



Green Environments and Allergic Diseases in Children: a Scoping Review

João Cavaleiro Rufo¹ · Inês Paciência¹ · Ana Isabel Ribeiro^{1,2}

© Springer Nature Switzerland AG 2019

Abstract

Purpose of Review Urbanization and urbanization-related detrimental exposures are commonly indicated as responsible determinants for the dramatic increase in allergy and asthma, and one of the main urbanization factors that have been recently associated with the development of allergic sensitization is the reduced access to natural and biodiverse spaces. The present review aimed to compile and discuss the recent findings from studies focused on neighbourhood greenspace effect on asthma and allergic disease development in children.

Recent Findings Green areas neighbouring children residences play a role on the prevalence of allergy and asthma. However, whether greenness is a protective factor, or an exacerbation driver, is yet to be elucidated. This may be due to the confounding factors associated with greenspace exposure, such as vegetation biodiversity, environmental microbiome, human behaviour, or the region itself.

Summary It is not possible to concretely discern the importance of early life exposure to green areas on asthma and allergy development. More studies on determinant factors associated with green areas, such as biodiversity or environmental microbiome, may help to elucidate these associations.

Keywords Allergy · Asthma · Greenspace · Neighbourhood · Residential · Urban environment

Introduction

The Burden of Allergy and Asthma in Industrialized Countries

The high prevalence of asthma and allergic diseases in industrialized countries remains one of the most debatable concerns for the World Health Organization when it comes to non-communicable diseases [1, 2]. In Europe, more than 150 million individuals suffer from allergic diseases and estimates suggest that, by 2025, half of the European population will be affected [3, 4]. These diseases are characterized by a

hypersensitive and abnormal response to common allergens, possibly resulting in a cascade of symptoms, from simple rhinorrhoea or wheezing, to anaphylaxis or bronchial hyper-reactivity [5]. These symptoms may be caused by several allergic diseases, ranging from atopic dermatitis (eczema) to the highly prevalent allergic rhinitis, which affects roughly half of the adolescents [4]. Allergic asthma is closely associated with these allergic conditions as it usually develops in allergen-sensitized individuals during childhood, affecting between 5 and 15% of the children in European countries and being the first cause of hospitalizations for chronic diseases and absenteeism in children [2, 6].

Urbanization and urbanization-related detrimental exposures are commonly indicated as responsible determinants for such dramatic increase in allergy and asthma [7], and one of the main urbanization factors that have been recently associated with the development of allergic sensitization is the reduced access to natural and biodiverse spaces. An emerging theory—the ‘biodiversity hypothesis’—states that reduced contact with natural environments and biodiversity in the first years of life may disrupt the development of immune function, causing susceptibility to allergens and abnormal immune

This article is part of the Topical Collection on *Social Epidemiology*

✉ Ana Isabel Ribeiro
ana.isabel.ribeiro@ispup.up.pt

¹ EPIUnit – Instituto de Saúde Pública, Universidade do Porto, Rua das Taipas n°135, 4050-600 Porto, Portugal

² Department of Public Health, Forensic Sciences and Medical Education University of Porto Medical School, 4200-319 Porto, Portugal

responses to common epitopes later in life [8, 9]. On the other hand, the theory defends that early contact with multiple microbiological agents appears to contribute to a preventive immunomodulation, inducing tolerance to allergens through both adaptive and innate immune mechanisms [10]. Therefore, the reduced access to green areas in urban environments may be impairing immunomodulation in young children, consequently resulting in a higher prevalence of allergy and asthma [11].

The Nature Effect on Allergy and Asthma

It is important to refer that the contact with nature may have dual, and opposing, effects on allergic diseases and asthma, both beneficial and detrimental. Beneficial, as it conveys greater exposure to number and diversity of microbial agents [9] and improves air quality [12, 13]; detrimental, as it may cause exacerbation of symptoms in sensitized individuals [14]. Exploring the co-effects (simultaneously negative/positive effects) of urban environmental exposures is crucial to guide planners and policymakers in the definition of urban planning actions [15]. Due to those dual and opposing effects, evidence on the topic is mixed and inconsistent. Therefore, there is an undeniable need to better understand all the available information on the subject. For that reason, the present review aimed to compile and discuss the recent findings from studies focused on neighbourhood greenspace effect on asthma and allergic disease development in children.

