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Natural environment and childhood obesity: A systematic review

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Summary

The associations between built and food environments and childhood obesity have been studied extensively. However, the association between the natural environment and childhood obesity has received too little scholarly attention. This study reviewed the literature published before 1 January 2019, which described associations between a full range of natural environmental factors (e.g., rainfall, temperature, sunlight, natural disasters, flood and drought) and weight-related behaviours and childhood obesity. Five cross-sectional studies and one longitudinal study were identified. Measures of natural environmental factors varied across six included studies, falling into five broad categories: weather conditions, altitude, natural disaster risk, air quality and day length. It was found that temperature was a significant weather indicator in most included studies and was associated with a reduction of daily physical activity. Children living in high-altitude areas were more likely to be shorter and heavier than their counterparts in low-altitude areas. Findings of this study will contribute to helping multiple stakeholders, including policy makers and urban planners, and formulate health policies and interventions to mitigate the detrimental impact of the natural environment on childhood obesity. More longitudinal studies should be designed to confirm these effects and explore the potential health effects of more natural environmental factors.

KEYWORDS

child, natural environment, obesity, physical activity

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1 | INTRODUCTION

Obesity is a major cause of morbidity and premature death worldwide.[1] As the second leading cause of death after smoking in the United States,[2] obesity is related to lifestyle and natural environment and has many health consequences, such as heart disease, diabetes, high blood pressure, stroke, sleep apnoea, dyslipidaemia and some types of cancer.[3,4] Also, the incidence of obesity has been increasing rapidly all over the world in the past decades.[5] According to the World Health Organization, the prevalence of obesity and overweight in children and adolescents aged 5–19 increased sharply from 4% in 1975 to 18% in 2016.[5] Therefore, it is necessary to explore the causes of obesity in children and adolescents in order to develop effective interventions.

The associations between the built environment, food environment and childhood obesity have been studied and reviewed extensively.[6–18] However, the association between the natural environment and childhood obesity has received too little scholarly attention. Along with climate change, obesity is a global human-environmental issue affecting the majority of the world population to some degree, and the two maladies are linked in insidious ways.[18] The natural environment, including air quality and human comfort indices, could affect personal behaviours, such as transportation and recreational decisions, in ways that may lead to a lack of exercise and increased obesity rates in children and adolescents.[19] It has been shown that food insecurity and climate change are closely related to childhood obesity in low-income countries; in developed countries, the impact of greenhouse gas emissions from agricultural production and industrialization is more important in influencing childhood obesity.[18,20] In short, natural environment and childhood obesity interact in important and complex ways, on biological, psychological and social levels. Although previous work on the association between global warming and obesity was groundbreaking,[18] there remains an important research gap on the topic. Global warming only narrowly describes the environmental influences associated with climate change. There is evidence that extreme weather events (such as cold waves, drought and flood) have become more frequent in recent years, and the scope of 'global warming' excludes these events. The impacts of climate change on obesity may differ from those of 'global warming'.[20]

Despite the relatively sparse literature, it is important to inventory the work that has been done so that the most glaring gaps can be addressed. This is particularly important given the need for swift action to address the causes and impacts of climate change, because of the expected time lag between the implementation of prevention, mitigation and/or adaptation measures and the experience of tangible results. Therefore, we reviewed the literature describing associations between a full range of natural environmental factors, including rainfall, temperature, sunlight, natural disasters, flood and drought and weight-related behaviours and childhood obesity. The findings of this review will help urban planners to formulate health policies and interventions to reduce the detrimental impact of the natural environment and childhood obesity.

2 | METHODS

A systematic review and meta-analysis were conducted under the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

2.1 | Study inclusion criteria

Studies that met all of the following criteria were included in the review: (a) topics: those that incorporate measures of natural environment or weight-related behaviours/outcomes; (b) study designs: cross-sectional and longitudinal studies (i.e., no controlled experiments conducted in manipulated rather than naturalistic settings); (c) subjects: children and adolescents aged under 18 years (i.e., no computer-based simulation studies without the inclusion of human participants); (d) study outcomes: weight-related behaviours (e.g., physical activity [PA], sedentary behaviour and diet) and/or outcomes (e.g., body mass index [BMI, kg/m^2], overweight, obesity, waist circumference, waist-to-hip ratio and body fat); (e) article types: peer-reviewed publications (i.e., no letters, editorials, study/review protocols or review articles); (f) time of publication: from the inception of an electronic bibliographic database to 31 December 2018 and (g) language: articles written in English.

