buffer significantly decreased odds of being overweight, OR (95% CI):0.88(0.86, 0.91) in the highest quintile compared to the lowest quintile.	Age, sex, marital status, country of origin, work, household income, level of education, smoking status, alcohol use, indoor physical activity, and degree of urbanization.
Li et al. (2008)	General	Cross-sectional	USA	N=1221 (50–75 years)	The total acreage of green and open spaces	Overweight/obesity (BMI)	Article did not provide the effect estimate of overweight/ obesity and green and open spaces.	Residential density, median household income, percentage of African-American and Hispanic residents, age, gender, race/ethnicity, employment status, home ownership, household income, health status, fruit and vegetable intake, fried-food consumption, and BMI.

Li et al. (2018)	General	Cross-sectional	USA	149,797 males, 155,498 females (18-84years)	GVI	BMI	Street greenery has a more significant association with decreased BMI for females than males.	Age, gender, and residential location of residents.
Liu et al. (2007)	General	Cross-sectional	USA	7,334 children (3-18 years)	Per 0.1 increments of NDVI-2km	Overweight (BMI)	Per 0.1 increments of NDVI-2km was significantly associated with child overweight in higher population density townships, OR(SE): 0.899(1.038), p<0.01, but not in low population density townships.	Age, race, gender, and median family income of the neighborhood
Lovasi et al. (2013)	General	Cross-sectional	USA	11,562 children (3-5 years)	Density of street trees	Obesity（BMI z-score）	Density of street tree was significantly associated with prevalence of obesity, PR (95% CI): 0.88(0.79,0.99).	Sex, race, ethnicity, age, and neighborhood characteristics.
Mowafi et al. (2012)	General	Cross-sectional	Egypt	3,546 adults (⩾22 years,)	Number of green spaces	BMI	No association between green space and BMI.	Age, marital status, education, household expenditure, household asset index, subjective wealth index, father’s education, current general health status, and childhood general health status.
Nielsen & Hansen (2007)	General	Cross-sectional	Denmark	2,000 adults (18–80 years)	Distance to green areas(meters)	Overweight/obesity (BMI)	Access to garden or shared green areas from the dwelling are associated with a lower likelihood of obesity, OR=0.517, p<0.05.	Employment, level of education, ownership to dwelling, age, gender, household type second home, and bicycling for work.
Norman et al. (2006)	General	Cross-sectional	USA	789 (11-15 years)	Number of parks within 1mile buffer	BMI	No statistically significant correlations were found between environmental variables and BMI percentile for girls or boys.	NR
Oreskovic et al. (2009)	General	Cross-sectional	USA	21,008 children (2 - 18 years)	Mean number of parks (in meters squared)	Overweight/obesity（BMI）	No significantly association between open space and overweight OR (95% CI): 0.89(0.92, 1.04), or obesity 0.93(0.86-1.00).	Age, gender, race, and income.
Ortega Hinojosa et al. (2018)	General	Cross-sectional	USA	5,265,265 children	NDVI-1km	BMI	The most highly ranked built or physical environment variables were distance to the nearest highway and greenness, but did not be selected and included in the models.	Age, gender, year, and race.
Paquet et al. (2014)	General	Cohort	Australia	3,205 adults (>18 years,)	NDVI-1km	Abdominal obesity (WC)	No significantly association between greenness and abdominal obesity, RR (95% CI): 1.04(0.92,1.16), p=0.55.	Age, gender, education, household income, and area-level deprivation.