Search Methodology

A PRISMA oriented systematic search [16] was performed until 8 July 2019 in PubMed database. The search was conducted for manuscripts published in the past 5 years and according to the following search query: '(neighbourhood[Title/Abstract] OR neighborhood[Title/Abstract] OR residential[Title/Abstract]) AND (childhood[Title/Abstract] OR children[Title/Abstract] OR infants[Title/Abstract] OR pediatric[Title/Abstract] OR paediatric[Title/Abstract]) AND (allergy[Title/Abstract] OR allergic[Title/Abstract] OR atopy[Title/Abstract] OR asthma[Title/Abstract])'. Published peer-reviewed full-text articles in English, focused on neighbourhood greenspace effect on asthma and allergic disease development in children, were assessed for eligibility. The inclusion criterion consisted on having studied associations between a quantifiable greenspace surrogate and the development of asthma and/or allergic diseases. Review studies, protocol articles, or conference abstracts without respective full-text publications were excluded from the present review. Two reviewers (JCR and AIR) independently applied the inclusion and exclusion criteria and any differences were resolved by consensus.

Conclusions

Search Results and General Observations

A total of 169 studies were found using the described search methodology. Through screening, 73 articles were removed for not meeting the search scope. From those, 15 studies met the inclusion criteria. Finally, two of the 15 studies were excluded for not being original studies, and one other for not comprising a paediatric population. The search therefore resulted in 12 studies, summarized in Table 1, that were thoroughly reviewed by the authors [17–25, 26•, 27, 28•]. These comprised scientific observations on the effect of greenness exposure—in countries from Europe, North America, Asia and Oceania—on childhood allergy and asthma prevalence.

As a general observation, and having in mind the results provided by the reviewed studies, greenness exposure on asthma and allergic disease is quite complex, varying significantly between studies, regions, locations or participant status, which supports the aforementioned dual and opposing effects of nature on these diseases [9, 12–14]. Although there were indeed some studies that found negative associations between neighbouring greenness and the prevalence of allergic diseases or asthma, there were also a similar number of studies that found positive associations, or no associations at all (Fig. 1). It is also important to note that the majority of the studies were conducted using one or more birth cohorts, which often generated a high sample size. Moreover, studies focused on asthma prevalence failed to distinguish between the different phenotypes of asthma involved. As the pathophysiological mechanisms of asthma are significantly different between phenotypes, these could have an impact on the results [29]. Nevertheless, the studies did distinguish associations between asthma and allergy, and the results often revealed different directions for the observed associations.

Green Environments and Allergic Diseases

Allergic reactions are caused by an abnormal immune response to an otherwise harmless antigen. These allergens are often found in nature, and green areas are one of the major sources for these airborne agents in the urban environments [30]. For instance, Dadvand and co-workers [17] observed, in the Spanish city of Sabadell, that children who lived closer to forests had a tendency for a higher prevalence of allergic rhinoconjunctivitis (OR [95%CI] 1.27 [0.94, 1.70]). However, this association was weaker in regard to the proximity to parks (OR [95%CI] 1.10 [0.90, 1.35]). A logical explanation for these results could be the difference of vegetation density between the two environments. In fact, results from a study performed by Fuertes et al. showed that the geographic region affects the influence that the green environment may have on allergic diseases [19]. This study included

