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Green spaces exposure and the risk of common psychiatric disorders: A meta-analysis

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ABSTRACT

Objective: To explore the effects of green spaces exposure on common psychiatric disorders.
Methods: PubMed, Embase, Web of Science and MEDLINE were screened and articles published prior to November 15, 2023 were included. Analyses were performed on common psychiatric disorders, categorized into depression, anxiety, dementia, schizophrenia, and attention deficit hyperactivity disorder (ADHD). And the subgroup analyses were conducted for depression, anxiety, dementia, and schizophrenia.
Results: In total, 2,0064 studies were retrieved, 59 of which were included in our study; 37 for depression, 14 for anxiety, 8 for dementia, 7 for schizophrenia and 5 for ADHD. Green spaces were found to benefit the moderation of psychiatric disorders (OR = 0.91, 95% CI: 0.89 to 0.92). Green spaces positively influence depression (OR = 0.89, 95% CI: 0.86 to 0.93), regardless of the cross-sectional or cohort studies. Green spaces can also help mitigate the risk of anxiety (OR = 0.94, 95%CI:0.92 to 0.96). As an important index for measuring green spaces, a higher normalized difference vegetation index (NDVI) level related to a lower level of depression (OR = 0.95, 95%CI:0.91 to 0.98) and anxiety (OR = 0.95, 95%:0.92 to 0.98). The protection was also found in dementia (OR = 0.95, 95% CI: 0.93 to 0.96), schizophrenia (OR = 0.74, 95% CI: 0.67 to 0.82), and ADHD (OR = 0.89, 95% CI: 0.86 to 0.92) results.
Conclusion: Green spaces decrease the risk of psychiatric disorders, including depression, anxiety, dementia, schizophrenia, and ADHD. Further studies on green spaces and psychiatric disorders are needed, and more green spaces should be considered in city planning.

1. Introduction

Psychiatric disorders stress large burdens on society around the world. And as common psychiatric disorders, depression, anxiety, dementia, schizophrenia, and ADHD afflict an increasing number of individuals (Marshall, 2020; Posner et al., 2020; Prince et al., 2013). By 2030, depression is expected to become the main reason of death worldwide, imposing a large social burden (Hou et al., 2022). Some studies have indicated that up to 44% of the adult US population may suffer from anxiety (Kavelaars et al., 2023). The number of global dementia patients is predicted to reach to 65.7 million in 2030 (Prince et al., 2013). People with schizophrenia suffer from cognition function disturbance, abnormal behavior, and may sink into apathy, which bothered 1 in 100 individuals (Campeau et al., 2022). And as a neurodevelopmental disorder, ADHD held prevalence over 5%, especially found in children (Drechsler et al., 2020). The situations mentioned above point to the importance of exploring ways to reduce the incidence of psychiatric disorders.

Research has demonstrated the positive impact of being connected to nature on well-being and promoting pro-environmental behaviors (Lumber et al., 2017). It is said that exposure to greenness at youth could reduce odds of having a range of psychiatric disorders (Engemann et al., 2019). And an increasing number of researches have revealed that green spaces separately played a potential role in reducing depression,

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anxiety, dementia, schizophrenia, and ADHD. After searching a large number of articles, although most researchers are optimistic about the role of green space, we cannot rule out whether the effect of green space on psychiatric illness is disturbed by a variety of factors, including country development (Bloemsma et al., 2022; Mukherjee et al., 2017), gender (Donovan et al., 2019; Heo et al., 2021; Reklaitiene et al., 2014), related green space exposure indicators or the measurement of green space types (Astell-Burt et al., 2020, p. 145; Feng et al., 2022; Nishigaki et al., 2020). In addition, in the process of searching for articles, we also found a meta-analysis of the effects of green space on anxiety and depression (Liu et al., 2023), which is undeniably useful for improving our research, but it is worth mentioning that their research scope is relatively limited, analyzing the main indicators of green space exposure, i.e., the in-depth impact of NDVI and green space proportion on anxiety and depression, while we analyzed depression and anxiety on the basis of the general direction of psychiatric disorders, which are more macroscopic, including larger sample sizes, and exploring more confounding factors and the underlying mechanisms.

We conducted a meta-analysis to systematically study the relationships between green spaces and psychiatric illnesses mentioned above. And we conducted further subgroup analysis of the geographical analysis units to explore different possibilities between them. Moreover, the large and diverse sample size of depression also facilitated our subgroup analysis of study method, gender, region. We hope that this study will broaden the scope of research on the significance of green spaces toward alleviating common psychiatric illness and supply a scientific basis for the improved planning of green spaces construction.

2. Materials and method

2.1. Search strategy

The meta-analysis was conducted under the guidance of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement guidelines. We screened PubMed, Embase, Web of science and MEDLINE databases for studies published before November 15, 2023. The search string is accessible in the Supplementary Material.

2.2. Selection criteria

Studies satisfying the following standards were included and considered to be of high quality: (1) The study must be observation research; (2) Newcastle-Ottawa scale (NOS) (Margulis et al., 2014) score and Joanna Briggs Institute (JBI) (Papalia et al., 2022) score respectively evaluate cohort and cross-sectional studies. Only when NOS score >7 or JBI score has “no” or “unclear” responses below two (score ≥ 7), the study can be included; (3) The study must have specific and appropriate standards to measure green spaces (e.g., NDVI, view, area, accessibility, numbers); (4) Psychiatric disorders including depression, anxiety, dementia, schizophrenia, and ADHD must be evaluated by scale, questionnaire or hospital diagnosis; (5) The study should not be meta-analyses, reviews, comments, books, or conference records; (6) Studies with original texts; (7) Study results should be shown in concrete Odds Ratio (OR), Risk Ratio (RR) Hazard Ratio (HR) or Prevalence Radio (PR).

2.3. Data collection

Studies included in the review provided the following information: author, publication year, region, sample size, age, study method, geographic analysis units, disease, adjusted OR with 95% confidence interval (CI) and NOS or JBI scores. The PR was similarly equal to the OR value and RR value could be converted into OR (Shor et al., 2017). Notably, several studies combined depression and anxiety as a total result, while others considered them separately or only one of them. Therefore, when encountering mixed studies, we chose separate values; otherwise, the values were combined. Studies of dementia, schizophrenia, and ADHD each has its own definite outcome.

2.4. Risk of bias assessment

Two investigators examined the quality of the included studies separately. Disagreements were intensively discussed, and finally, a unified outcome was presented. We used the NOS scores to measure cohort studies and the JBI scores to evaluate cross-sectional studies (Peng et al., 2022). We considered that a study with a NOS score >7 was of high quality or a JBI assessment that had “no” or “unclear” responses below two, indicated a low risk of bias (Papalia et al., 2022); otherwise, it would be low quality or high risk of bias.

