

Higher greenspace exposure is associated with a decreased risk of childhood asthma in Shanghai – A megacity in China

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ABSTRACT

Inconsistent evidence exists about whether exposure to greenspace benefits childhood asthma. Previous studies have only focused on residential or school greenspace, and no research has combined greenspace exposures at both homes and schools to determine their link with childhood asthma. A population-based cross-sectional study was conducted among 16,605 children during 2019 in Shanghai, China. Self-reported questionnaires were used to collect information on childhood asthma and demographic, socioeconomic and behavioural factors. Environmental data including ambient temperature, particulate matter with aerodynamic diameter less than 1 μm (PM_{10}), enhanced vegetation index (EVI), and normalized difference vegetation index (NDVI) were collected from satellite data. Binomial generalized linear models with a logit link were carried out to evaluate the association between greenspace exposure and children's asthma, as well as the effect modifiers. An interquartile range increment of whole greenspace (NDVI_{500} , NDVI_{250} , EVI_{500} , and EVI_{250}) exposure was associated with a reduced odds ratio of children's asthma (0.88, 95% CI: 0.78, 0.99; 0.89, 95% CI: 0.79, 1.01; 0.87, 95% CI: 0.77, 0.99; and 0.88, 95% CI: 0.78, 0.99, respectively) after controlling potential confounders. Low temperature, low PM_{10} , males, vaginal delivery, suburban/rural area, and without family history of allergy appeared to enhance the greenspace-asthma association. Increased greenspace exposure was associated with a lower risk of childhood asthma, and the association was modified by a range of socio-environmental factors. These findings add to the body of evidence on the benefits of biodiversity and supporting the promotion of urban greenspace to protect children's health.

1. Introduction

Asthma is one of the most prevalent chronic illnesses, placing a tremendous economical and health burden worldwide (GINA 2022). Asthma prevalence is increasing in many countries and regions, particularly among children (Asher et al., 2021, GINA 2022). For example,

China has had a sharp rise in the prevalence of pediatric asthma from 0.9% in 1990 to 3.0% in 2010, with Shanghai having the higher prevalence rates across the nation – viz., 1.5% and 7.6%, respectively (NCGCA, and, 2004, 2013).

Genetic and environmental factors may both contribute to the onset of childhood asthma (von Mutius and Smits, 2020). A wide range of risk

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and protective factors have been identified, and targeted strategies for asthma prevention and control were proposed and carried out (Tong et al., 2022a and 2022b; von Mutius and Smits, 2020). The question of whether greenspace may benefit childhood asthma attracts increasing attention (Andrusaityte et al., 2016; Cavaleiro Rufo et al., 2021; DePriest et al., 2019; Eldeirawi et al., 2019; Hartley et al., 2022; Hsieh et al., 2019; Lin et al., 2022; Winnicki et al., 2022; Wu et al., 2021). However, there have been mixed findings to date (Cavaleiro Rufo et al., 2021; DePriest et al., 2019; Hartley et al., 2022; Hsieh et al., 2019). For example, Rufo et al. (2021) found that living surrounded by higher greenspace was associated with a lower prevalence of asthma at seven years old. By contrast, DePriest et al. (2019) reported that greenspace exposure was not associated with children's asthma control. Lin et al. (2022) showed that higher greenspace was associated with higher odds of any childhood allergic disease.

Mechanisms underlying greenspace's benefits to children's asthma remain unclear, but some potential causal pathways have been proposed, including increased microorganism biodiversity (Rook, 2013), improved air quality (Diener and Mudu, 2021), and incremented outdoor activities (Almanza et al., 2012). Clearly, urbanization is accompanied by air pollution from vehicle exhaust, biodiversity loss, less space for outdoor activity, and so on. These are all linked to a rise in the prevalence of childhood asthma (Asher et al., 2021; Tong et al., 2022a). More greenspace exposure can provide more microbial richness, which may aid in the development of children's immune systems (Rook, 2013). Additionally, more greenspace can improve air quality by lowering the dispersion of air pollutants or depositing them more quickly (Diener and Mudu, 2021), and encourage increased physical activity (Almanza et al., 2012).

