



Associations of Residential Greenness with Depression and Anxiety in Rural Chinese Adults

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GRAPHICAL ABSTRACT



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PUBLIC SUMMARY

- Mental disorders, particularly depression and anxiety, have become one of the most serious public health issues globally.
- Symptoms of depression and anxiety and level of residential greenness were investigated for 27,366 participants from the Henan Rural Cohort.
- The mixed effect linear regression model was used to examine the associations between level of residential greenness and depression and anxiety in rural areas of Henan Province, China.
- Higher residential greenness was significantly associated with lower risks of depression and anxiety.
- Stronger effects of residential greenness were observed in males and in those with higher income and education level.



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BACKGROUND

Depression and anxiety are top contributors to non-fatal health loss globally. Several studies have indicated the association between residential greenness and mental health.

METHOD

The participants (n = 27,366) were recruited from four counties in Henan Province, China during 2015–2017. Symptoms of depression and anxiety were evaluated using the Patient Health Questionnaire-2 (PHQ-2) and the Generalized Anxiety Disorder-2 (GAD-2) in the baseline survey. The level of residential greenness during the 3-year period before the baseline survey was assessed using the Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). The mixed-effect linear regression model was applied to examine the associations of residential greenness with depression and anxiety.

RESULTS

The results of adjusted models showed that the score of PHQ-2 (Δ score and 95% confidence interval [CI]) decreased by -0.024 (-0.041 , -0.006) and -0.022 (-0.038 , -0.004) with an interquartile range (IQR) increase in NDVI and EVI within a 1,000-m buffer radius, respectively. The score of GAD-2 (Δ score and 95% CI) decreased by -0.024 (-0.040 , -0.006) and -0.028 (-0.044 , -0.011), in relation to an IQR increase in NDVI and EVI within a 1,000-m buffer radius, respectively.

CONCLUSIONS

A higher level of residential greenness was significantly associated with lower risk of depression and anxiety in rural areas of Henan Province. Improving residential greenness accessibility may help to promote the mental health of rural populations.

KEYWORDS: RESIDENTIAL GREENNESS; DEPRESSION; ANXIETY; RURAL RESIDENTS; EPIDEMIOLOGY

INTRODUCTION

Mental disorders, particularly depression and anxiety, have become one of the serious public health problems globally. Chronic depression is frequently accompanied by the presence of anxiety disorders, which may further lead to schizophrenia and even suicide.^{1,2} The prevalence of depression and anxiety was estimated to be 4.4% and 3.6% globally in 2015.¹ According to the Global Burden of Diseases study, the years lived with the disability of depression and anxiety rose by 14.3% and 12.8% during the period 2007–2017.³ In China, the prevalence of mental disorders has shown a rapid growing trend during the

past few decades.^{4,5} Evidence has shown that the natural, social, and built environment can affect the status of mental illness.^{6,7} Previous studies indicated that living in a greener environment could help to improve mental health.^{8–11} For example, a cross-sectional study based on an adult cohort (ALFA—Alzheimer and Families) demonstrated that an increase in urban green spaces was related to reduced use of benzodiazepines, indicating a potential protective effect of green space on depression and anxiety in adults.⁸ Another cohort study in the United States illustrated that a higher level of surrounding greenness was associated with a low incidence of depression.⁹

At present, studies investigating the effect of residential greenness on human health are mainly focusing on cardiovascular health.^{12,13} Few studies have addressed greenspace-related mental health outcomes such as depression and anxiety.^{9–11} Additionally, while most of the existing studies were conducted in Western countries,^{9,10} more than 80% of the burden of depression occurred in low- and middle-income countries,¹ such as China and India. During the past decades, the epidemic of infectious disease in rural China and other developing countries has been a public health issue of great concern,^{14,15} with the mental health problem being given little attention. With rapid urbanization, vegetation coverage in rural areas has been deteriorating. During the period 2000–2016, the mean Enhanced Vegetation Index (EVI) of Shanghai decreased by 16%, among which the EVI of peri-urban and rural areas decreased by 38%.¹⁶ Therefore, evaluating the impact of residential greenness on mental health among rural residents may help to prevent mental health problems and improve their quality of lives.