2.5. Data analysis

We used Stata version 15 (College Station, TX, USA) to conduct the analysis. Heterogeneity was determined using the I^2 statistic. A random-effects model was employed when $I^2 > 50\%$, indicating substantial heterogeneity. Fixed effects model was chosen when $I^2 \leq 50$ (Zhou et al., 2021). The random-effects model was applied when the heterogeneity of outcomes exceeded 50%. Subgroup analyses were conducted and forest plots were presented. Begg’s test (Begg & Mazumdar, 1994), trim and fill method (Duval & Tweedie, 2000), and funnel plots were used to detect publication bias. Finally, the sensitivity analysis was conducted by “leave-one-out”.

3. Results

3.1. Search results

After thorough search and retrieval, 20,064 studies were included in our study, of which 15,117 remained after the removal of duplicate studies. A total of 14,892 studies were excluded after a review of titles and abstracts. 225 were further assessed by screening the full text. Finally, 59 articles were included in our study, among which 37 were on depression (Asri et al., 2021; Astell-Burt & Feng, 2019; Bezold et al., 2018a, 2018b; Bustamante et al., 2022; Dzhambov et al., 2021; Generaal et al., 2019; Gonzales-Inca et al., 2022; Heo et al., 2021; Hou et al., 2022; Hystad et al., 2019; Kim & Kim, 2017; Klompmaker et al., 2019; Lee & Lee, 2019; Maas et al., 2009; McEachan et al., 2016; Min, Kim, Kim, & Min, 2017; Nazif-Munoz et al., 2020; Nichani et al., 2017; Nieuwenhuijsen et al., 2022; Nishigaki et al., 2020; Pelgrims et al., 2021; Peng et al., 2022; Pouso et al., 2021; Rugel et al., 2019; Sarkar et al., 2018; Song et al., 2019; Sun et al., 2023; Tomita et al., 2017; Triebner et al., 2022; Tsai et al., 2023; Van den Berg et al., 2016; White et al., 2021; Zayas-Costa et al., 2021; Zhang et al., 2022, p. 811; Zhang et al., 2023; Zhou et al., 2022), 14 on anxiety (Astell-Burt & Feng, 2019; Bustamante et al., 2022; Dzhambov et al., 2021; Generaal et al., 2019; Heo et al., 2021; Hystad et al., 2019; Klompmaker et al., 2019; Maas et al., 2009; Mouly, Mishra, Hystad, Nieuwenhuijsen, & Knibbs, 2023; Nutsford et al., 2013; Pelgrims et al., 2021; Pouso et al., 2021; Triebner et al., 2022; White et al., 2021), 8 on dementia (Astell-Burt et al., 2020, 2023, p. 145, p. 82; Klompmaker et al., 2022; Paul et al., 2020; Rodriguez-Loureiro et al., 2022; Slawsky et al., 2022; Wu et al., 2020; Yuchi et al., 2020), 7 on schizophrenia (Chang et al., 2020; Engemann et al., 2018, 2019, 2020a, 2020b, 2020c; Rotenberg et al., 2022), 5 on ADHD (Donovan et al., 2019; Markevych et al., 2014; Thygesen et al., 2020; Yang et al., 2019; Yuchi et al., 2022) (see Fig. 1).

3.2. Study characteristics

The basic characteristics of the 59 selected studies are shown in Table S1. A majority of studies published in the last decade have paid attention to on the correlation between green spaces and common

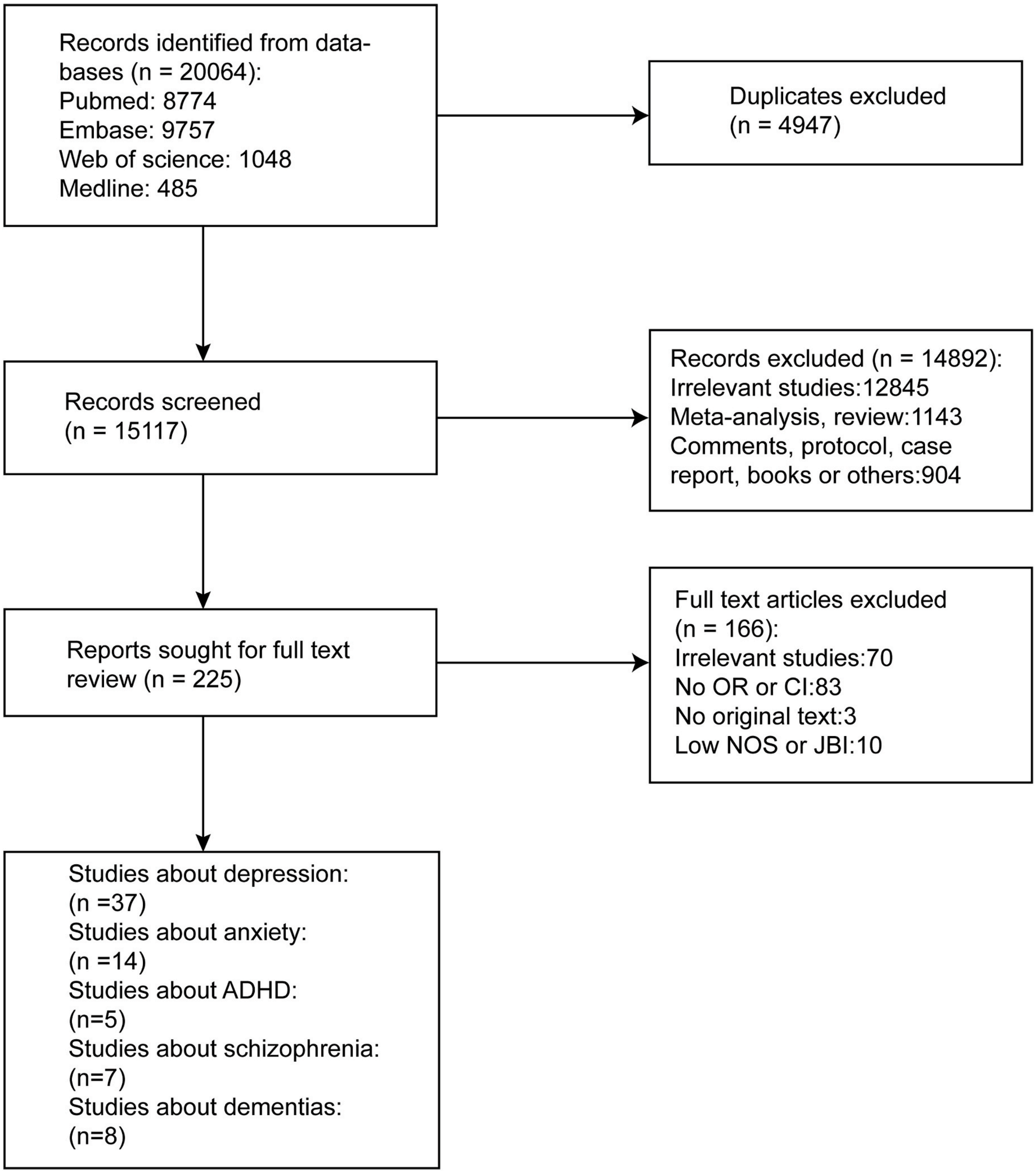

Fig. 1. Flow diagram of the study selection process.