2.2 | Search strategy

A keyword search was performed in four electronic bibliographic databases: Cochrane Library, PubMed, Web of Science and Google Scholar. The search strategy included all possible combinations of keywords from the three groups related to the natural environment, children and weight-related behaviours/outcomes (Appendix S1).

Titles and abstracts of the articles identified through the keyword search were screened against the study selection criteria. Potentially relevant articles were retrieved for an evaluation of the full text. Two reviewers conducted the title and abstract screening independently and identified potentially relevant articles for the full-text review. Discrepancies were screened by a third reviewer. The three reviewers jointly determined the list of articles for the full-text review through a discussion. Then, two reviewers independently reviewed the full texts of all articles in the list and determined the final pool of articles included in the review.

2.3 | Data extraction and preparation

A standardized data extraction form was used to collect methodological and outcome variables from each selected study, including authors, year of publication, country, sampling strategy, sample size, age at baseline, follow-up years, number of repeated measures, sample characteristics, analytical model, attrition rate, measures of the natural environment, measures of weight-related behaviours, measures of body-weight status and key findings on the association between natural environment and weight-related behaviours and/or outcomes. Two reviewers independently extracted data from each study included in the review, and discrepancies were resolved by the third reviewer.

2.4 | Study quality assessment

We used the National Institutes of Health's Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies to assess the quality of each included study. This assessment tool rates each study based on 14 criteria (Appendix S2). For each criterion, a score of one was assigned if 'yes' was the response, whereas a score of zero was assigned otherwise (i.e., an answer of 'no', 'not applicable', 'not reported' or 'cannot determine'). A study-specific global score ranging from 0 to 14 was calculated by summing scores across all criteria. The study quality assessment measured the strength of scientific evidence but was not used to determine the inclusion of studies.

3 | RESULTS

3.1 | Study characteristics

Six relevant studies satisfying the inclusion criteria were identified (Figure 1), composed of five cross-sectional studies (including one qualitative study) and one longitudinal study. The sample sizes of