This study aims to examine the associations between residential greenness and depression and anxiety among rural residents in Henan Province, China.

RESULTS

A summary of participants' characteristics is shown in Table 1. The mean (SD) age of participants was 54.70 (12.42) years, and the majority of them were females (59.6%). Most of the participants never smoke or drink (72.3% and 77.7%). Among all the participants, 82.5% had the education level of junior high school. Participants' scores of the Patient Health Questionnaire-2 (PHQ-2) and the Generalized Anxiety Disorder-2 (GAD-2), and residential Normalized Difference Vegetation Index (NDVI) and EVI, during the 3-year period prior to the baseline survey are summarized in Table 2. The mean (SD) of PHQ-2 and GAD-2 were 0.49 (1.09) and 0.45 (1.09), respectively. As most of participants (n > 20,000) did not show any symptom of depression or anxiety, the median and IQR of scores of PHQ-2 and GAD-2 were both 0. The mean (SD) of NDVI and EVI within a 1,000-m buffer radius were 0.51 (0.06) and 0.36 (0.05), respectively.

The associations between NDVI/EVI and PHQ-2/GAD-2 are shown in Figure 1. Findings from the crude models showed that a decreased score of

Table 1. Basic Characteristics of Study Participants

Factors	N	%
Age (mean ± SD), years	54.70 ± 12.42	–
Gender		
Male	11,048	40.4
Female	16,318	59.6
BMI (kg/m ²)		
≤24	12,077	44.2
>24	15,230	55.8
Smoking status		
Non-smoker	19,790	72.3
Smoker	7,576	27.7
Drinking status		
Non-drinker	21,255	77.7
Drinker	6,111	22.3
Physical activity		
Low	8,530	31.1
Moderate	10,096	36.9
High	8,767	32
Marital status		
Married or cohabiting	24,773	90.5
Widowed	1,941	7.1
Divorced or separation	161	0.6
Single	491	1.8
Education level		
Primary school or illiteracy	11,760	43.0
Junior high school	10,816	39.5
High school or above	4,790	17.5
Income (RMB per month)		
<1,000	18,313	66.9
≥1,000	9,053	33.1
PM _{2.5} , median (P25, P75), μg/m ³	71.97 (70.54, 74.12)	–
Total	27,366	100

BMI, body mass index; PM_{2.5}, particulate matter less than 2.5 μm in aerodynamic diameter.

PHQ-2/GAD-2 was associated with increased NDVI/EVI within a 1,000-m buffer radius. After adjusting for potential confounders (Model 3), the score of PHQ-2 decreased with each interquartile range (IQR) increment in NDVI and EVI (Δ score [95% CI]: -0.024 [-0.041 , -0.006] and -0.022 [-0.038 , -0.004]). The score of GAD-2 decreased with each IQR increase in NDVI and EVI as well (Δ score [95% CI]: -0.024 [-0.040 , -0.006] and -0.028 [-0.044 , -0.011]). Estimates from crude models (Model 1) were consistent with results from adjusted models (Model 2 and Model 3).

The results of interaction analyses are presented in Figure 2. The modification effect of age was only observed in the association between EVI and depression. The effects of residential greenness on depression and anxiety

Table 2. Summary of Participants' Scores of PHQ-2/GAD-2 and Levels of NDVI_{1000 m}/EVI_{1000 m} during the 3-Year Period Prior to the Survey

Variable	Mean	SD	Median	P25–P75	Range
PHQ-2 score	0.49	1.09	0.00	0.00–0.00	0.00–6.00
GAD-2 score	0.45	1.09	0.00	0.00–0.00	0.00–6.00
NDVI _{1000 m}	0.51	0.06	0.53	0.49–0.55	0.19–0.60
EVI _{1000 m}	0.36	0.05	0.37	0.33–0.39	0.11–0.43

PHQ-2, Patient Health Questionnaire-2; GAD-2, Generalized Anxiety Disorder-2; NDVI, Normalized Difference Vegetation Index; EVI, Enhanced Vegetation Index.