psychiatric illness, indicating a growing interest in this research area. The contained studies were from 21 countries. Most of the research was performed in developed countries, with only eleven in developing countries. The sample sizes covered a wide range, from 322 to 61, 662, 472. Exposure to green spaces was judged by more than one objective or subjective geographic analysis units' data in the vast majority of studies of psychiatric disorders. There were studies on view of green (n = 5) (Dzhambov et al., 2021; Pelgrims et al., 2021; Pouso et al., 2021; Rugel et al., 2019; Zhang et al., 2023), NDVI (n = 31) (Asri et al., 2021; Bezold et al., 2018a; 2018b; Donovan et al., 2019; Engemann et al., 2018, 2019, 2020a, 2020b, 2020c; Gonzales-Inca et al., 2022; Hystad et al., 2019; Klompmaker et al., 2019; Markevych et al., 2014; McEachan et al., 2016; Mouly, Mishra, Hystad, Nieuwenhuijsen, & Knibbs, 2023; Nazif-Munoz et al., 2020; Nieuwenhuijsen et al., 2022; Paul et al., 2020; Peng et al., 2022; Rodriguez-Loureiro et al., 2022; Slawsky et al., 2022; Song et al., 2019; Sun et al., 2023; Thygesen et al., 2020; Triebner et al., 2022; Yang et al., 2019; Yuchi et al., 2022; Zhang et al., 2022, p. 811; Yuchi et al., 2020; Tomita et al., 2017; Sarkar et al., 2018), area of green space (n = 27) (Asri et al., 2021; Astell-Burt et al., 2020, p. 145; Astell-Burt et al., 2023, p. 82; Chang et al., 2020; Engemann et al., 2020b; Engemann et al., 2020c; Gonzales-Inca et al., 2022; Hou et al., 2022; Generaal et al., 2019; Maas et al., 2009; Nieuwenhuijsen et al., 2022; Nishigaki et al., 2020; Nutsford et al., 2013; Rotenberg et al., 2022; Rugel et al., 2019; Pelgrims et al., 2021; Sun et al., 2023; Tsai et al., 2023; Wu et al., 2020; Zayas-Costa et al., 2021; Zhang et al., 2023; White et al., 2021; Zhou et al., 2022; Kim & Kim, 2017; Lee and Lee, 2019; Min et al., 2017; Nichani et al., 2017), green spaces accessibility (n = 4) (Nieuwenhuijsen et al., 2022; Rugel et al., 2019; Wu et al., 2020; Zayas-Costa et al., 2021), parks (n = 4) (Bustamante et al., 2022; Klompmaker et al., 2022; Sun et al., 2023; Zayas-Costa et al., 2021), other exposure index (n = 5)

(Chang et al., 2020; Gonzales-Inca et al., 2022; Heo et al., 2021; Peng et al., 2022; Zhang et al., 2022, p. 811) and others (n = 2) (Bustamante et al., 2022; Nutsford et al., 2013). In addition, for gender in depression, there were studies on male (n = 2) (Hou et al., 2022; Hystad et al., 2019) and female (n = 11) (Dzhambov et al., 2021; Heo et al., 2021; Hou et al., 2022; Hystad et al., 2019; McEachan et al., 2016; Nazif-Munoz et al., 2020; Nichani et al., 2017; Sarkar et al., 2018; Sun et al., 2023; Triebner et al., 2022; Tsai et al., 2023). For region in depression, there were studies on urban (n = 13) (Astell-Burt & Feng, 2019; Bustamante et al., 2022; Gonzales-Inca et al., 2022; Maas et al., 2009; Nichani et al., 2017; Nishigaki et al., 2020; Pelgrims et al., 2021; Peng et al., 2022; Rugel et al., 2019; Song et al., 2019; Sun et al., 2023; Tomita et al., 2017; Zhou et al., 2022) and rural areas (n = 4) (Bustamante et al., 2022; Nishigaki et al., 2020; Peng et al., 2022; Tomita et al., 2017).

3.3. Findings about associations between green spaces and psychiatric disorders

We collected data of psychiatric disorders which went through a series analysis. We firstly chose the fixed-effect model ($I^2 = 83.7\%$), but used the random-effect model for high heterogeneity at last. As Fig. 2 shows, generally, green spaces moderate the risk of having psychiatric disorders (OR = 0.91, 95% CI: 0.89 to 0.92). And then depression, anxiety, dementia, schizophrenia, and ADHD were performed to discover whether green spaces have diverse influences on each specific psychiatric disorder.

3.4. Studies of common psychiatric disorders

3.4.1. Exposure to green spaces and the risk of depression

We used a fixed-effects model ($I^2 = 87.4\%$) at first and high heterogeneity was exhibited, so the random-effects model was finally employed. Judging by the overall findings of the analysis between green spaces and depression with the random effects model ($I^2 = 87.4\%$, $p < 0.001$), we demonstrated that green spaces alleviate the odds of depression (OR = 0.89, 95% CI: 0.86 to 0.93) (Fig. 3). Then we conducted subgroup analyses to further explore the correlation between them. Subgroups analysis revealed that the level of effect was related to certain factors, such as gender, region, and geographic analysis units (especially NDVI). Different study designs can also lead to variability in results.

3.4.1.1. The relationship between green spaces and study method of depression. By analyzing cross-sectional studies, we demonstrated that green spaces are protective factors to depression (OR = 0.89, 95% CI:0.85 to 0.93). After employing the random effects model, heterogeneity was still substantial ($I^2 = 89.4\%$, $p < 0.001$) (Fig. S1a). The analysis of cohort studies also suggested that green spaces can mitigate the developing of depression (OR = 0.91, 95%CI:0.84 to 0.98). Substantial heterogeneity was also observed ($I^2 = 61.7\%$, $p = 0.008$) (Fig. S1b).

3.4.1.2. Various geographic analysis units show different connections with depression. The geographic analysis units were divided into view of green, NDVI, area of green space, green spaces accessibility, parks, and other exposure index. Most studies preferred to use area of green space (OR = 0.97, 95%CI:0.94 to 1.01) or NDVI (OR = 0.95, 95%CI:0.91 to 0.98) for measurement, and NDVI showed a higher correlation between green spaces and depression. Influences were also reflected in the subgroups of view of green (OR = 0.89, 95%CI:0.74 to 1.06) and green spaces accessibility (OR = 0.85, 95%CI:0.67 to 1.08), suggesting that the exposure to green spaces is positively related to depression (Fig. 4).