Previous research only focused on greenspace exposure around home or school but did not take into account the whole exposure (Cavaleiro Rufo et al., 2021; Zeng et al., 2020). Furthermore, few data are available on whether and how socio-environmental factors modify such a link. In this research, we assessed the association of the whole greenspace exposure around homes and schools with children's asthma, and evaluated possible modification effects of socio-environmental variables in Shanghai, a megacity in China.

2. Methods

2.1. Study design and population

The detailed procedure was described in previous studies (Chen, and et al., 2020, 2022; Hu et al., 2021a, 2021b and, 2023). Shanghai city, consisting of 16 districts, is located in eastern China and served as the research site. In brief, from April to June 2019, a population-based cross-sectional study was conducted, in which we randomly selected 17 primary schools and 31 kindergartens from 13 districts with a multi-stage and multi-strata sampling approach. Each child's mother (or guardian) completed the questionnaire (response rate > 95%). After excluding several participants who exceeded the age range of 3–12 years, 16605 of 17089 children (97.2%) were included in the final analysis.

2.2. Ethics

The ethical applications and consent process for this study were approved by the Ethics Committees of Shanghai Children's Medical Center and Shanghai Jiao Tong University School of Medicine. All participants involved in this study gave an informed consent.

2.3. Questionnaire data collection

Self-administered questionnaire was developed on the basis of the International Study of Asthma and Allergies in Childhood, and its quality was verified (e.g., the Cronbach's alpha coefficient of the ISAAC

allergic questionnaire was 0.91 in our study. The intra-class correlation coefficient of retest reliability was 0.94 at two weeks intervals) (Asher et al., 1995; Chen, and et al., 2020, 2022; Hu et al., 2021a, 2021b and, 2023). Children with current asthma were defined as those who responded "yes" to both the following questions: i) Ever asthma: Has a doctor ever given your child an asthma diagnosis? ii) Current symptoms: Has your child had wheezing, whistling in the chest or other asthma symptoms in the last 12 months?

Information on the following covariates was also collected:

Home and school addresses for the child; Age and gender of the child; gestational week: 37 weeks for preterm, 37–42 weeks for full-term, and 42 weeks for post-term; mode of delivery: vaginal or cesarean delivery; breastfeeding exclusively for six months or longer; history of miscarriage; family history of allergy; residential area: urban, suburban or rural; ownership of the house: yes or no, which reflects their socioeconomic status (SES); yes or no for passive smoking (if any family members smoke) and indoor plants; child's outdoor activity/day: < 0.5, 0.5–1, 1–2 or > 2 h; sleeping time for a child/day: (weekdays' hours $\times$ 5 + weekends' hours $\times$ 2) / 7; screen exposure for children: never, once or twice a month, once or twice a week, three to four times a week, or up to five times a week.

2.4. Environmental exposures

The Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra satellite were used to assess greenspace exposures surrounding the child's residence and school at 500 and 250 m resolution (Figueira Branco et al., 2019; Soltani et al., 2021). As an indicator of exposure, we averaged the NDVI or EVI annual mean values in the area around their present residence and school from 2016 to 2018 - three years prior to the 2019 study's execution. In recent research, the indices of NDVI and EVI have been frequently used to characterize greenspace exposure in epidemiological research (Eldeirawi et al., 2019; Hartley et al., 2022). The NDVI and EVI both have a range of -1–1: the negative values were replaced with 0 (frequency < 10), higher value corresponds to higher greenspace.

Data on mean ambient temperature for 2016–2018 were gathered with a 1000 m precision from the National Meteorological Science Data Center (<http://data.cma.cn/>).

Information on particulate matter with aerodynamic diameter less than 1 μm (PM₁) at a resolution of 1000 m was acquired from Wei et al. (2019) high-quality and high-resolution air pollutants data collection in China (ChinaHighAirPollutants, CHAP).

The residential addresses and schools of each participant were coded with latitude and longitude coordinates. The locations for the children's residences and schools were then matched with all environmental exposures including ambient temperature, PM₁, NDVI₅₀₀, NDVI₂₅₀, EVI₅₀₀ and EVI₂₅₀ using a single pixel (i.e., the 500 m $\times$ 500 m or the 250 m $\times$ 250 m) that contains the child's home or school. Children aged 3–12 years generally spend 8 h at school in Shanghai, so we calculated the combined environmental exposure as: residential exposure $\times$ 2 / 3 + school exposure $\times$ 1 / 3.