Pearson et al. (2014)	General	Cross-sectional	New Zealand	12,488 adults (15 years and over)	Proportion of useable greenspace by five levels	Overweight/obesity（BMI）	overweight status was significantly associated with decreased proportion of greenspace for each category, compared to the best access, OR (95% CI):1.39(1.10, 1.75).	Age, sex, ethnicity, Economic Living Standard Index, individual-level deprivation, highest educational qualification, household composition, smoking status, and alcohol consumption.
Pereira et al. (2013)	General	Cross-sectional	Australia	10,208 adults (>16 years)	NDVI-1.6km (low, moderate and high level)	Overweight/obesity（BMI）	The adjusted odds ratio for being overweight/obese was lower for adults with high levels of mean greenness (highest tertile), OR (95% CI): 0.84(0.76, 0.92), compared with those in neighborhoods with low levels of mean greenness.	Age, sex, education, daily servings of fruits and vegetables, and smoking.
Persson et al. (2018)	General	Cohort	Sweden	5,126 adults (35-56 years)	Per IQR (0.07) increase in NDVI-500m	Overweight/obesity （BMI），central obesity (WC), WC	Per IQR (0.07) increase in NDVI-500m buffer was significantly associated with WC, β (95% CI): −0.11 (−0.14, −0.08), and central obesity, Incidence Risk Ratios (95% CI):0.88 (0.79; 0.99) in females, but not in males.	Sex, age, alcohol consumption, tobacco use, psychological distress, shift work, aircraft noise, railway noise, and distance to water.
Petraviciene et al. (2018)	General	Cross-sectional	Lithuania	1,489 children (4-6 years)1489 mother-child pairs	Per IQR increase in NDVI-100m, 300m, 500m & distance to a city park (per 100m increase)	Overweight/obesity（BMI）	An increase in the distance to a park beyond 300 m from the child's home had a tendency to increase the risk of being overweight/obese, but the result was not statistically significant OR (95% CI): 1.01 (0.98–1.05). Per IQR (0.12) increased in NDVI-100m buffer was significantly associated with children being overweight/ obese OR (95% CI):1.43 (1.10-1.91). Per IQR (0.11) increase in NDVI-500m buffer was no significantly associated with children being overweight/ obese OR (95% CI):1.19 (0.82-1.91).	Family status, maternal age, education, employment status, smoking during pregnancy, secondhand smoking, mother-child relations, NO_2, the child's sex, birth weight, and sedentary behavior.
Potestio et al. (2009)	General	Cross-sectional	Canada	6,772 children (mean age of 4.95 years)	Number of parks per 1000 residents/proportion of greenspace within a community/ distance to the nearest parks/gree	Overweight/obesity（BMI）	No significantly association between distance to park and overweight/obesity, OR (95% CI): 0.87 (0.73,1.04); No significantly association between proportion of park area and overweight/obesity, OR (95% CI): 0.55 (0.08,3.90); No significantly association between number of parks/green space per 10,000 people and childhood overweight/obesity, OR (95% CI): 1.01 (0.88,1.17).	Sex, family income, community-level education, and visible minority.

					n space by tertile			
Potwarka et al. (2008)	General	Cross-sectional	Canada	108 children	Number of parks within 1 km/distance to the closest park(meter)/ park area within 1 km	BMI, overweight/obesity (BMI)	No significantly association between distance to the closest park and overweight/obesity, OR (95% CI): 1.02 (0.73,1.44); No significantly association between proportion of park area and overweight/obesity, OR (95% CI): 1.00 (0.99,1.01); No significantly association between number of parks within 1 km and childhood overweight/obesity, OR (95% CI): 0.92 (0.69,1.24).	Age, gender, neighborhood of residence, and parent's BMI.
Prince et al. (2011)	General	Cross-sectional	Canada	3,883 adults (⩾22 years)	Green space (km^2) per 1,000 people	Overweight/obesity（BMI）	Higher green space was associated with increased odds of overweight and obesity in men OR (95% CI): 1.10(1.01, 1.19), and decreased odds of overweight/obesity in women 0.66(0.44, 0.89).	Age, education, household income, smoking status, and season of collection.
Richardson et al. (2014)	General	Cross-sectional	New Zealand	8,157 respondents	Proportion of green space by four levels	Overweight/obesity（BMI）	Green space availability was not related to overweight. OR (95% CI): 0.93 (0.78,1.12).	Sex, age group, smoking behavior, and an index of individual socio-economic deprivation.
Rundle et al. (2013)	General	Cross-sectional	USA	13,102 adults (median age 45 years)	Proximity to parks by three levels	BMI	Higher proximity to large park space was significantly associated with lower BMI β(95% CI): −1.69(−2.76, −0.63).	Age, gender, race/ethnicity, education, neighborhood-level proportion Black, proportion Hispanic, percent poverty, and population density.
Sander et al. (2017)	General	Cross-sectional	USA	546 US Census block groups (18-84years)	Percentage of greenspace	BMI	Recreational park percentage was significantly negatively related to mean BMI for only middle-adult females (β=−0.014588, p<0.05).	Tract-level economic, education, population density, and household income.
Sanders et al. (2015)	General	Cohort	Australia	4,423 children (6 -13 years)	Proportions of green space by six levels	BMI	A beneficial effect of green space on BMI emerges as children grow older.	Weekly family income, race, child speaks language other than English, and maternal education.