3.4.1.3. The association of gender difference and the risk of depression. Ten studies were classified into two groups: male and female. Two studies included data of both male and female, hence, they were included in both groups. Results indicated that the protective effects of green spaces on depression among male (OR = 0.95, 95%CI:0.84 to 1.09) were not as strong as that in female (OR = 0.93, 95%CI:0.90 to 0.97) (Fig. S2a).

3.4.1.4. The correlation between green spaces and depression in different regions. Thirteen studies were conducted research in urban areas (OR = 0.96, 95%CI:0.92 to 1.00) and four were conducted in rural areas (OR = 0.86, 95%:0.73 to 1.01) (Fig. S2b). The overall results were positive for both, but a higher OR was found for urban areas than rural areas.

3.4.2. Exposure to green spaces and the risk of anxiety

We analyzed the association between green spaces and the odds of anxiety. The fixed-effects model ($I^2 = 57.2\%$) showed high heterogeneity, so the analysis of green spaces and anxiety was also presented in the random-effects model ($I^2 = 57.2\%$, $p = 0.004$) (Fig. 5a). Green spaces are discovered to alleviate the danger of anxiety (OR = 0.94, 95% CI:0.92 to 0.96) (Fig. 5a). Anxiety-related studies were stratified by geographic analysis units. Various geographic analysis units showed an insignificant relationship between green spaces and anxiety. However, in one of the geographic analysis units, the NDVI potentially played a significant role in the reduction of anxiety.

3.4.2.1. Various geographic analysis units show different connections with anxiety. For anxiety, geographic analysis units were divided into view of green, area of green space, NDVI and others. Among the last group, one was regarding the number of parks accessible to people and the other was regarding the distance to the nearest total green spaces. View of green (OR = 0.84, 95%CI:0.78 to 0.91), area of green space (OR = 0.98, 95%CI:0.93 to 1.03), NDVI (OR = 0.95, 95%:0.92 to 0.98), and others (OR = 0.93, 95%CI:0.85 to 1.03) completely supported the existing research conclusions (Fig. 6). Significant positive connections were revealed in all studies on NDVI.

3.4.3. Exposure to green spaces and the risk of dementia

After analyzing the data from the eight existing relevant researches, we found green spaces can be a protective factor for dementia (OR = 0.95, 95% CI: 0.93 to 0.96). The fixed-effects model ($I^2 = 52.0\%$) was used initially, and we finally chose the random-effected model ($I^2 = 52.0\%$, $p = 0.034$) for significant heterogeneity (Fig. 5b).

3.4.3.1. Various geographic analysis units show different connections with dementia. For dementia, geographic analysis units were sorted into NDVI, and green space accessibility. Results of NDVI (OR = 0.95, 95% CI: 0.94 to 0.96) and area of green space (OR = 0.93, 95% CI: 0.84 to 1.03) showed consistency, but green space accessibility (OR = 1.03, 95% CI: 0.83 to 1.28) exhibited a variation (Fig. S3a).

3.4.4. Exposure to green spaces and the risk of schizophrenia and ADHD

We separately analyzed the relationship between exposure to green spaces and schizophrenia (OR = 0.74, 95% CI: 0.67 to 0.82) (Fig. 5c) and ADHD (OR = 0.89, 95% CI: 0.86 to 0.92) (Fig. 5d). The results of the above two mental diseases both supported exposure to green spaces was inversely associated with them. For schizophrenia, high heterogeneity ($I^2 = 52.0\%$) existed so we used the random-effects model ($I^2 = 60.6\%$, $p = 0.019$) to analyze. For ADHD, we just employed the fixed-effects model ($I^2 = 37.3\%$, $p = 0.172$) due to low heterogeneity.

Each article included in schizophrenia and ADHD supported their overall results, respectively. It was not controversially indicated green spaces played a beneficial role in schizophrenia and ADHD. But the insufficient number of studies make the results less persuasive.

3.4.4.1. Various geographic analysis units have different links to schizophrenia. For schizophrenia, geographic analysis units were categorized

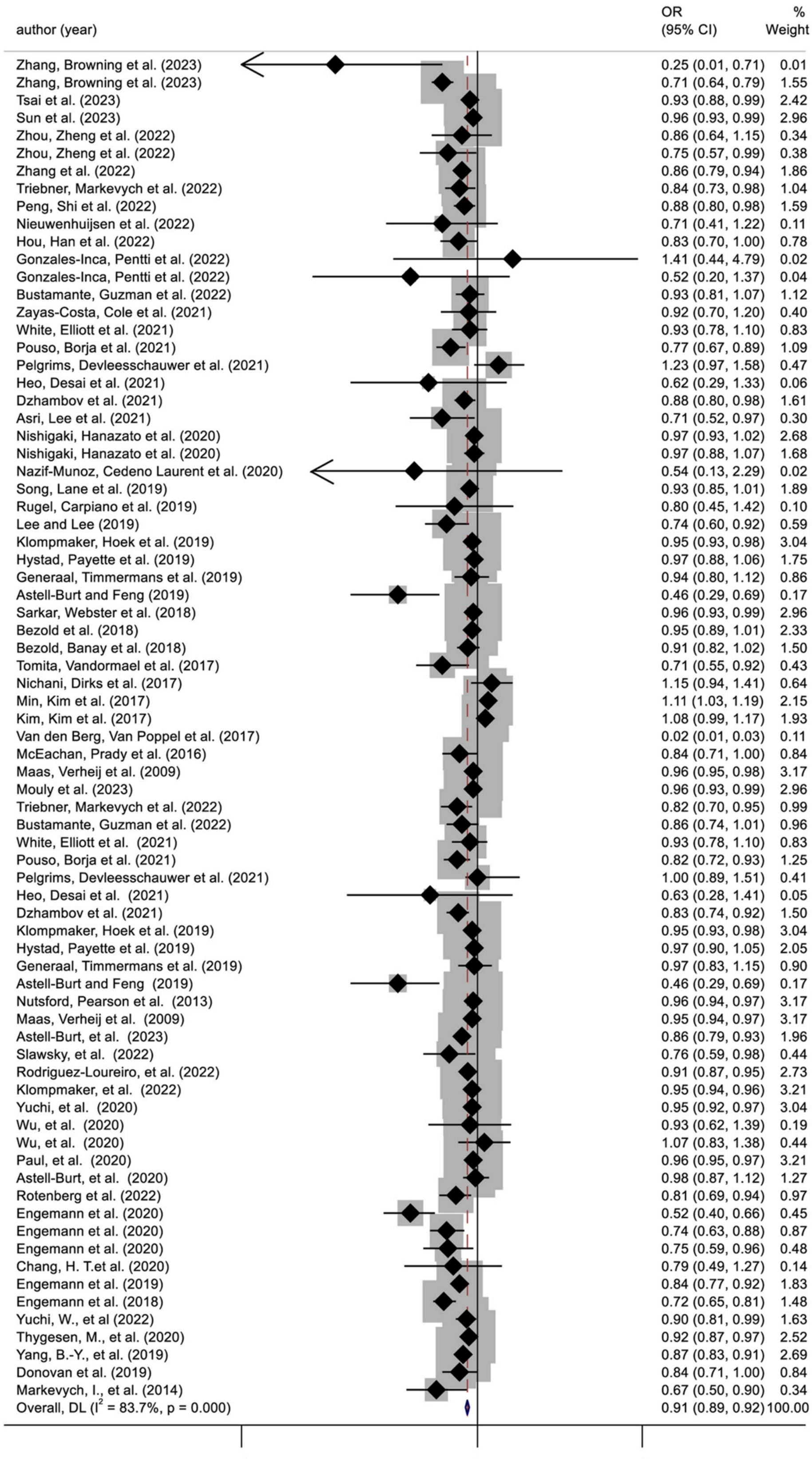

Fig. 2. Forest plot of the studies of psychiatric disorders.