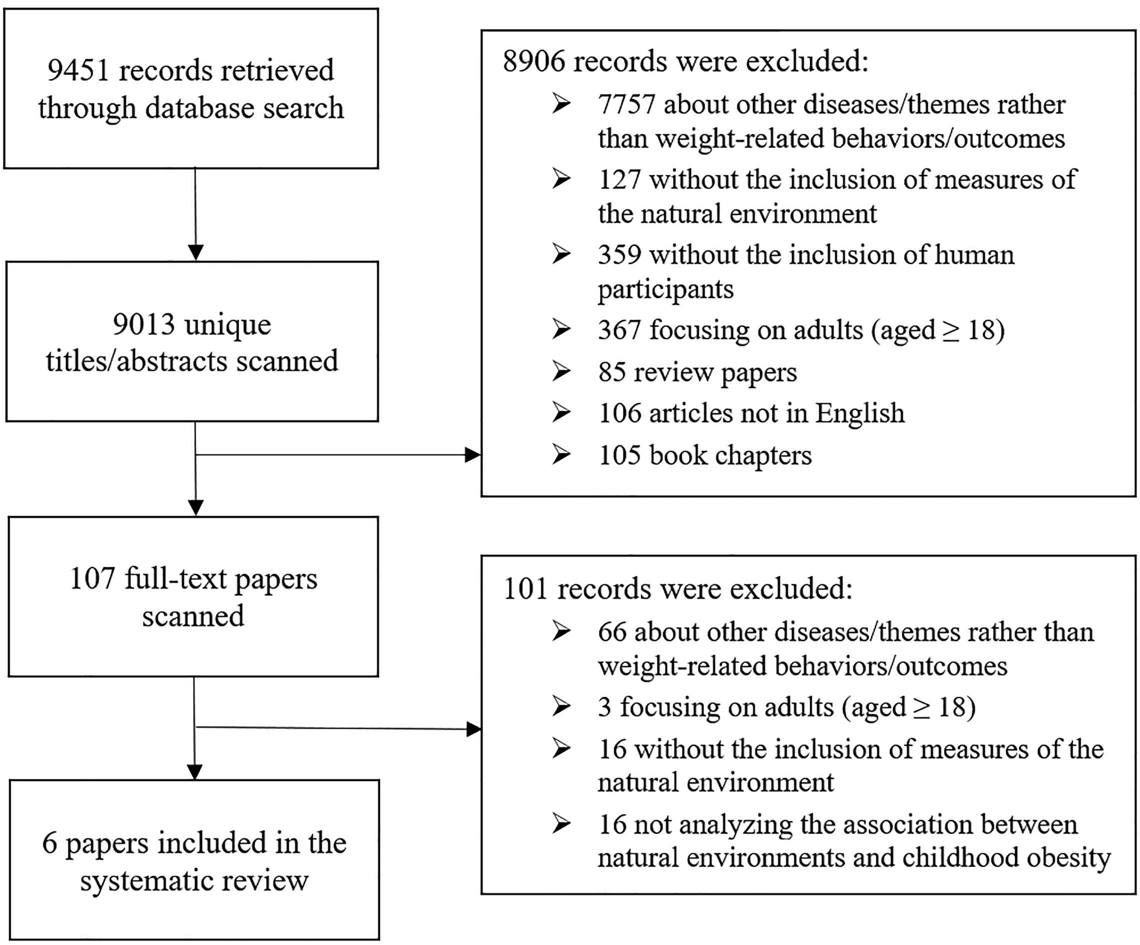

FIGURE 1 Study exclusion and inclusion flowchart

TABLE 1 Basic characteristics of the six included studies

First author (year)	Study area (scale)[a]	Study design[b]	Sample size	Sample age (years, range and/or mean ± SD)[c]	Sample characteristics (follow-up status for longitudinal studies)	Models
Coughenour (2014)[21]	Las Vegas, the US (C)	C	1421	<18 in 2012	Youth playing and conducting leisure activities in 10 parks	Multinomial logistic regression
Dwyer (2008)[22]	Hamilton, Canada (C)	C	39	2–5 in 2003	Parents who were English speaking and had a child aged 2–5 years who had been attending a childcare centre for at least 3 months	Social ecological model
Edwards (2015)[23]	Cincinnati, the US (C)	L	372	3.4 ± 0.3 in 2001	Children enrolled in a cohort study of early childhood growth	Mixed model regression
Gubbels (2010)[24]	Maastricht, the Netherlands (CT)	C	175	2 and 3 in 2008	Children in 9 child-care centres	Multilevel linear regression
Mueller (2001)[25]	Papua New Guinea (N)	C	18 868	<5 in 1982	Children from a total of 1096 villages in almost all parts of the country	Hierarchical Bayesian spatial models
Peyer (2016)[26]	Pennsylvania, the US (S)	C	NA	NA	Elementary students in grades K-6 and middle/high schools in grades 7–12	Multivariate analysis of covariance

Abbreviation: NA, not available.
[a]Study area: (N)—National; (S)—State (e.g., in the US) or equivalent unit; (CT)—County or equivalent unit; (C)—City.
[b]Study design: C—Cross-sectional; L—Longitudinal
[c]Sample age: Age in baseline year for longitudinal studies or mean age in survey year for cross-sectional studies.

TABLE 2 Quality assessment of the six included studies (see Appendix B for criteria)

First author (year)	Study quality assessment criteria														Total score
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Coughenour (2014)[21]	Y	Y	U	Y	Y	N	N	Y	Y	Y	Y	U	U	Y	9
Dwyer (2008)[22]	Y	Y	U	Y	Y	N	N	N	Y	U	Y	N	U	U	6
Edwards (2015)[23]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	U	Y	12
Gubbels (2010)[24]	Y	Y	U	Y	Y	N	N	Y	Y	N	Y	N	U	Y	8
Mueller (2001)[25]	Y	Y	U	Y	Y	N	N	Y	Y	N	Y	U	U	Y	8
Peyer (2016)[26]	Y	Y	U	Y	N	N	Y	N	Y	Y	Y	N	U	N	8

Abbreviations: N, No; U, Unclear; Y, Yes.

these studies ranged from 37 to 18 868 (Table 1). Three studies were conducted in the United States, and one study each was carried out in Canada, Papua New Guinea and the Netherlands. Three studies were conducted at the municipal level, and one each was carried out at the national, state and county levels. The study quality of the six studies was scored from 6 to 12, with three scored 8 (Table 2).