Sarkar (2017)	General	Cross-sectional	UK	333,183 adults (38-73 years)	Per IQR (0.24) increment in NDVI-500m	BMI, WC, Whole body fat obesity	An IQR (0.24) increment in NDVI-500m buffer was significantly associated with lower BMI, β (95% CI): −0.123(−0.14, −0.10), WC: −0.551 (−0.61, −0.50), and WBF: −0.138 (−0.18, −0.10) as well as a reduced relative risk of obesity, RR (95% CI): 0.968 (0.96, 0.98).	Age in years, gender, ethnicity, education, and employment status.
Schalkwijk et al. (2018)	General	Cohort	UK	6,467 children	Percentage of green space by tertile	Overweight/obesity（BMI）	Statistically significant associations were found between low levels of green space (<30%) and childhood overweight/obesity, OR (95% CI): 1.14 (1.02,1.27).	National Vocational Qualification and household income.
Scott et al. (2009)	General	Cross-sectional	USA	1,124 Whites and 691 Blacks	Number of parks within 1 mile	BMI	Number of parks within 1 mile was associated with BMI in non-Hispanic whites (β= -0.01, p=0.04), but not in African Americans (β=0.01, p=0.17).	Age, gender, median tract household income, and race/ethnicity.
Sun et al. (2018)	General	Cross-sectional	China	4,114 individuals	Green coverage rate (%)	BMI	No association between green coverage rate and BMI, β (SE): 0.127(0.199), p>0.1.	Gender, age, education, income, household type, smoking, drinking, frequency of eating out, car ownership, and moped ownership.
Tilt et al. (2007)	General	Cross-sectional	USA	529 adults (52.5% > 51 years)	NDVI-4miles (high and low level)	BMI	BMI was lower in areas that had high NDVI (>0.426), or more greenness (r^2=0.129, p<0.0001).	Age, gender, education, and income.
Toftager et al. (2011)	General	Cross-sectional	Denmark	21,832 adults (⩾16 years)	Distance to green space by three group (<300m, 300-1km and >1km)	Overweight/obesity（BMI）	Persons living more than 1 km from green space had higher odds of being obese (BMI ≥ 30) than those living less than 300 m from green space, OR (95% CI): 1.36(1.08,1.71).	Educational level, accommodation type, size of municipality, marital status, self-reported long-term activity limitation, sex, and age.
Tsai et al. (2016)	General	Cross-sectional	USA	> 1 million	Density of shrub land	BMI	Higher patch density of shrubland type (β= –0.504, p<0.01) was associated with lower proportion of normal BMI.	Total population, total housing units, median household income, and percentage black/African American population for each county.
van der Zwaard et al. (2018)	General	Cohort	UK	6,001 children	Number of green space and gardens by ten levels	BMI/ overweight	The amount of garden in the area was significantly associated with BMI, β(95% CI): -0.019(−0.040, −0.001). No significantly association between number of gardens and overweight OR (95% CI):1.007(0.967, 1.050).	Age and sex.