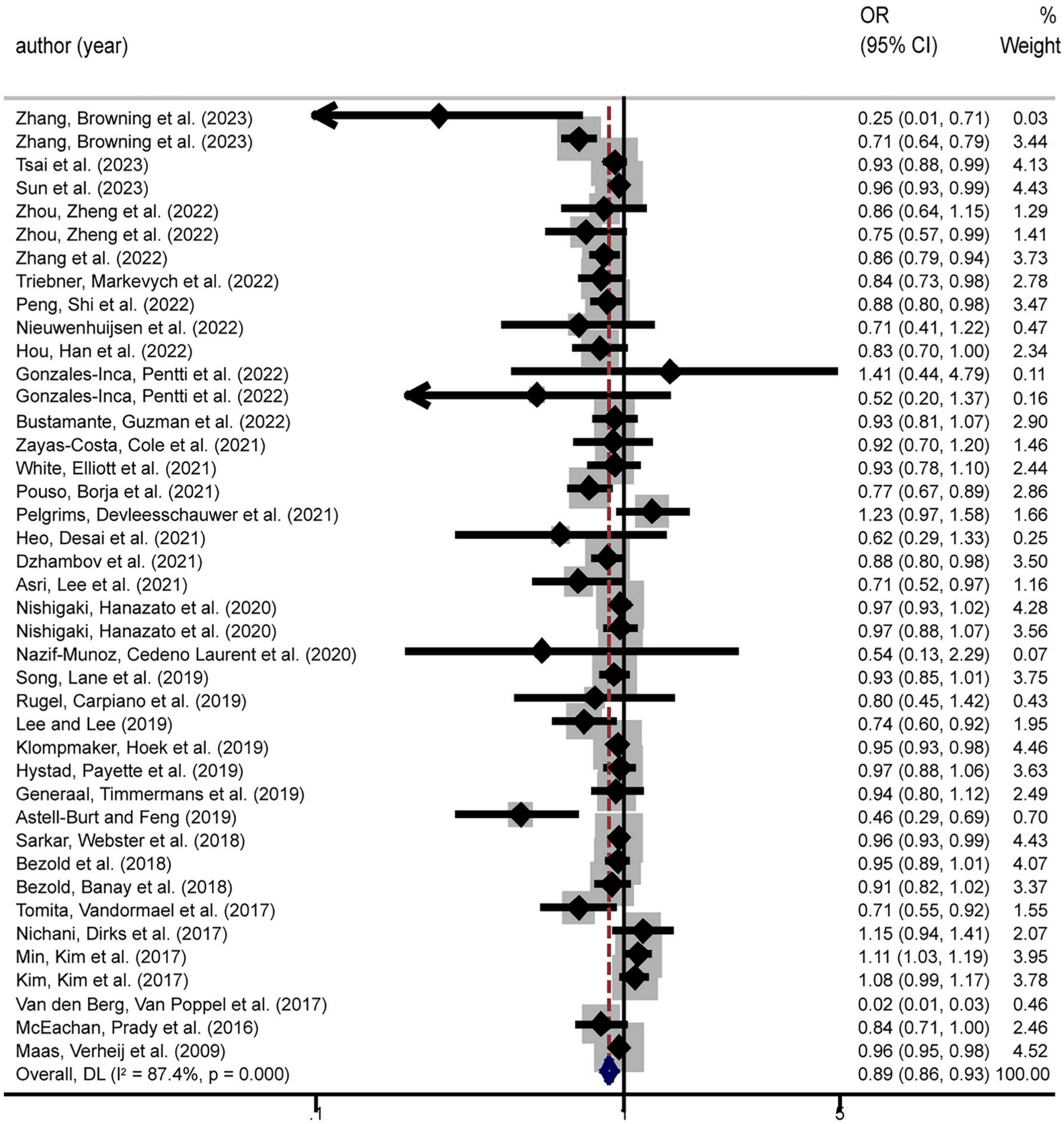

Fig. 3. Forest plot of the studies of depression.

into NDVI (OR = 0.72, 95% CI: 0.64 to 0.82) and area of green space (OR = 0.77, 95% CI: 0.70 to 0.85), among which indicated the same direction (Fig. S3b).

3.5. Publication bias

We use Begg's test to detect publication bias at first. Cohort studies of depression (p = 0.405) (Fig. S5b), dementia (p = 0.197) (Fig. S6b), schizophrenia (p = 0.267) (Fig. S6c) and ADHD (p = 0.312) (Fig. S6d) did not show publication bias, while anxiety (p = 0.01) (Fig. S6a), depression (p = 0.006) (Fig. S4a) and cross-sectional studies of depression (p = 0.015) (Fig. S5a) both had p-scores of less than 0.05 which were subject to publication bias. So, we conducted the trim-and-fill to examine the reliability of the results and found the outcomes of anxiety (OR = 2.56, 95%CI: 2.50 to 2.62) (Fig. S7b), depression (OR = 2.44, 95%CI: 2.36 to 2.53) (Fig. S4b) and cross-sectional studies of depression (OR = 2.43, 95%CI: 2.34 to 2.53) (Fig. S7a) with green spaces did not change.

3.6. Sensitivity analysis

We chose "leave-one-out" method to conduct sensitivity analysis of depression (Fig. S8), cross-sectional studies in depression, cohort studies in depression, anxiety, dementia, schizophrenia, and ADHD (Fig. S9). No obvious changes of outcomes between green spaces and psychiatric disorders were observed after omitting any single study.

4. Discussion

Using 59 studies, the meta-analysis analyzed the existing scientific evidence to determine whether green spaces can alleviate psychiatric disorders. We confirmed that positive influences can be found between green spaces and psychiatric disorders. Referring to subgroups analysis, the results were more pronounced for the NDVI.