2.5. Statistical analysis

The analysis was mainly divided into four steps. Descriptive and Spearman correlation analyses were first conducted. Continuous data (such as environmental exposures) were reported as means and standard deviation (SD), and Wilcoxon rank sum test was used to compare the difference between two groups. Categorical data were shown in numbers and percentages. Spearman correlation coefficients (r_s) between environmental exposures such as greenspace (NDVI₅₀₀, NDVI₂₅₀, EVI₅₀₀ and EVI₂₅₀), ambient temperature, and PM₁, were calculated. Second, univariate and multivariable binomial generalized linear models with a logit link were performed to calculate the odds ratio (OR) and 95%

confidence interval (CI) of childhood asthma linked to greenspace exposure. To select appropriate covariates for final multivariable models, we took into account the literature, single-variable modelling results, and the directed acyclic graph (Fig. S1) drawn by DAGitty software (Textor et al., 2016). In this step, we also calculated the variance inflation factor (VIF) to avoid collinearity in final multivariable models. Besides, we performed the multilevel analysis using a mixed-effect regression model in which the school or district was treated as a random effect. Thirdly, restricted cubic spline models with 4 knots after adjustment for potential confounders were performed to visualize the concentration-response curves between greenspace exposure and the prevalence of asthma. Finally, stratified analyses were carried out to investigate the possible effect modification by sociodemographic and environmental variables. The Z-test was used to assess the differences in estimates of the greenspace-asthma relationship between subgroups (Altman and Bland, 2003).

All analyses were carried out using “dplyr”, “psych”, “forestmodel”, “ggplot2”, “ggrrcs”, “rms”, and “patchwork” packages based on R language, version 4.1.2 (R Core Team). A two-tailed p -value of 0.05 was set as the level of statistical significance.

3. Results

3.1. Descriptive and Spearman correlation analyses

In this study, the prevalence of current asthma was 4.8% (802/16605). Table S1 presents the detailed distribution of socio-environmental factors among children with asthma or not. Table 1 shows the descriptive data for environmental exposures from 2016 to 2018 and Spearman correlation coefficients. Differences in exposure levels of NDVI, EVI, PM₁, and temperature between children with or without asthma were statistically significant (all p -values < 0.05). Spearman correlation analyses reveal that, NDVI and EVI with 500 m and 250 m resolution had a positive correlation with each other (r_s range: 0.80–0.86, all p -values < 0.01). Ambient temperature was negatively correlated with NDVI and EVI (r_s range: −0.54 to −0.65, all p -values < 0.01), but positively with PM₁ (r_s = 0.75, p -value < 0.01). PM₁ was also negatively correlated with NDVI and EVI (r_s range: −0.44 to −0.59, all p -values < 0.01).

3.2. Association of greenspace exposure with childhood asthma

Fig. 1 presents the association between exposure to greenspace and odds ratio (OR) of children's asthma. In model I, the single variable model, an interquartile range (IQR) increment of NDVI₅₀₀, NDVI₂₅₀, EVI₅₀₀, and EVI₂₅₀ was associated with a decreased risk of asthma (OR = 0.79, 95% CI: 0.72, 0.86; 0.80, 95% CI: 0.72, 0.88; 0.79, 95% CI: 0.72, 0.88; and 0.83, 95% CI: 0.75, 0.91, respectively).

In Model II, per IQR increase of NDVI₅₀₀, EVI₅₀₀, and EVI₂₅₀ was also associated with an attenuated risk of children's asthma (OR = 0.89, 95% CI: 0.80, 0.99; 0.88, 95% CI: 0.78, 0.98; and 0.89, 95% CI: 0.79, 0.99, respectively), after adjustment for potential confounders (Fig. S2).

After further controlling temperature and PM₁ in Model III, an IQR

increase of NDVI₅₀₀, EVI₅₀₀, and EVI₂₅₀ was still associated with a reduced OR of children's asthma (0.88, 95% CI: 0.78, 0.99; 0.87, 95% CI: 0.77, 0.99; and 0.88, 95% CI: 0.78, 0.99, respectively) (Fig. S3).