Villeneuve et al. (2018)	People have high risk of breast cancer	Cross-sectional	USA	50,884 women (35–74 years)	Proportion of green space by tertile	Obesity (BMI)	Women who lived in areas with the highest tertile of greenness (based on a 500 m buffer) had a reduced risk of obesity (BMI ≥ 30) relative to those in the lowest tertile (odds ratio OR (95% CI): 0.83(0.79–0.87).	Age, socioeconomic, place of residence (i.e. rural vs urban), census tract population, and census region.
Wen & Maloney (2011)	General	Cross-sectional	USA	735,974 adults (25–64 years)	Percentage of area covered by tree canopy within each 30 m pixel/ distance (in miles) to the nearest parks	Obesity (BMI)	Park access (distance to nearest park) becomes significant and associated with a lower risk of obesity for women, OR (95% CI):0.96(0.94,0.99), but not for men, OR (95% CI):0.99(0.97,1.01). Percentage of tree canopy was significantly associated with a lower risk of obesity for women OR (95% CI):0.89(0.87,0.91) and men OR (95% CI):0.89(0.88,0.91).	Age, gender, and ethnic/immigrant group.
Wen & Kowaleski-Jones (2012)	General	Cross-sectional	USA	2,000 (20-64 years)	Distance to parks (mile)	Obesity (BMI)	Distance to parks is a negative covariate of obesity among men (OR=1.100, p<0.01) and women (OR=1.074, p<0.01).	Age, gender, race, immigrant status, marital status, education, poverty income ratio, and smoking status.
Wilhelmsen et al. (2017)	General	Cross-sectional	Norway	10,527 adolescents (14-17 years)	Percentage of green areas within 1 km and 5 km buffers by five levels	Overweight/obesity（BMI）	The odds for being overweight was 1.38 times higher (95% CI: 1.02–1.85) for participants living in the greenest surroundings compared to participants living in the least green surroundings (1 km buffer).	Age, gender, ethnicity, physical activity, transportation mode, use of nature, social support from friends and family, family situation, diet, smoking habits, county, moving history, and climatic variables (precipitation, altitude, and temperature).
Witten et al. (2009)	General	Cross-sectional	New Zealand	n=12,529 adults (15+ years)	Access to parks by quartiles	BMI	Access to parks was not associated with BMI, β(95% CI): -0.03(-0.08, 0.02).	Number of adults in the household and ethnicity, Sex age, education, social class, receipt of benefits, working/not working, and household income.
Wolch et al. (2010)	General	Cohort	USA	3,173 children (9–10years)	Park space (acres) within 500m buffer	BMI	For park acres within a 500 m distance of children's homes, there were significant inverse associations with attained BMI at age 18, β(95% CI): -0.1389 (-0.0322, -0.2456).	Distance from residence to the nearest freeway, town level forcible rape rate, population density, average urban imperviousness, average tree canopy, agriculture land use (km2), number of "X" intersections, NDVI, and percent below poverty.

Yang et al. (2018)	General	Cross-sectional	USA	41,283 children	Distance to nearest park (mile)	Overweight/obesity（BMI）	The risk of overweight and obesity was positively associated with distance to park OR (95% CI):1.01(1.00, 1.01)	Age, gender, race, economically disadvantaged status, school type, and school level.
Ying et al. (2015)	General	Cross-sectional and ecologic	China	1,100 residents (46 to 80 years)	Green and open spaces (m^2) within 500m buffer	BMI, Overweight/obesity (BMI)	Green and open spaces were positively related with BMI (β=-0.118, P <0.01)	Age, gender, employment status, and education.
Zhang et al. (2019)	General	Cohort	USA	8,365 Mexican American adults (20–60 years)	Distance the nearest parks (kilometer)	BMI/ Overweight/obesity (BMI)	Networked distance to the nearest park had statistically significantly linear associations with BMI, β (95% CI): −0.29 (−0.47, −0.10), and significantly associated with lower odds of obesity OR (95% CI):0.91(0.85, 0.98).	Age, gender, country of birth, household income, and the interaction term of age versus gender.

Abbreviations: BMI: Body Mass Index; GVI: Green View Index; NDVI: Normalized Difference Vegetation Index; NR: Not Reported; Overweight/obesity (BMI): overweight/obesity defined by BMI; Overweight/obesity (WC): overweight/obesity defined by WC; WC: Waist Circumference; WBF: Whole Body Fat.

Table 2 Meta-analysis results for association between four greenspace metrics (NDVI, proximity to the nearest greenspace, proportion of greenspace, and number of parks) and overweight/obesity.

Greenspace	No. of studies	Sample size	OR (95% CI)	I^2	$P_{heterogeneity}$	GRADE
NDVI	6	97,615,290	0.88 (0.84, 0.91)	38.95	0.15	Low
Proximity to the nearest greenspace	4	747,828	0.99 (0.99, 1.00)	0	0.81	Very low
Proportion of greenspace	6	98,322,450	0.96 (0.85, 1.08)	97.32	<0.001	Very low
Number of parks in an area	5	42,753	0.98 (0.97, 1.00)	0	0.46	Very low

Abbreviations: OR, odds ratio; CI, confidence interval; GRADE, the Grading of Recommendations Assessment, Development, and Evaluation; NDVI, normalized difference vegetation index.; $P_{heterogeneity}$, P value for heterogeneity test.