were more pronounced for males than for females. Compared with females, more remarkable changes in the score of PHQ-2 were observed among males associated with each IQR increase in NDVI (Δ score [95% CI]: -0.051 [-0.075 , -0.025] versus -0.008 [-0.029 , 0.012]) and EVI (Δ score [95% CI]: -0.090 [-0.142 , -0.039] versus -0.048 [-0.073 , -0.023]). We also observed interaction effects of gender on the relationship of the score of GAD-2 with NDVI (Δ score [95% CI]: Female, -0.011 [-0.031 , 0.010] versus Male, -0.044 [-0.069 , -0.019]) and EVI (Δ score [95% CI]: Female, -0.048 [-0.073 , -0.023] versus Male, -0.081 [-0.132 , -0.029]). For depression, participants with higher education level and income were more strongly affected by residential greenness. Compared with participants with lower education levels (primary school or illiteracy), more remarkable changes in the score of PHQ-2 with increment in EVI were observed among residents with higher education level (Δ score [95% CI]: Primary school or illiteracy, -0.010 [-0.034 , 0.016] versus High school or above, -0.059 [-0.092 , -0.025]). Interaction effects of income were also observed for the relationship between PHQ-2 and EVI. No significant modification effect of body mass index (BMI) was observed.

The results of sensitivity analyses are shown in Supplemental Information. The associations between NDVI/EVI and dichotomous variables of PHQ-2/GAD-2 examined by logistic regression models are summarized in Table S1. The results were consistent with those from mixed linear models. Results summarized in Table S2 were estimated by models using the NDVI and EVI within 500-m and 3,000-m buffer radiuses, which were similar to those in models using the 1,000-m buffer radius. Also, the associations between the score of PHQ-2/GAD-2 and NDVI/EVI did not change substantially upon changing the 3-year exposure period to 2-year or 1-year exposure period (Table S3).

DISCUSSION

Our study revealed that a higher level of residential greenness was associated with a lower risk of depression and anxiety in rural areas of Henan Province.

To date, epidemiological evidence is limited in China and even globally regarding the beneficial effects of residential greenness on depression and anxiety. Existing evidence comes mainly from Western countries.^{6,17,18} A cross-sectional study based on the Survey of the Health of Wisconsin database in the United States reported that the score of Depression Anxiety and Stress Scales decreased by 1.369 and 0.512, respectively, associated with per 25% increase in NDVI.⁶ Another cross-sectional study also reported a negative correlation between urban greenness and depressive symptoms in 48 cities in Korea. The higher NDVI (fourth quartile) was associated with a lower risk of depression (odds ratio and 95% CI: 0.813 [0.747, 0.884]).¹⁸ One cross-sectional study in Wuhan, China found positive associations between greenness and developed behavior of children. The T score in the Childhood Behavioral Checklist of depression and anxiety decreased by -0.46 (-0.82 , -0.10) and -0.65 (-1.13 , -0.17), respectively, for each IQR increase in NDVI.¹⁷ Consistent with these previous studies, our study also indicated that environmental greenness had beneficial effects on symptoms of depression and anxiety.

Three potential pathways have been reported for the associations between greenness and mental health, relating to three functions of greenness: reducing harm, restoring capacities, and building capacities. For instance,