Table 1 Summary of the 12 studies included for revision

Ref.	Year	Study location	Objective	Participants	Short conclusion
Dadvand et al. [17]	2014	Sabadell, Spain	To simultaneously investigate the potential health benefits and risks associated with exposure to different types of greenness in children.	A total of 3178 homes from participants who answered a questionnaire were geocoded.	Residential proximity to forests was positively associated with current allergic rhinoconjunctivitis but not current asthma. Residential proximity to parks was positively associated with current asthma and weakly associated with allergic rhinoconjunctivitis.
Andrusaityte et al. [18]	2016	Kaunas city, Lithuania	To evaluate the long-term impact of quantified greenness levels in the urban environment on the risk of asthma in 4–6-year-old children.	1489 children (4–6 years old) whose mothers did not change their residence address from the pregnancy.	There are positive associations between surrounding greenness quantity within the buffer of 100 m from each child's home and the prevalence of asthma among children, and this association persists after adjusting for individual-level covariates and exposures to air pollution.
Fuertes et al. [19]	2016	7 cohorts from Australia, Canada, Germany, the Netherlands, and Sweden.	To examine cross-sectional associations between residential greenness and allergic rhinitis and aeroallergen sensitization during childhood and early adolescence.	In total, 13,016 children (from all cohorts) participated in the study.	Although residential greenness appears to be associated with childhood allergic rhinitis and aeroallergen sensitization, the effect direction varies by location.
Chen et al. [20]	2017	Chicago, USA	To understand if living in areas high in greenspace may help buffer the effects of difficult family relationships for children with asthma.	150 children ages 9 to 17 with physician-diagnosed asthma	Children with asthma appear to benefit the most when they both live in high greenspace areas and have positive family relationships.
Sbihi et al. [21]	2017	Metropolitan area of Vancouver, British Columbia, Canada	To identify trajectories of childhood asthma and to characterize the potential impact of residential greenness and air pollution on asthma trajectory subgroups.	A total of 68,195 singleton births were eligible for inclusion in the final analytic cohort.	Three distinct trajectories of asthma were identified using group-based trajectory modelling of the annual prevalence of asthma in the participants, followed from birth to age 10. Greenness was not associated with any of the asthma trajectories.
Tischer et al. [22]	2017	Asturias, Gipuzkoa, Sabadell and Valencia, all in Spain	To prospectively evaluate the association between indicators of urban green and grey built environments and respiratory and allergic health outcomes in young children.	2472 children participants (outcomes measured at the age of 4)	Several associations were found for respiratory health, but these differed in direction across the indices studied and by geographic region.
Bukalasa et al. [23]	2018	Northern, middle and western parts of the Netherlands	To study the association between residential exposure to pesticides and asthma and related respiratory symptoms among adolescents within the Dutch PIAMA birth cohort study.	3963 participants (at age of 14) who were born in 1996 and 1997	There was no evidence found for an association between living near agricultural fields likely treated with pesticides and the prevalence of asthma and related respiratory symptoms.
Cilluffo et al. [24]	2018	Palermo, Italy	To simultaneously evaluate the association between indicators of urban-related environmental exposures, including those for “green”, “grey” and NO ₂ exposure, with respiratory/allergic and general symptoms in schoolchildren from the city of Palermo, Italy.	219 children (8–10 years old)	A very low exposure to normalized difference vegetation index (NDVI) had a higher odds of nasal symptoms.
Donovan et al. [25]	2018	New Zealand (countrywide)	To address the limitations and inconsistencies of the available literature by assessing the association between asthma and the	49,956 participants followed for 18 years since birth	Children who lived in greener areas, as measured by the NDVI, were less likely to be asthmatic. However, an increase in the area

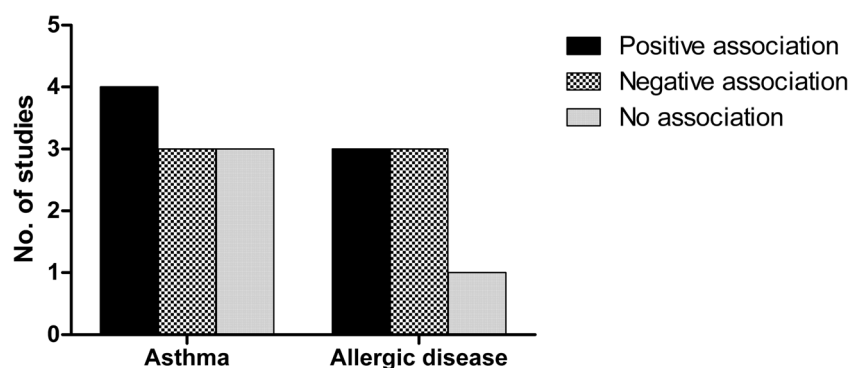
Table 1 (continued)