3.2 | Measures of natural environmental factors

Measures of natural environmental factors varied in six included studies, with four studies measuring two or more natural environmental factors (Table 2). Environmental factors measured were in five major categories: weather conditions,[21–25] altitude,[25] natural disaster risk (e.g., rainfall inundation risk),[25] air quality (e.g., the annual number of days with unhealthy air quality due to ozone and fine particulate matter)[26] and day length (i.e., the number of minutes between sunrise and sunset).[23] Weather conditions were qualitatively measured in two studies, that is, being reported as bad or good weather in one study[22] and being reported as sunny with clear skies or rain in the other[24] and more specifically measured by weather indicators, that is, temperature, rainfall and wind speed.[21,23–25] Among them, temperature and rainfall had more detailed measures. The temperature was expressed as a continuous variable in two studies[21,24] and as a categorical variable in another (high and low temperature, representing mean temperature less than 18.3°C and greater than or equal to 18.3°C, respectively).[23] Rainfall was measured directly (unit: inches) in one study[23] and as three categorical variables in another: the classification of direct measurements (less than 3000 mm/year and greater than or equal to 3000 mm/year), rainfall deficit (none/irregular and moderate to severe) and seasonality of rainfall (none, moderate and high).[25] Altitude was measured as categorical (0–600 m, 600–1200 m and greater than 1200 m) and as the relief of terrain (i.e., the difference between highest and lowest point in area) in three categories (less than 30, 30–100 m and more than 100 m).[25] The aforementioned factors were collected from different sources: the U.S. National Climatic Data Center (now the National Center for Environmental Information),[23] Papua New Guinea Resource Information System,[25] reporting by parents[22] and direct measures of weather conditions.[24]

3.3 | Measures of weight-related behaviours/outcomes

PA was measured as outcome variables in three studies by various methods: an adapted and translated version of an observational system for recording PA in children-preschool version,[27] the system for observing playing and leisure activity in youth (i.e., it uses direct observation through a momentary time sampling technology to conduct a systematic scan of the target area and classify youth into sedentary, walking or very active)[21] and self-administered questionnaire (Table 3).[22] Weight-related outcomes were used in two studies, including BMI and *z*-scores for weight-for-age, length-for-age and weight-for-length.[28,29] Besides, there is one study that measures the weight outcome variables including both PA (measured by a triaxial accelerometer) and BMI. Obesity/overweight was defined in the included studies by the growth chart proposed by the U.S. Center for Disease Prevention and Control.

3.4 | Association between natural environmental factors and weight-related behaviours/outcomes

Twelve associations between weather conditions (temperature, precipitation and wind speed) and weight-related behaviours/outcomes (PA, moderate-vigorous physical activity [MVPA] and height) were reported in three cross-sectional studies and one longitudinal study. The temperature was a significant weather indicator in most included studies. For example, an increase of every 10 heating and cooling degrees was associated with a reduction of daily MVPA by 5 and 17 min, respectively[23]; two positive associations were also reported between both heating degree and cooling degree days and inactivity ($p < 0.0001$).[23] Also, altitude was found to be associated with childhood growth, which means that children living in high-altitude areas were more likely to be shorter and heavier than their counterparts in low-altitude areas. However, some studies also reported no significant associations of natural environmental factors with weight-related behaviours/outcomes, for example, inconsistent and weak correlations with BMI (average $r = -0.17$)[26] and null associations with PA intensity.[21,24]

4 | DISCUSSION

This review found 14 associations between natural environmental factors and weight-related behaviours and/or outcomes from six original studies. Natural environmental factors were found to be health-damaging in three studies, but the natural environmental factors varied among these studies.