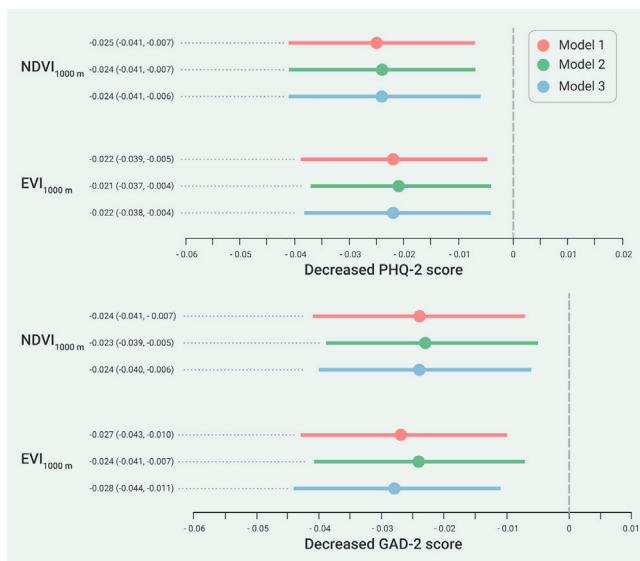


Figure 1. Decreased PHQ-2/GAD-2 Score (and 95% CI) Associated with Each IQR Increase in NDVI_{1000 m}/EVI_{1000 m} during the 3-Year Period Prior to the Survey IQR = 0.064 for NDVI_{1000 m}; IQR = 0.058 for EVI_{1000 m}. Model 2 was adjusted for age, gender, and body mass index; Model 3 was further adjusted for smoking status, drinking status, physical activity, marital status, education level, income, and PM_{2.5} based on Model 2. PHQ-2, Patient Health Questionnaire-2; GAD-2, Generalized Anxiety Disorder-2; NDVI, Normalized Difference Vegetation Index; EVI, Enhanced Vegetation Index.

greenspace can reduce air-pollution exposure, absorb heat and noise, and encourage physical and social activity.^{19–21} However, the biological mechanisms are complex and have not been well understood. Living close to greenspaces may protect the structural and functional integrity of brain regions that are associated with mental disorders. One pathway is related to the prefrontal cortex activity. The levels of total hemoglobin and oxyhemoglobin in blood were low in greenspace (e.g., forest), compared with other microenvironments, and a smaller amount of oxygen was transmitted to the prefrontal

cortex tissue. In this case, the prefrontal cortex activity was more stable, resulting in the relaxation of brain function.^{22,23} Long-term exposure to greenspace was positively associated with the gray matter and white matter volumes in the prefrontal region as well as other areas of the brain related to cognition, and a larger volume in these areas signified better memory and reduced inattentiveness.²⁴

In our interaction analyses, we found that males were more strongly affected by residential greenness compared with females, showing greater decreases in the scores of PHQ-2 and GAD-2 for each IQR increase in NDVI/EVI. Male adults constitute the main labor force in rural China. As they undertake most of the outdoor work, males have a greater chance of exposure to greenness. This gender difference in the greenness-health association was also reported by a previous study.²⁵ The more pronounced association between greenness and depression among people with higher education level and income was consistent with results from previous studies.^{26–28} However, inconsistent results were reported by existing studies regarding the interaction between greenspace and BMI on mental health.²⁹ Future studies, especially prospective cohort studies, are needed to confirm these results and identify vulnerable populations.

NDVI is a widely used satellite-retrieved data product for vegetation cover and greenness.³⁰ The retrieval algorithm of NDVI can reduce noise caused by sun angles, topographic and atmospheric conditions, and some uncertainties related to cloud and shadow.^{31,32} However, it does not control the atmospheric and canopy background conditions, resulting in possible errors from various sources. Due to scaling issues, NDVI shows limited capability in predicting senesced vegetation and is sensitive to soil environment.³¹ In particular, the NDVI tends to be saturated when viewing areas with large amounts of chlorophyll.³² In contrast, the EVI adds convergent canopy background adjustment and atmospheric resistance terms to the NDVI, which improves vegetation monitoring capability and provides improved sensitivity to high-biomass regions,^{31–33} such as a lush and diverse countryside. Thus, EVI is more suitable to reflect level of greenness than NDVI in rural areas.

Our study has several limitations. First, due to the cross-sectional design and unavailability of the exact onset date of depression and anxiety, the findings cannot confirm the causal relationship between residential greenness and depression and anxiety. Second, we used PHQ-2 and GAD-2 to screen