Ref.	Year	Study location	Objective	Participants	Short conclusion
			natural environment in a large New Zealand birth cohort followed for 18 years.		covered by gorse or exotic conifers, both non-native, low-biodiversity land-cover types, was associated with a 3.2% (95% CI 0.0–6.0%) and 4.2% (95% CI 0.9–7.5%) increased risk of asthma, respectively. The results suggest that exposure to greenness and vegetation diversity may be protective of asthma.
Müller-Rompa et al. [26•]	2018	Bavaria region, Germany	To determine differences in residential exposures of farm children and their classmates and to quantify the protective effects of these exposures on asthma and atopy.	2265 children recruited from the Bavarian arm of the GABRIELA cohort	Asthma and atopy were inversely associated with the presence of a farm within a radius of maximum 100 m. The environmental variables greenness, tree cover, soil sealing, altitude, air pollution differed not only between farm and non-farm children but also between farm children with and without another farm nearby.
Gernes et al. [27]	2019	Southwest Ohio and Northern Kentucky, USA	To compare residential greenspace based on two aerial measures of greenspace in relation to childhood allergic disease.	478 children (age of 7)	Residential proximity to grassy areas appears to be associated with higher odds of atopic sensitization to different outdoor aeroallergens in a high-risk regional cohort.
Hsieh et al. [28•]	2019	Taiwan	To examine the association between the first occurrence of asthma and greenness exposure in children and teenagers.	3520 subjects with asthma, and 3520 subjects without asthma (controls)	The risk of a first asthma occurrence is significantly associated with higher levels of greenness exposure in preschool children. Exposure to the highest level of green coverage did not lead to a significantly increased risk of asthma. These results indicate that the greenness exposure on asthma is quite complex even when adjusted for some important air pollutants related to asthma occurrence in the models.

seven cohorts recruited in Australia (MACS), Germany (GINI-plus and LISApplus), Sweden (BAMSE), Netherlands (PIAMA), and Canada (CAPPS and SAGE), and while the association between greenness in a 500-m buffer, measured

through the normalized difference vegetation index (NDVI), and allergic rhinitis was positive and significant in the BAMSE (OR [95%CI] 1.42 [1.13, 1.79]) and GINI/LISA South (OR [95%CI] 1.69 [1.19, 2.41]) cohorts, inverse

Fig. 1 The number and direction of associations between greenness exposure and the prevalence of allergy and asthma, in the 12 reviewed studies. Occasionally, there were contradicting association directions reported in the same study, due to different study regions being included



associations were found for the GINI/LISA North (OR [95%CI] 0.61 [0.36, 1.01]) and PIAMA (OR [95%CI] 0.67 [0.47, 0.95]). No significant associations were observed for the remaining cohorts.

The concept of geographic region affecting the influence of greenness on allergic diseases has later been supported by Tischer and co-workers [22], who reported that the effect of exposure to green areas varied significantly between the Euro-Siberian and Mediterranean regions of Spain. These effect differences may be associated with the probably distinct environmental microbiome in the urban settings for those regions [22].

In a study conducted in Palermo, Italy, Cilluffo et al. [24] showed that a very low exposure to green areas in the city ($\text{NDVI} \leq 0.15$) was associated with a significantly higher prevalence of nasal symptoms in children (OR [95%CI] 1.47 [1.07, 2.03]). These symptoms were mostly associated with allergic rhinitis, including rhinorrhea, nasal congestion, or rhinoconjunctivitis. Similar results were reported by Müller-Rompa and co-workers [26], but for rural environments. In this study, comprising the Bavarian arm of the GABRIELA birth cohort, the presence of a farm within a maximum of 100-m radius was found to be a protective factor for atopy (OR [95%CI] for a farm at 50 m 0.49 [0.37, 0.64]). It is important to bear in mind that the variables greenness, tree cover, soil sealing, altitude, and air pollution differed not only between farm and non-farm children but also between farm children with and without another farm nearby [26]. However, a contradicting association was found by Gernes et al. [27], in a study conducted in the Cincinnati region of USA (Southwest Ohio and Northern Kentucky), where the residential proximity to grassy areas was associated with higher odds of atopic sensitization to different outdoor aeroallergens in 7-year-old children (OR [95%CI] 1.27 [1.02, 1.58]).

Concluding, the association between green environment exposure and allergic diseases is complex, as it may vary according to the region, vegetation biodiversity, or the type of setting (urban or rural), notwithstanding the duality of effects green areas may have on children with different atopic status, as it may be beneficial during early life exposure in healthy children, while being detrimental in already sensitized individuals [14].