Table S2 shows the VIF of all variables included in the final models. All values including the mean VIF < 2, indicating there is not obvious collinearity in final models, and the results were robust. Compared with results of mixed-effect regression models in which treating schools or districts as random effects, the results were almost identical to those in Model III (Table S3).

3.3. Concentration-response relationship between greenspace exposure and asthma

Fig. 2 displays the concentration-response curves between the prevalence of asthma and greenspace (NDVI₅₀₀, NDVI₂₅₀, EVI₅₀₀, and EVI₂₅₀) exposure using a restricted cubic spline function with 4 knots. There were nonlinear associations of the OR for childhood asthma with NDVI₅₀₀, NDVI₂₅₀, EVI₅₀₀, and EVI₂₅₀ (all p -values < 0.05). Using the median value as the reference, the higher the greenspace, the lower the OR of childhood asthma.

3.4. Effect modification

Table 2 shows the greenspace-asthma association stratified by environmental and sociodemographic factors. The results indicate that the association was significantly modified by outdoor temperature, PM₁, sex of the child, residential area, mode of delivery, and family history of allergy (p -values < 0.05). Both in low levels of temperature and PM₁ groups (< the median value), per IQR increment of NDVI₅₀₀, NDVI₂₅₀, EVI₅₀₀, and EVI₂₅₀ was associated with a reduced risk of children's asthma but these associations were not statistically significant in the group with the high levels of temperature and PM₁ (> the median value). An IQR increase of EVI₅₀₀ exposure in males was associated with an attenuated risk of childhood asthma (OR = 0.77, 95% CI: 0.66, 0.91), but no association was found in females (OR = 1.06, 95% CI: 0.87, 1.29). In suburban/rural area, per IQR increase of EVI₅₀₀ and EVI₂₅₀ was associated with a reduced OR of children's asthma (0.76, 95% CI: 0.63, 0.91; 0.79, 95% CI: 0.67, 0.94, respectively). No significant association was found in urban region (OR = 1.01, 95% CI: 0.85, 1.20; 1.01, 95% CI: 0.85, 1.21, respectively). Among children born through vaginal delivery, an IQR increase of NDVI₂₅₀ was associated with a reduced OR of asthma (0.75, 95% CI: 0.60, 0.92). However, such association was not found among children born in cesarean section (OR = 0.99, 95% CI: 0.85, 1.16). For children without family history of allergy, an IQR increase of NDVI₂₅₀ was associated with a decreased OR of asthma (0.74, 95% CI: 0.62, 0.89). But there was no significant association in children with family history of allergy (OR = 1.06, 95% CI: 0.89, 1.27).

4. Discussion

4.1. Main findings

This is the first study examining the association of whole greenspace

Table 1
Summary statistics of environmental exposures and Spearman correlation coefficients^a.

Variables	Overall N = 16,605	Children without asthma N = 15,803	Asthmatic children N = 802	p -value ^b	NDVI ₅₀₀ r_s	NDVI ₂₅₀	EVI ₅₀₀	EVI ₂₅₀	Temperature
NDVI ₅₀₀	0.45 (0.09)	0.45 (0.09)	0.44 (0.08)	< 0.001					
NDVI ₂₅₀	0.46 (0.09)	0.46 (0.09)	0.45 (0.08)	< 0.001	0.86**				
EVI ₅₀₀	0.28 (0.07)	0.28 (0.07)	0.27 (0.06)	< 0.001	0.85**	0.80**			
EVI ₂₅₀	0.29 (0.07)	0.29 (0.07)	0.28 (0.06)	0.001	0.86**	0.86**	0.84**		
Temperature	17.65 (0.05)	17.65 (0.05)	17.66 (0.05)	< 0.001	−0.65**	−0.54**	−0.54**	−0.56**	
PM ₁	27.82 (2.27)	27.82 (2.27)	28.00 (2.23)	0.008	−0.59**	−0.50**	−0.44**	−0.47**	0.75**

^a Data are presented with mean (standard deviation) and Spearman correlation coefficient (r_s);

^b Wilcoxon rank sum test; ** indicates p -value < 0.01.