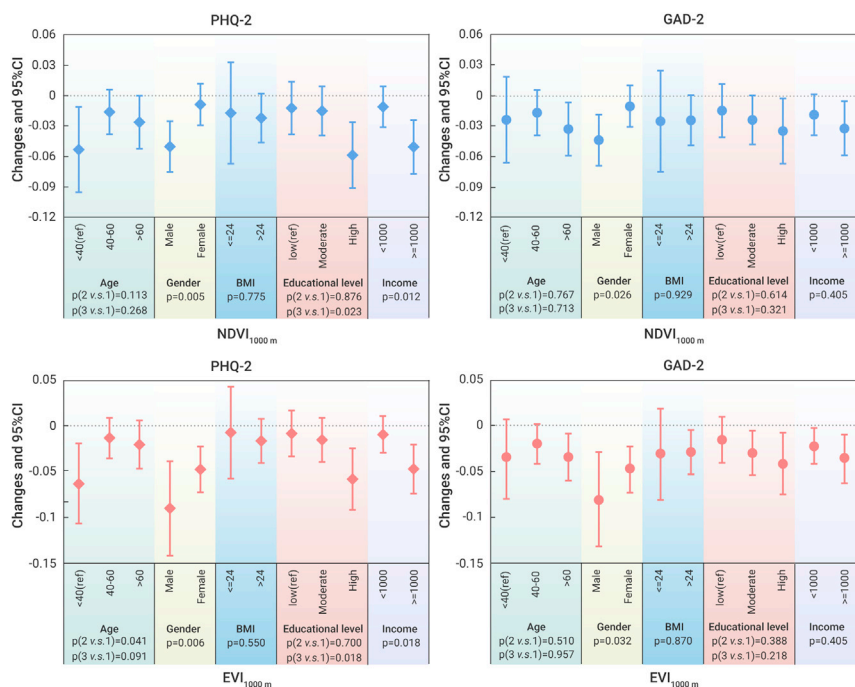


Figure 2. Changes in the Score of PHQ-2/GAD-2 Associated with NDVI_{1000 m}/EVI_{1000 m} during the 3-Year Period Prior to the Survey Modified by Age, Gender, BMI, Education Level, and Income Low, primary school or illiteracy; Moderate, junior high school; High, high school or above. PHQ-2, Patient Health Questionnaire-2; GAD-2, Generalized Anxiety Disorder-2; NDVI, Normalized Difference Vegetation Index; BMI, body mass index; EVI, Enhanced Vegetation Index.

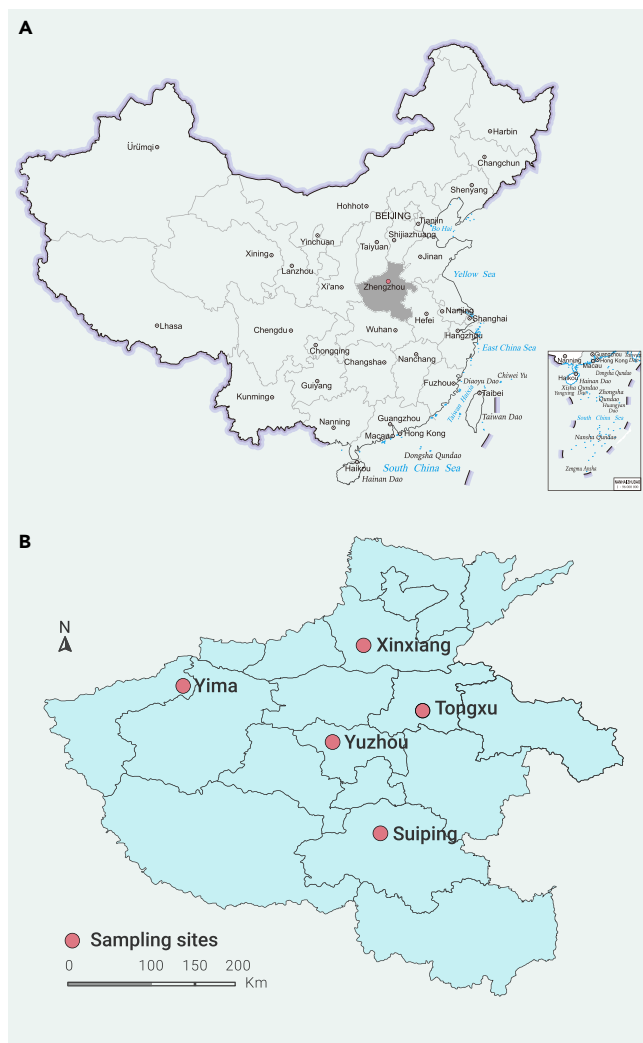


Figure 3. The Study Region (A) Location of Henan Province, China. (B) Location of the five counties studied in Henan.