Regarding depression, it was interesting to find that the difference in results between male and female may be attributed to the fact that female had considerably poorer mental health outcomes for depression

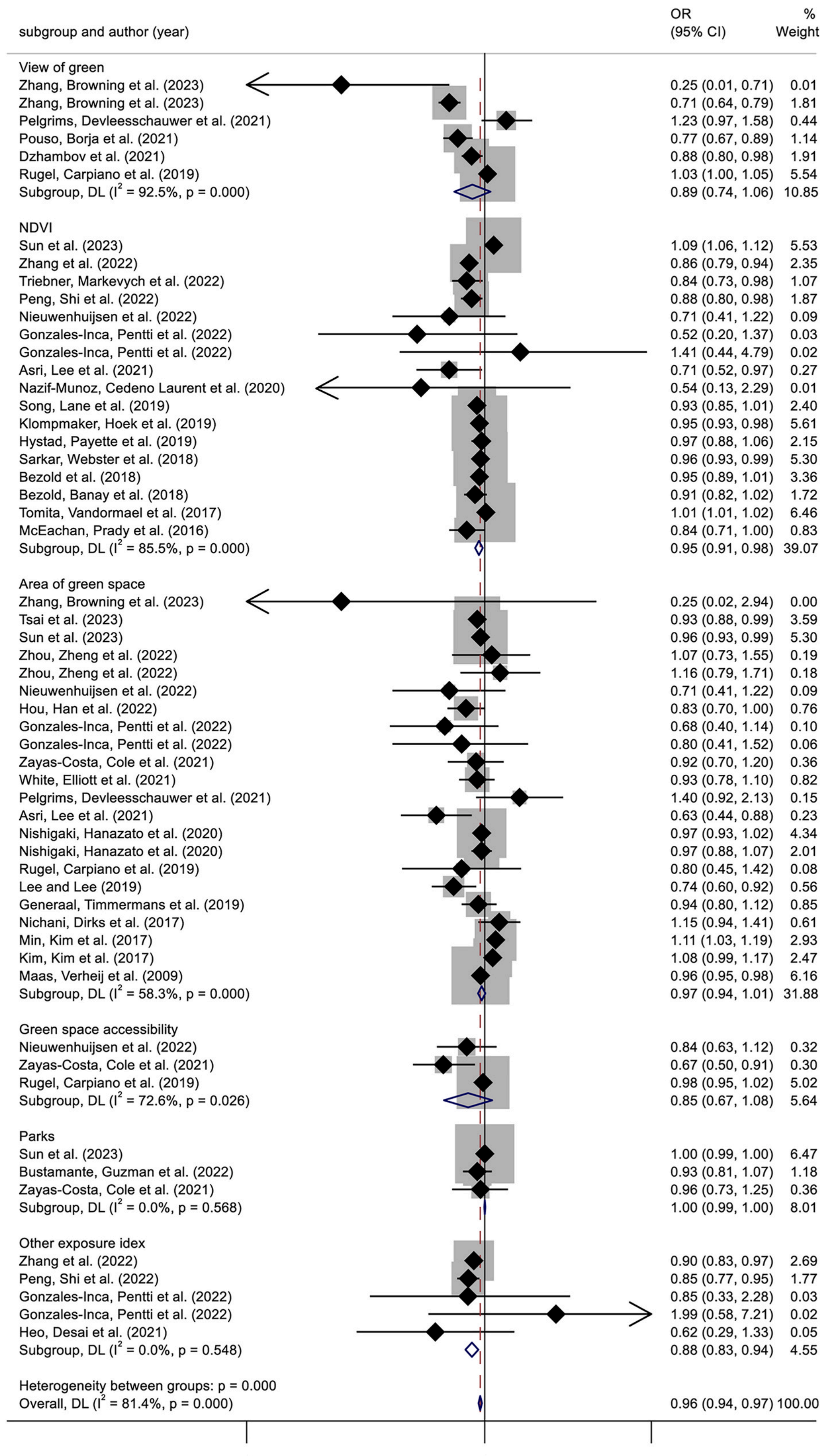

Fig. 4. Subgroup analysis of different geographic units about depression.

than male (Kim & Kim, 2017). Moreover, we noticed that effects of greenness exposure on depression during and after pregnancy appeared to be different. A decreased risk of depression during pregnancy was correlated to NDVI (McEachan et al., 2016). Previous studies have confirmed that depression is more common in urban environments (Blazer et al., 1985), and the factors influencing the effect of urban green spaces on depression are complex (Lauwers et al., 2021). Some studies showed plentiful trees in urban region as well as suitable numbers of