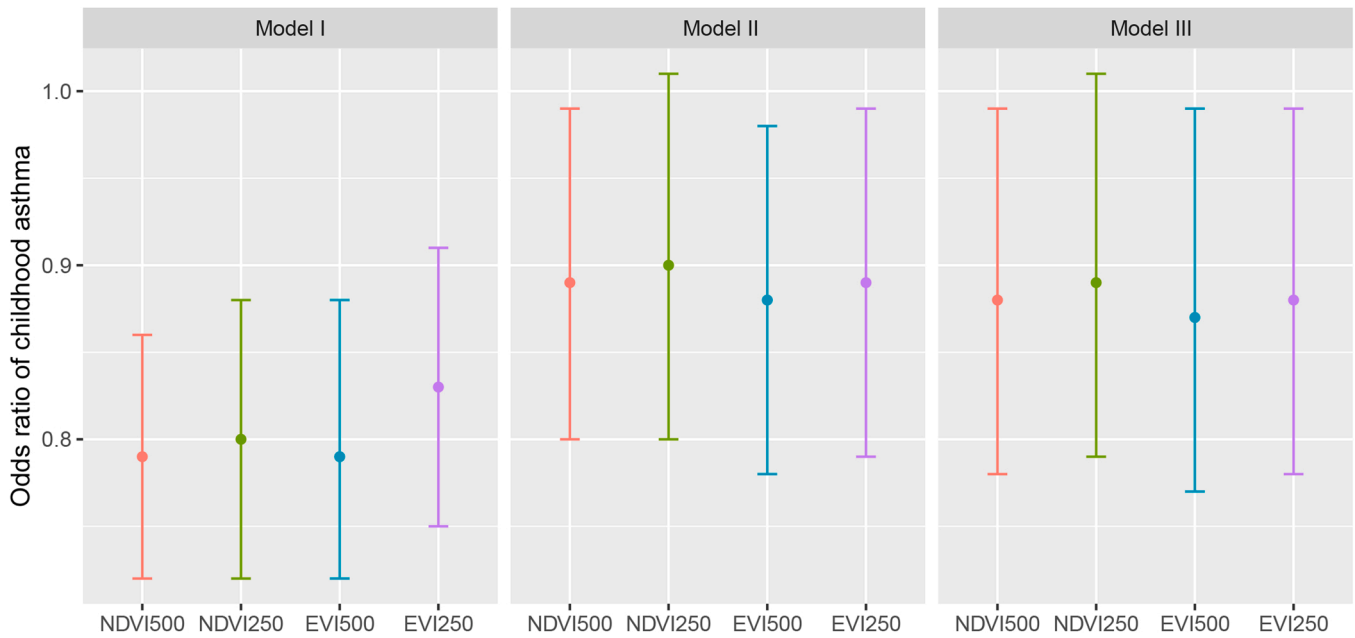


Fig. 1. Association of an interquartile range increase in NDVI and EVI with odds ratio of childhood asthma. Model I: univariate model; Model II: multivariable model where child's age, sex, physical activity, passive smoking, sleeping time, screen exposure, and gestational week, mode of delivery, exclusive breastfeeding duration, miscarriage, family history of allergy, SES, residential area, and indoor plants were controlled; Model III: Further control of temperature and PM₁ based on model II.