depression and anxiety, but suspected cases were not confirmed by clinical diagnoses. This may lead to diagnostic errors. Although PHQ-2 and GAD-2 have been validated by previous studies,^{34–36} the sensitivity, specificity, and best cutoffs may vary by several social-economic factors, including study area, language used, and economic status. In addition, previous studies showed that indoor air-pollution exposures were associated with mental health,^{37–39} however, we were not able to control the confounding effect of indoor air exposure because of unavailability of such data. Moreover, we did not take short-term fluctuation of mental health status into consideration. The status of mental health may change over time,⁴⁰ the score of PHQ-2 and GAD-2 can only reflect symptoms of depression and anxiety for the previous 2 weeks. Finally, the results may be biased by unmeasured potential confounders, including variation in genotypes^{40,41} or other family factors.

Conclusion

The results of this study indicated that increased access to greenspace was associated with a lower risk of depression and anxiety, highlighting the impact of the environment on mental health. Our findings suggested that greenspace contributes to the improvement of mental health among the rural population. Policymakers and the public should pay more attention to mental health effects of residential greenness, and the government should provide effective policies and measures to improve greenness accessibility and protect the natural environment.

MATERIAL AND METHODS

Study Population

The study population was from the Henan Rural Cohort Study established between July 2015 and September 2017, which recruited rural residents without serious illness from five counties of Henan Province (Figure 3) using a multistage stratified cluster sampling method. First, five counties were selected from Henan Province by simple cluster sampling. Second, considering the compliance of the residents, population stability, and local medical conditions, one to three townships were selected by the local Center for Disease Control and Prevention of each county. Finally, all permanent residents who signed informed consent in selected townships were included in the study. Overall, 39,259 participants responded to the study invitations ($n = 41,893$) and completed the baseline survey, with a response rate of 93.7%. As participants from Yuzhou county were not assessed for depression or anxiety, a total of 29,993 participants from the other four counties were included. Participants with stroke ($n = 2,118$), cancer ($n = 292$), emphysema ($n = 151$), heart failure ($n = 55$), and no geoinformation ($n = 56$) were also excluded. Finally, a total of 27,366 (91.2%) participants were included in the analyses. Details of the study designs and characteristics of the study population have been reported previously.⁴² The study was approved by the scientific review and ethics committee of the Zhengzhou University Life Science Ethics Committee.

Outcome Assessment

In accordance with the DSM-IV (*Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition*) criteria, symptoms of depression and anxiety were assessed by PHQ-2 and GAD-2. The PHQ-2 and GAD-2 contain two items related to the main symptoms of depression and anxiety, respectively.^{34,43} Each item is rated from 0 to 3 according to a respondent's answer. The total score ranges from 0 to 6, where larger scores indicate higher risk of depression and anxiety. Several studies have suggested that PHQ-2 and GAD-2 are feasible tools for depression and anxiety screening.^{34,43} In rural China, the sensitivity and specificity were both 0.90 for PHQ-2,⁴⁴ and 0.87 and 0.98, respectively, for GAD-2.⁴⁵ Details of the quality control of PHQ-2 and GAD-2 have been reported previously.^{42,46} In brief, the validity and reliability of PHQ-2 and GAD-2 were assessed by a small pilot survey of 76 participants. In the pilot survey, investigators checked the integrity and logical errors of participants' responses. Additionally, 2.5% of the participants in the baseline survey were randomly selected for repeat measures, which provided estimates of the reliability and were used to check against any serious organizational failure.⁴²