Green Environments and Asthma

Asthma is a respiratory disease characterized by generally unspecific symptomatology such as wheezing, dyspnoea or dry cough [31]. A particular manifestation of asthma, commonly known as allergic asthma, is usually associated with exacerbations and bronchial hyperresponsiveness when the patient is exposed to a specific allergen. Therefore, asthma exacerbations may be tightly linked to environmental allergens, which are usually found in higher concentrations

proximate to green areas, in urban environments. On the other hand, neighbouring greenness may improve immunomodulation and reduce the odds for developing the disease. Both hypotheses have been supported by the reviewed studies. One example that supports the first hypothesis is the aforementioned study conducted by Dadvand et al. [17], where residential proximity to parks in Sabadell city was significantly associated with a higher prevalence of asthma (OR [95%CI] 1.60 [1.09, 2.36]). However, the same was not observed for the proximity to forests (OR [95%CI] 1.02 [0.56, 1.87]). Similarly, Andrusaityte and co-workers [18] found positive associations between surrounding greenness quantity within the buffer of 100 m from the participants' homes and the prevalence of asthma among 4- to 6-year-old children, even after adjusting for individual-level covariates and exposures to air pollution (OR [95%CI] 1.43 [1.10, 1.85]).

Conversely, Chen et al. [20] reported that, in children aged 9 to 17 with physician-diagnosed asthma, interactions between residential greenspace and difficult family relationships were found for asthma control, asthma functional limitations and airway inflammation. Therefore, it is possible that the psychosocial state of children may also influence the greenspace effect on asthma.

Interestingly, Sbihi and co-workers [21] found no associations between three distinct trajectories of asthma (transient asthma, late-onset chronic asthma and early onset chronic asthma) and greenness exposure. The OR [95%CI] for asthma, comparing highest green vs lowest green exposure (NDVI quartile 3 vs quartile 0), were 0.91 [0.80, 1.05], 1.05 [0.90, 1.23] and 1.01 [0.81, 1.25], for transient asthma, late-onset chronic asthma and early onset chronic asthma, respectively [21]. Effects also appear to vary with geographic regions, as Tischer and colleagues [22] found that exposure to greenspaces differently affected symptoms of asthma between the Euro-Siberian and Mediterranean regions of Spain, with a higher residential surrounding greenness and higher proximity to green spaces being negatively associated with wheezing in the first, while higher residential proximity to green spaces was associated with a reduced risk for bronchitis in the latter.

Through a different perspective, Bukalasa et al. [23] explored the influence of living near agricultural fields likely treated with pesticides on the prevalence of asthma. The study was conducted using the PIAMA birth cohort study, and the presence of pesticides was estimated based on the identification of crops through spatial data. Nevertheless, no associations were found between living within 100, 500 and 1000 m of agricultural fields and the presence of asthma symptoms.

Vegetation biodiversity may also play an important role in the effect of urban greenspaces on asthma. This has been shown by Donovan and co-workers [25], who reported that, although children living in greener areas (measured by NDVI) were less likely to be asthmatic (OR [95%CI] 6.0% [1.9, 9.9%]), an increase in the area covered by gorse (*Ulex*

europaeus) or exotic conifers, both non-native, low-biodiversity land-cover types, was associated with an increased risk of asthma (OR [95%CI] 3.2% [0.0, 6.0%] and 4.2% [0.9, 7.5%], respectively, for each species).

In the aforementioned study performed by Müller-Rompa and colleagues [26•], authors also found the asthma prevalence to be inversely associated with the presence of farms in a maximum of 100-m radius. The effect for a farm at 50 m was significant when crudely modelled (OR [95%CI] 0.65 [0.46, 0.90]), but lost significance when adjusted for the presence of straw, cow contact or farm milk ingestion. Therefore, the protective effect associated with the proximity of farms may not entirely be associated with the larger neighbouring vegetation concentration, but also from the exposure to a more diverse environmental microbiome.

On the contrary, Chia-Jung et al. [28•] showed, in a case-control study comprising 3520 children with asthma and respective controls, that the risk of a first asthma occurrence was significantly associated with higher level of greenness exposure in preschool children. Nevertheless, exposure to the highest level of green coverage (81–100%) did not lead to a significantly increased risk of asthma. These results demonstrate that, although greenness may have a protective effect on asthma risk, the associations are certainly not linear, as some confounding factors, such as the environmental biodiversity, may significant model the effect.