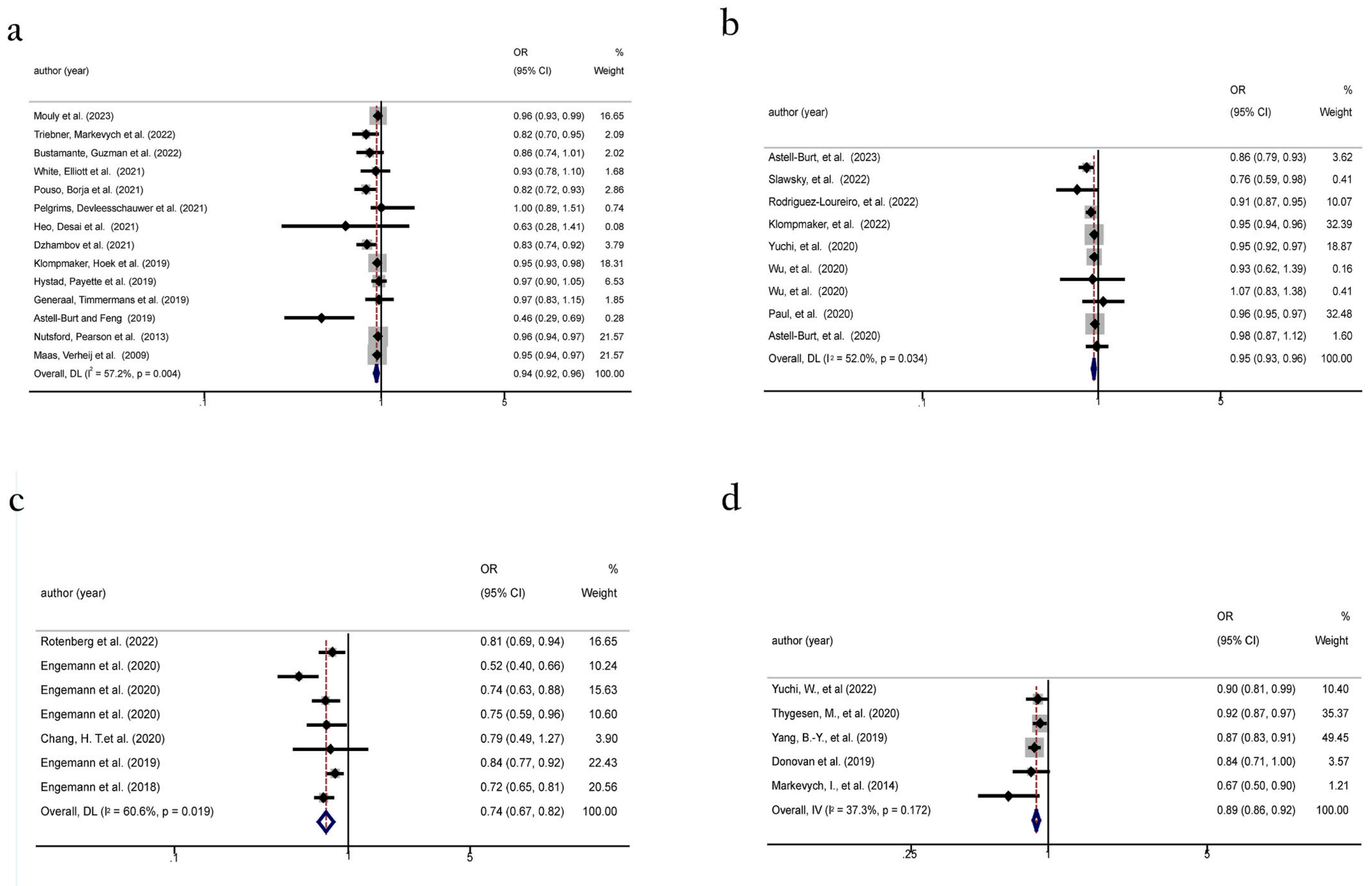

Fig. 5. Forest plot of the studies of anxiety(a); Forest plot of the studies of dementia(b); Forest plot of the studies of schizophrenia (c); Forest plot of the studies of ADHD(d).

grassland in rural region were both related to the decreased probability of depression (Nishigaki et al., 2020). Additionally, Cross-sectional and cohort studies of depression showed differences on data. The diversity came from the difference in quantity or time span. At a 5-years follow-up, scientists discovered a great correlation between green spaces and depression but less association over a 14-year period (Gonzales-Inca et al., 2022). This indicates that the follow-up duration also affected the results.

Although the general association between green spaces and anxiety is not as strong as that between green spaces and depression, a protective effect can still be revealed. Associating green spaces with anxiety may be related to green spaces in the neighborhood or within walking distance of a home (Nutsford et al., 2013). One reason suggested from Astell-Burt et al. is that greenness may provide people chances to recover from tiredness and promote the interpersonal communication. Additionally, biodiversity may also have beneficial effects (Astell-Burt & Feng, 2019).

Consistent with some of the existing results (Astell-Burt et al., 2020, p. 145; Paul et al., 2020; Rodriguez-Loureiro et al., 2022), our results generally indicated positive correlation between the exposure of greenness and dementia. But it should be noted that in some studies, moderate levels of green spaces reduce the risk of dementia to a greater extent than other levels (Slawsky et al., 2022). And there are also related studies that have been proposed high available green spaces was not associated with low dementia (Wu et al., 2020). About schizophrenia, scientists demonstrated that residing in more greenness correlated with a decreased odd of developing schizophrenia. Green space exposure during childhood is associated with schizophrenia risk on a dose-response basis (Engemann et al., 2018). Then more in-depth researches from Engemann et al. were conduct and found that gene did not disturb the association between green spaces and schizophrenia (Engemann et al., 2020a). Furthermore, higher vegetation density had been revealed associated with lower danger of schizophrenia in urban (Engemann et al., 2020c). Articles of ADHD also supported that increased hyperactivity problems were related with less green spaces. And the growth of exposure to minimum green spaces of children appeared to offer the maximum protection (Donovan et al., 2019). Notely, researches from Markevych et al. pointed out that based on sex stratification, only men exhibited statistically significant associations with ADHD (Markevych et al., 2014). However, limited articles cannot fully substantiate the benefits of green spaces to schizophrenia and ADHD, and a better knowledge of the role of greenness factors in reducing them requires more studies.

Heterogeneity was exhibited in studies of depression, anxiety, dementia, and schizophrenia. This may lead to the effect of high heterogeneity on the statistical power of meta-analysis, as well as the reliability and direction of the summary effect. There are differences in the measurement methods, sample sizes, types of green spaces, and sample characteristics (like age, gender) in studies. We can also speculate from subgroups analysis that studies design and geographic analysis units can be major sources of high heterogeneity, among which cross-sectional studies, view of green, NDVI, green space accessibility showed instability. This may because the way to view of green various, and NDVI were divided into a wide range of buffers and radius, and green spaces accessibility including distance or accessibility. We attempted to use the buffer radius for grouping but did not find a suitable classification method. Thus, the scattered distributions of different buffer radii were arranged in the existing subgroups. Some scientists estimated a buffer radius of 100 m around individuals' homes and found no significant associations (Gonzales-Inca et al., 2022). This indicates that different buffer radii may have different effects on depression,

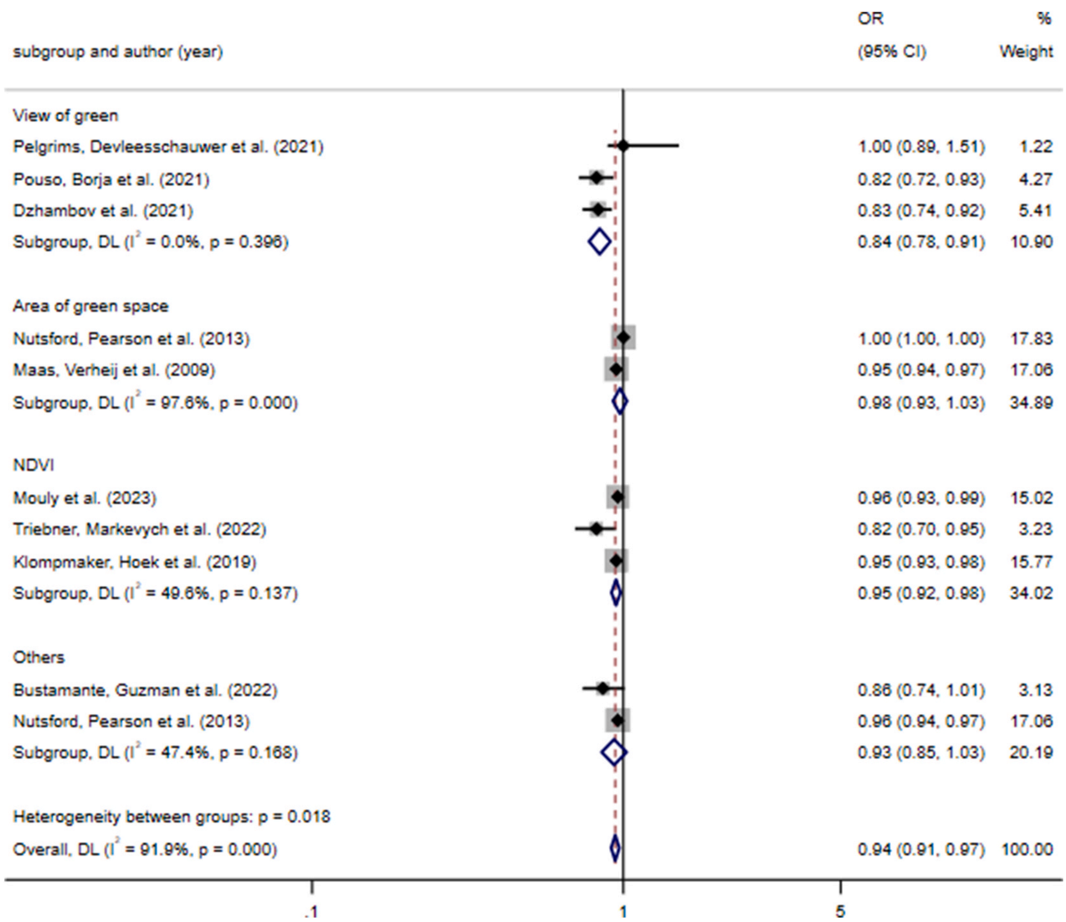

Fig. 6. Subgroup analysis of different geographic units about anxiety.