Exposure Assessment

Data of residential greenness were obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) NDVI and EVI of the MOD13Q1 product. The NDVI and EVI of the MOD13Q1 product are Terra vegetation indices that provide continuous measurements for every 16 days at a spatial resolution of 500 m. NDVI is calculated based on observations under red and near-infrared wavelengths.^{31–33} The value ranges from -1 to 1 , where a larger positive value indicates a higher vegetation coverage density.⁹ In addition to the observation under red and near-infrared wavelengths, EVI includes an atmospheric resistance term representing reflectance at the blue wavelength. EVI also includes canopy background adjustment term, gain factor, and aerosol correction terms to control aerosol scattering in the red band and the blue band.^{31–33} These added items make EVI more sensitive in high-biomass areas. We calculated the mean value of NDVI and EVI within the buffer radiuses of 500 m, 1,000 m, and 3,000 m around each participant's home address. Finally, the averages of NDVI and EVI during the 3-year period before the baseline survey were calculated.¹⁷

Covariates

In accordance with previous studies, we considered a variety of potential confounders in the analyses.^{9,10} Demographic variables included age (" <40 years," " $40–60$ years," and " >60 years") and gender ("Male" and "Female"). Socioeconomic variables included marital status ("Married or cohabiting," "Widowed," "Divorced or separation," and "Single"), education level ("Primary school or illiteracy," "Junior high school," and "High school or above"), and monthly income (" $<1,000$ RMB" and " $\geq 1,000$ RMB"). Health behavior variables included smoking and drinking status ("Non-smoker/Drinker" and "Smoker/Drinker") and physical activity ("Low," "Moderate," and "High").⁴⁷ Moreover, BMI (" ≤ 24 kg/m²" and " >24 kg/m²") was also adjusted in the analyses.⁴⁸

Statistical Analysis

Mixed-effect linear regression models were employed to examine the association between NDVI/EVI within a 1,000-m buffer radius and the score of PHQ-2/GAD-2,^{49,50} considering the potential regional discrepancy of the association. Firstly, a crude model (Model 1) was developed incorporating NDVI/EVI as the fixed-effect term and study regions as the random-effect term. An intermediate model (Model 2) based on Model 1 was then developed to adjust for age, gender, and BMI. Finally, an adjusted model (Model 3) based on Model 2 was developed to further control for marital status, education level, monthly income, smoking and drinking status, physical activity, and

the 3-year average concentration of particulate matter less than 2.5 μm in aerodynamic diameter ($\text{PM}_{2.5}$). Estimated effects were presented as change of PHQ-2/GAD-2 scores (Δscore) and corresponding 95% confidence interval (CI) in relation to each IQR increment of NDVI/EVI. In addition, interaction analyses were performed between residential greenness and age, gender, BMI, education level, and monthly income. To assess the robustness of the results, we performed sensitivity analyses by applying logistic regression models to examine the association between NDVI/EVI within a 1,000-m buffer radius and dichotomous variable of PHQ-2/GAD-2 score. We also considered different exposure periods of NDVI/EVI (1-year and 2-year averages) and their different buffer radiuses (500 m and 3,000 m).

All the statistical analyses were performed using R software (version 3.6.2). The "lme4" and "multcomp" packages were used for the mixed-effect linear regression model, with $p < 0.05$ indicating statistical significance.

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AUTHOR CONTRIBUTIONS

G.C. and Y.G. had full access to all of the study data and take responsibility for the integrity of the data and the accuracy of the data analysis. N.D. and S.L. drafted the manuscript. N.D. contributed to the literature review and data analyses. Y.G., S.L.,

and G.C. contributed to the exposure assessment. Y.X. and Z.M. drafted and revised the manuscript. H.X., J.H., X.L., W.H., B.Y., and G.D. collected the data and revised the manuscript. G.C. and C.W. conceived of the study, designed the study, supervised the study, interpreted the results, and revised the manuscript. All authors contributed to the critical reading of and commented on the manuscript, helped to interpret the data, and approved the final manuscript.

DECLARATION OF INTERESTS

All authors declare no competing interests.

LEAD CONTACT WEBSITE

<http://sph.sysu.edu.cn/teacher/1349>; <http://www5.zzu.edu.cn/ggws/info/1023/1032.htm>.

SUPPLEMENTAL INFORMATION

Supplemental Information can be found online at <https://doi.org/10.1016/j.xinn.2020.100054>.