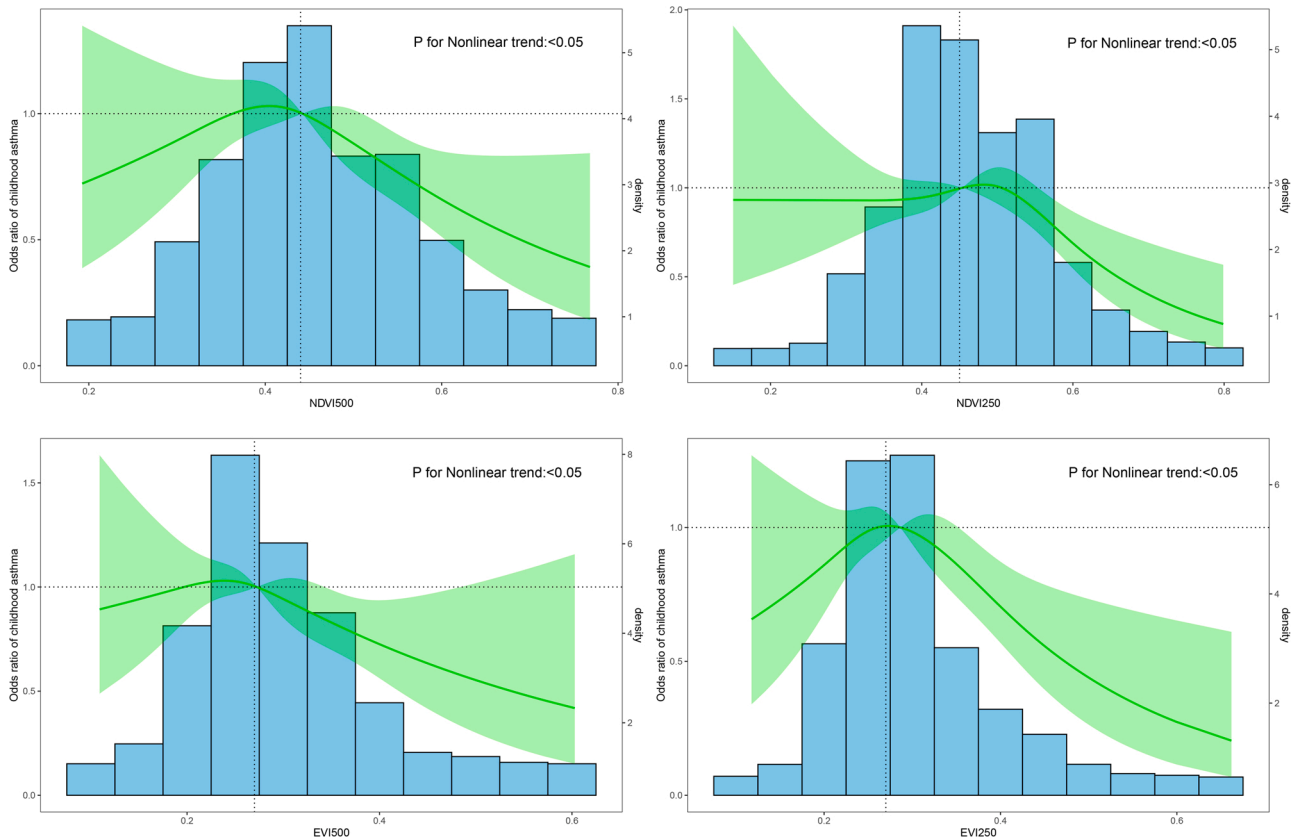


Fig. 2. Concentration-response relationship between the prevalence of asthma and greenspace (NDVI₅₀₀, NDVI₂₅₀, EVI₅₀₀, and EVI₂₅₀) exposure using a restricted cubic spline function with 4 knots.

exposure surrounding homes and schools with childhood asthma. In this population-based cross-sectional study, higher greenspace exposure including NDVI₅₀₀, NDVI₂₅₀, EVI₅₀₀, and EVI₂₅₀ seemed to reduce the risk of childhood asthma, and this association was modified by child's

sex, delivery mode, family history of allergy, residential area, ambient temperature, and PM₁.

Table 2

Effect modification of the greenspace-asthma association by environmental and sociodemographic factors.