which is expected to broaden the range of tacks in the future. Besides, difference in region can also be one of the reasons. Studies of ADHD were not classified into subgroups as they only assess green by NDVI.

When exploring the relationship between green spaces and psychiatric disorders, scientists are also trying to explore the relevant mechanisms behind it. The mainstream claim that green spaces alleviate psychiatric disorders by reducing the exposure to environmental air pollution (Bloemsma et al., 2022; Triebner et al., 2022). Green spaces can decrease PM_{10} in the air remarkably and minimize exposure to $PM_{2.5}$ and NO_2 in pregnant women (Nieuwenhuijsen et al., 2017). One study from Thygesen et al. revealed that areas with more green spaces tend to have less pollution, which may benefit from the filtration deposition of plants (Thygesen et al., 2020). The same assertion is reflected in some of other articles. What's more, Bloemsma et al. said that the differentiation of mental health between urban and rural areas is also possible to provide an explanation (Bloemsma et al., 2022). This is also consistent with the results of the regional subgroup analysis of depression in our article, which can provide ideas for the future targeted construction of urban and rural health. There are also a number of studies demonstrated noise reduction may also contribute to the outcomes (Thygesen et al., 2020; Yang et al., 2019). Green spaces can play a role as a "wall", which can minimize noise by diffraction, absorption, or destructive interference of sound waves (Van Renterghem et al., 2015). Some studies provided evidence that physical exercise, diabetes, social support and psychiatric distress may be the mediators (Astell-Burt et al., 2023, p. 82). Among these factors, stress, and social cohesion influence the outcomes primarily (De Vries, Van Dillen, Groenewegen, & Spreeuwenberg, 2013). However, many studies have not yet found a clear link. Learning from a related meta-analysis for dementia, they indicated a non-linear relationship between green spaces and dementia, but potential mechanisms could not be found due to the limitations (Zagnoli et al., 2022). Rotenberg et al. said the cause of schizophrenic symptoms may be influenced by environment but the mechanism remains unclear (Rotenberg et al., 2022). Exploration in the mechanism is still much needed in the future.

Through the analysis of the above five common psychiatric disorders, we suggested that people can promote the development of public health by improving green space facilities in the future, and through our research, green space construction is more important in the urban environment, which provides ideas for the development of urbanization in the future. There are already many approaches or policy internationally to promote the development of green spaces in cities. In Denmark, approximately one quarter of health policies include references to the significance of promoting the utilization of green spaces (Schipperijn et al., 2010). A pattern named 3-30-300 green space rule is recommended, which requires that every citizen should be able to see at least three trees from their home, have 30 percent tree canopy cover in their neighborhood and not live more than 300 m away from the nearest park or green space (Nieuwenhuijsen et al., 2022). Small Public Urban Green Spaces (SPUGS) is also a promoted form of green spaces in cities (Peschardt et al., 2012). Some cities also built pocket park (Dong, Guo, Guo, & Cai, 2024). As the scarcity of urban land, green spaces of small scale demonstrate its potential. The development of green spaces still present challenges. We can draw from experience and look forward to more innovation and progress. Furthermore, we should continue striving to address inequality of urban green space (UGS) distribution (Wu & Kim, 2021) and environmental injustice (Wolch et al., 2014), thereby enabling the green space to better realize its benefits. Economic development will be a positive factor, and it is significant to prioritize not only the quantity but also the quality of green spaces (Wu & Kim, 2021).

Our meta-analysis holds some strengths as follows. First, we use extensive search string for the outcomes, and we conducted the exploration on four big databases, thus, this can provide a large sample source for our study. Second, our study consisted of five common psychiatric disorders. We started with an overview of all the diseases, and then analyze each disease individually, which providing a more comprehensive view on psychiatry. Thirdly, subgroups were employed in certain diseases, which demonstrate different influencing factors in detail. Admittedly, we also had many limitations and a wide space to improve the quality and rigor. Insufficient research has constrained our exploration of factors which may also have effect, like ethnicity, age, etc. We cannot adequately eliminate the interference caused by factors such as sample size, age, and geographic location. Besides, the mechanisms of some psychiatric disorders are still needed more in-depth discussion. The limited articles of schizophrenia and ADHD make our results less convincing. And our meta-analysis did not include grey literature, and involved studies in English only. When including studies, we did not strictly limit participant characteristics. The included articles encompassed studies targeting elderly individuals as well as studies focusing on pregnant women. These can all lead to bias.

5. Conclusion

Our meta-analysis revealed that green space is linked to lower odds of depression, anxiety, dementia, schizophrenia, and ADHD. Women and rural areas may benefit more from it. A high NDVI could be the major impact factor. Our meta-analysis encourages the local authorities and policymakers to attach greater importance to green infrastructure construction and urges the public to spend more time enjoying greenery. In the future, further studies are expected to explore the roles of gender, geographical locations, ethnicity, quality of greenness, potential mechanisms, as well as specific investigations into dementia, schizophrenia, and ADHD.

Ethical statement

I certify that this manuscript is original and has not been published and will not be submitted elsewhere for publication while being considered by **SSM - Population Health**. And the study is not split up into several parts to increase the quantity of submissions and submitted to various journals or to one journal over time. No data have been fabricated or manipulated (including images) to support your conclusions. No data, text, or theories by others are presented as if they were our own.

The submission has been received explicitly from all co-authors. And authors whose names appear on the submission have contributed sufficiently to the scientific work and therefore share collective responsibility and accountability for the results.

CRediT authorship contribution statement

Yimin Zhang: Writing – original draft, Software, Investigation. **Tongyan Wu:** Writing – original draft, Validation, Formal analysis. **Hao Yu:** Writing – review & editing, Validation, Methodology. **Jianfei Fu:** Software, Funding acquisition, Conceptualization. **Jin Xu:** Supervision, Conceptualization. **Liya Liu:** Validation, Supervision. **Chunlan Tang:** Writing – review & editing, Validation. **Zhen Li:** Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2024.101630.

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