The Greener Side of Allergy and Asthma

The present review compiled the recent published bibliography concerning the relation of greenspace exposure on asthma and allergies in children. Most studies appear to point that green areas neighbouring children residences play a role on the prevalence of allergy and asthma. However, whether greenness is a protective factor, or an exacerbation driver, is yet to be elucidated. The reason for such high number of contradicting results may have been caused by the confounding factors associated with greenspace exposure, such as vegetation biodiversity, environmental microbiome, human behaviour (farm vs urban life) or the region itself. However, despite the large inclusion of birth cohorts, the majority of the reviewed studies measured the asthma and allergy outcomes at a given stage of life, which does not allow a life-course estimation of the greenness effect on the studied diseases.

In conclusion, it is still not possible to concretely discern the importance of early life exposure to green areas on asthma and allergy development. More studies on the previously mentioned factors associated with green areas may help in elucidating these associations, as well as more longitudinal studies with a more methodical asthma and allergy monitoring approach.

Funding Information The EXALAR 21 project was funded by the European Regional Development Fund (FEDER), through the Competitiveness and Internationalization Operational Programme, and by national funding from the Foundation for Science and Technology (FCT) under the scope of the project PTDC/GES-AMB/30193/2017 (POCI-01-0145-FEDER-030193, 02/SAICT/2017 - Project n° 30193). This study was also funded by FEDER through the Operational Programme Competitiveness and Internationalization and national funding from the Foundation for Science and Technology – FCT (Portuguese Ministry of Science, Technology and Higher Education) under the Unidade de Investigação em Epidemiologia - Instituto de Saúde Pública da Universidade do Porto (EPIUnit) (POCI-01-0145-FEDER-006862; Ref. UID/DTP/04750/2019) and by the EXPOSE project, which is financed by FEDER/FNR and by Fundação para a Ciência e Tecnologia (EXPOSE 02/SAICT/2016 - Project n° 023222).

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:

- Of importance

1. WHO. Global status report on noncommunicable diseases 2010, Geneva: World Health Organization; 2011.
2. WHO. Prevention of allergy and allergic asthma. Geneva: World Health Organization; 2003.
3. EAACI. Tackling the allergy crisis in Europe - concerted policy action needed. Brussels: The European Academy of Allergy and Clinical Immunology (EAACI); 2015.
4. Akdis CA, Agache I. Global Atlas of Allergy: Section B - Epidemiology and Risk Factors. Zurich: European Academy of Allergy and Clinical Immunology; 2014.
5. Akdis CA, Agache I. Global Atlas of Allergy: Section A - Allergy Mechanisms. Zurich: European Academy of Allergy and Clinical Immunology; 2014.
6. Lewis KM, Ruiz M, Goldblatt P, Morrison J, Porta D, Forastiere F, et al. Mother's education and offspring asthma risk in 10 European cohort studies. *Eur J Epidemiol*. 2017;32(9):797–805.
7. Asher MI. Urbanisation, asthma and allergies. *Thorax*. 2011;66(12):1025–6.
8. Haahtela T. What is needed for allergic children? *Pediatr Allergy Immunol*. 2014;25(1):21–4.
9. von Hertzen L, Hanski I, Haahtela T. Natural immunity: biodiversity loss and inflammatory diseases are two global megatrends that might be related. *EMBO Rep*. 2011;12(11):1089–93.
10. Rook GA. Regulation of the immune system by biodiversity from the natural environment: an ecosystem service essential to health. *Proc Natl Acad Sci*. 2013;110(46):18360–7.
11. Malik HU-R, Kumar K, Frieri M. Minimal difference in the prevalence of asthma in the urban and rural environment. *Clin Med Insights Pediatr*. 2012;6:33–9.