Subgroups	NDVI ₅₀₀		NDVI ₂₅₀		EVI ₅₀₀		EVI ₂₅₀	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
PM ₁								
Low	0.77(0.65,0.91)	0.019	0.75(0.62,0.91)	0.011	0.78(0.66,0.92)	0.020	0.79(0.67,0.92)	0.011
High	1.03(0.86,1.22)		1.05(0.89,1.26)		1.06(0.87,1.29)		1.10(0.90,1.34)	
Temperature								
Low	0.75(0.63,0.89)	0.022	0.73(0.60,0.88)	0.009	0.74(0.63,0.88)	0.006	0.78(0.67,0.91)	0.018
High	1.00(0.84,1.19)		1.04(0.87,1.25)		1.06(0.87,1.28)		1.06(0.86,1.29)	
Passive smoking								
Yes	0.85(0.68,1.06)	0.734	0.95(0.76,1.19)	0.522	0.76(0.61,0.95)	0.139	0.84(0.68,1.04)	0.602
No	0.89(0.77,1.03)		0.87(0.75,1.01)		0.93(0.80,1.08)		0.90(0.78,1.05)	
School level								
Kindergarten	0.92(0.76,1.12)	0.477	0.91(0.75,1.09)	0.732	0.92(0.76,1.11)	0.479	0.90(0.75,1.07)	0.791
Primary school	0.84(0.72,0.99)		0.87(0.73,1.04)		0.84(0.71,0.99)		0.87(0.73,1.04)	
Child's sex								
Males	0.82(0.70,0.91)	0.136	0.83(0.70,0.97)	0.123	0.77(0.66,0.91)	0.014	0.82(0.70,0.96)	0.118
Females	0.98(0.80,1.18)		1.02(0.83,1.25)		1.06(0.87,1.29)		1.00(0.83,1.22)	
Residential area								
Urban area	0.96(0.82,1.13)	0.115	0.99(0.84,1.16)	0.055	1.01(0.85,1.20)	0.027	1.01(0.85,1.21)	0.049
Suburban/rural area	0.79(0.66,0.95)		0.77(0.63,0.94)		0.76(0.63,0.91)		0.79(0.67,0.94)	
Delivery mode								
Vaginal delivery	0.77(0.63,0.93)	0.083	0.75(0.60,0.92)	0.039	0.83(0.67,1.01)	0.481	0.81(0.66,0.99)	0.283
CS delivery	0.96(0.82,1.12)		0.99(0.85,1.16)		0.91(0.78,1.06)		0.93(0.80,1.08)	
Breastfeeding duration								
≤6 months	0.84(0.70,0.99)	0.414	0.81(0.67,0.97)	0.145	0.86(0.72,1.03)	0.787	0.83(0.69,0.99)	0.325
>6 months	0.93(0.78,1.10)		0.98(0.82,1.17)		0.89(0.75,1.06)		0.94(0.79,1.11)	
SES								
Low	0.85(0.65,1.10)	0.763	0.86(0.65,1.15)	0.779	0.81(0.63,1.05)	0.526	0.79(0.61,1.02)	0.345
High	0.89(0.77,1.02)		0.90(0.78,1.03)		0.89(0.78,1.03)		0.91(0.79,1.05)	
Family history of allergy								
Yes	0.98(0.82,1.17)	0.098	1.06(0.89,1.27)	0.005	0.98(0.82,1.18)	0.085	0.99(0.83,1.19)	0.091
No	0.80(0.68,0.94)		0.74(0.62,0.89)		0.79(0.67,0.93)		0.80(0.67,0.94)	

NDVI and EVI (500, 250), normalized difference vegetation index or enhanced vegetation index with 500, 250 m resolution; PM₁, particular matter with aerodynamic diameter $\leq 1 \mu\text{m}$; low level of PM₁ and temperature indicate $<$ median value; CS delivery: caesarean section delivery; SES: socioeconomic status; low SES means having no ownership of the house; OR, odds ratio; CI, confidence interval; p-value calculated by Z-test for testing the difference between subgroups.

4.2. Comparison with other studies

Recently, two systematic reviews demonstrated that the greenspace-asthma association was inconsistent among previous studies (Mueller et al., 2022; Ye et al., 2022). Several studies found an inverse association (protective effects) (Cavaleiro Rufo et al., 2021; De Roos et al., 2022; Eldeirawi et al., 2019; Sbihi et al., 2015; Squillacioti et al., 2019; Yu et al., 2021; Zeng et al., 2020), while others reported no association (DePriest et al., 2019; Hartley et al., 2022), or a positive association (adverse effects) (Andrusaityte et al., 2016; Hsieh et al., 2019; Parmes et al., 2020). These mixed results could be due to various factors, including different research designs (case-control, cross-sectional, and cohort studies), participants (ages and races), exposure evaluation (data from satellites or questionnaires), types of greenspace (tree, grass, NDVI, and EVI), geographical areas (nations, urban, or rural regions), and outcomes (asthma prevalence, exacerbations and hospitalisations) (Ferrante et al., 2020). Our finding provides additional evidence demonstrating the benefits of greenspace exposure to children's asthma.

Research is scarce on whether and how sociodemographic and environmental factors modified the greenspace-asthma association. Sbihi et al. (2015) in Canada reported that, in a birth cohort consisting of more than 65,000 children, per IQR increase of NDVI_{100 m} was associated with an attenuated risk of asthma (OR = 0.96, 95% CI: 0.93, 0.99) in preschool children, but no association was found among school children. Zeng et al. (2020) conducted a study in seven northeastern Chinese cities, and found that a 0.1 increase of NDVI_{1000 m} could decrease risks for current pediatric asthma (OR = 0.81, 95% CI: 0.75, 0.86). Such association appeared to be greater in higher air pollutants levels. Alcock et al. (2017) in England found that exposure to greenspace was associated with a reduction of asthma hospitalisations in lower air pollution levels but not in higher levels. Our stratified analysis showed that an IQR increase of greenspace was only significantly associated

with reduced risks of asthma among primary school children and at low levels of PM₁. In this study, we also observed that the association between greenspace exposure and children's asthma was significantly modified by ambient temperature, child's sex, delivery mode, residential area, and family history of allergy. Low temperature, males, vaginal delivery, suburban/rural area, and without family history of allergy might enhance the greenspace-asthma association.

4.3. Strengths and limitations

Our research has three key advantages. First, this is the first study examining the association of whole greenspace exposure surrounding both homes and schools with children's asthma. Second, the large sample size and high response rate could ensure sufficient statistical power for evaluating the association. Third, satellite-derived data on greenspace exposure (NDVI₅₀₀, NDVI₂₅₀, EVI₅₀₀, and EVI₂₅₀) were used to determine individual exposure as precisely as feasible.

Four major limitations must also be acknowledged. First, due to the cross-sectional design, causation could not be established in this study. To investigate the connection between greenspace exposure and childhood asthma, we have utilized the average greenspace of three years prior to the survey. Second, because the information on current asthma in children was gathered via questionnaires, without actual medical records confirmation, information bias possibly played a part to some extent, and the effects might be over or underestimated. Third, despite satellite-derived data on whole greenspace exposure surrounding both children's homes and schools with various resolution being utilized, there may still be misclassification in the individual exposure. Finally, although being standardized for assessing greenspace, NDVI and EVI cannot reflect the height of plants and discriminate between distinct plant types (i.e., grass and trees).

4.4. Future directions

To improve the understanding of the relationship between greenspace exposure and children's asthma, future research should pay attention to the following challenges:

- i) More assessments of the greenspace-asthma link amongst various locations and nations, especially in low-income and middle-income countries;
- ii) A more specialized or compound greenspace index. It may address what types of greenspace benefit/exacerbate children's asthma and in which way;
- iii) Longitudinal studies with a wide range of greenspace exposure. It may help to identify important windows of exposure on childhood asthma and aid in the investigation of potential mechanisms for such a link.

5. Conclusions

Higher exposure to whole greenspace surrounding children's homes and schools was associated with a lower risk for asthma, and the association was significantly modified by child's sex, delivery mode, family history of allergy, residential area, ambient temperature, and PM₁. These findings add to the body of evidence regarding health benefits of biodiversity, support the promotion of greenspace to protect children's health and wellbeing, and may also have significant implications for decision-making on urban planning and design.

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CRediT authorship contribution statement

Profs Li and Tong had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. All authors read and approved the final manuscript. *Concept and design:* Liu, Tan, Yu, Yan, Yin, Li, Tong. *Acquisition, analysis, or interpretation of data:* Hu, Chen, Li, Tong. *Drafting of the manuscript:* Hu, Tong. *Critical revision of the manuscript for important intellectual content:* All authors. *Statistical analysis:* Hu. *Obtained funding:* Liu, Tan, Yu, Yan, Yin, Li, Tong. *Administrative, technical, or material support:* Hu, Chen, Li, Tong. *Supervision:* Li, Tong

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. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.ecoenv.2023.114868](https://doi.org/10.1016/j.ecoenv.2023.114868).

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