12. Escobedo FJ, Nowak DJ. Spatial heterogeneity and air pollution removal by an urban forest. *Landsc Urban Plan.* 2009;90(3–4):102–10.
13. Nowak DJ, Civerolo KL, Trivikrama Rao S, Gopal S, Luley CJ, Crane DE. A modeling study of the impact of urban trees on ozone. *Atmos Environ.* 2000;34(10):1601–13.
14. Tham R, Vicendese D, Dharmage SC, Hyndman RJ, Newbiggin E, Lewis E, et al. Associations between outdoor fungal spores and childhood and adolescent asthma hospitalizations. *J Allergy Clin Immunol.* 2017;139(4):1140–7.
15. Younger M, Morrow-Almeida HR, Vindigni SM, Dannenberg AL. The built environment, climate change, and health: opportunities for co-benefits. *Am J Prev Med.* 2008;35(5):517–26.
16. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* 2009;6(7):e1000097.
17. Dadvand P, Villanueva CM, Font-Ribera L, Martinez D, Basagaña X, Belmonte J, et al. Risks and benefits of green spaces for children: a cross-sectional study of associations with sedentary behavior, obesity, asthma, and allergy. *Environ Health Perspect.* 2014;122(12):1329–35.
18. Andrusaityte S, Grazuleviciene R, Kudzyte J, Bernotiene A, Dedele A, Nieuwenhuijsen MJ. Associations between neighbourhood greenness and asthma in preschool children in Kaunas, Lithuania: a case-control study. *BMJ Open.* 2016;6(4):e010341.
19. Fuertes E, Markevych I, Bowatte G, Gruzieva O, Gehring U, Becker A, et al. Residential greenness is differentially associated with childhood allergic rhinitis and aeroallergen sensitization in seven birth cohorts. *Allergy.* 2016;71(10):1461–71.
20. Chen E, Miller GE, Shalowitz MU, Story RE, Levine CS, Hayen R, et al. Difficult family relationships, residential greenspace, and childhood asthma. *Pediatrics.* 2017;139(4):e20163056.
21. Sbihi H, Koehoorn M, Tamburic L, Brauer M. Asthma trajectories in a population-based birth cohort. Impacts of air pollution and greenness. *Am J Respir Crit Care Med.* 2017;195(5):607–13.
22. Tischer C, Gascon M, Fernández-Somoano A, Tardón A, Lertxundi Materola A, Ibarluzea J, et al. Urban green and grey space in relation to respiratory health in children. *Eur Respir J.* 2017;49(6):1502112.
23. Bukalasa JS, Brunekreef B, Brouwer M, Koppelman GH, Wijga AH, Huss A, et al. Associations of residential exposure to agricultural pesticides with asthma prevalence in adolescence: the PIAMA birth cohort. *Environ Int.* 2018;121(Pt 1):435–42.
24. Cilluffo G, Ferrante G, Fasola S, Montalbano L, Malizia V, Piscini A, et al. Associations of greenness, greyness and air pollution exposure with children's health: a cross-sectional study in southern Italy. *Environ Health.* 2018;17(1):86.
25. Donovan GH, Gatzolis D, Longley I, Douwes J. Vegetation diversity protects against childhood asthma: results from a large New Zealand birth cohort. *Nat Plants.* 2018;4(6):358–64.
26. Müller-Rompa SEK, Markevych I, Hose AJ, Loss G, Wouters IM, Genuneit J, et al. An approach to the asthma-protective farm effect by geocoding: good farms and better farms. *Pediatr Allergy Immunol.* 2018;29(3):275–82 **This study showed that the lower prevalence of asthma and atopy found in rural settings is not particularly justified by the higher greenness exposure, but is mainly associated with the different exposures and behaviours attributed to farm life.**
27. Gernes R, Brokamp C, Rice GE, Wright JM, Kondo MC, Michael YL, et al. Using high-resolution residential greenspace measures in an urban environment to assess risks of allergy outcomes in children. *Sci Total Environ.* 2019;668:760–7.
28. Hsieh C-J, Yu P-Y, Tai C-J, Jan R-H, Wen T-H, Lin S-W, et al. Association between the first occurrence of asthma and residential greenness in children and teenagers in Taiwan. *Int J Environ Res Public Health.* 2019;16(12):2076 **This study recently demonstrated the highly complex association between greenness exposure and asthma development. It shows that there are important, and still unidentified, factors that may be responsible for the contradicting results described.**
29. Hirose M, Horiguchi T. Asthma phenotypes. *J Gen Fam Med.* 2017;18(5):189–94.
30. Carinanos P, Adinolfi C, Diaz de la Guardia C, De Linares C, Casares-Porcel M. Characterization of allergen emission sources in urban areas. *J Environ Qual.* 2016;45(1):244–52.
31. Global Initiative for Asthma. Global Strategy for Asthma Management and Prevention, 2017.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.