Inclement natural environmental factors tend to exacerbate childhood obesity. An et al.[18] reviewed the published studies which examined the association between global warming and the obesity pandemic. They constructed a conceptual model linking the two subjects and found that global warming influenced the obesity pandemic through food supply, price and security. Similar results were found by Mueller et al.[25] However, a comprehensive report noted that the obesity prevalence differed under the different levels of food insecurity.[20] Although extreme weather has increased food insecurity, severe food insecurity has been associated with lower obesity prevalence.[20] Moreover, Tucker et al.[30] summarized the characteristics of previous studies which focused on the effect of season and inclement weather on levels of PA and confirmed that inclement or extreme weather has been identified as obstacles for children to be physically active.

PA-related indicators were the main weight-related outcomes used in the selected studies, which means that natural environmental factors affect childhood obesity through PA. Some studies find a negative association, but it is hard to draw clear conclusions on the associations between natural environmental factors and obesity, due to the limited number and different basic characteristics of the included studies. Several possible reasons could help to explain the negative associations and null findings for the weight-related outcomes. For instance, inclement weather conditions (e.g., high temperature, low temperature, precipitation and wind speed) force children to stay at home, which could result in a decrease in levels of PA due to the limitation of remaining indoors.[31] Furthermore, if inclement weather conditions occur at playtime, children may spend more time watching television and exhibiting sedentary behaviours.[32–34] However, the influence of inclement weather also depends on the specific time of year and time scale (daily, monthly and seasonally).[35] The weather conditions affected the spontaneous and unplanned PA mostly, due to a lack of a plan or schedule of the activities ahead of time.[36,37] On the contrary, structured activities lead to less possibility of cancellation of PA.[36,37] Additionally, the type of PA caused the different influences of weather. Walking, which requires no special facilities, is less influenced by inclement weather conditions.[38] Other activities similar to walking could account for the possible reasons to report the null association between inclement weather conditions and obesity. Furthermore, growth was another weight-related outcome analysed in the included studies, which reported negative associations with altitude. Children who lived in very steep terrain often engaged in the demand for energy intake and high-quality food, but the supply of high-quality food was also limited due to the higher altitude.[25] But it also was noted that altitude influenced childhood obesity indirectly through the linkages to many foods and cash crops as well as

TABLE 3 Measures of natural environmental factors and weight-related behaviours and outcomes in six included studies

First author (year)[a]	Measures of natural environmental factors	Other environmental factors adjusted for in the model	Detailed measures of weight-related outcomes	Results of weight-related outcomes
Coughenour (2014)[21]	• Temperature at observation time	• Neighbourhood environment (park size, amenities, incivilities, number of high speed streets, sidewalk condition, % of minority, % of Hispanic, neighbourhood income)	• PA (SOPLAY: using direct observation via a momentary time sampling technique which involves a systematic scan of the target data. In each scan youth are coded as sedentary, walking or very active)	• Incivilities and amenities were associated with greater odds of being vigorous. • No significant association between temperature and walking versus sedentary and vigorous versus sedentary. • Environmental and social determinants are associated with PA intensity levels at parks.
Dwyer (2008)[22]	• Parent-reported weather conditions (good or bad weather)	• Physical environment (accessibility of healthy foods, preschoolers with special needs, media influence, lack of safety, inaccessible resources)	• Healthy eating • PA	• Parents felt that environmental factors affected their children's eating and PA patterns. • Parents felt that bad weather and an unsafe environment are obstacles for their children to be physically active.
Edwards (2015)[23]	• Day length (the number of minutes between sunrise and sunset) • Heating degree (mean temperature ≥18.3°C) and cooling degree (mean temperature <18.3°C) • Wind speed • Precipitation (including rainfall and melted snowfall)	NA	• PA (measured by a triaxial accelerometer) • BMI (calculated as weight/height^2 [kg/m^2]) • Measured BMI *z*-score (based on the 2000 U.S. CDC growth reference)	• Precipitation and wind speed were negatively associated with total PA and MVPA ($p < 0.0001$). • Heating and cooling degrees were negatively associated with total PA and MVPA and positively associated with inactivity (all $p < 0.0001$), independent of age, sex, race, BMI, day length, wind and precipitation. • For every 10 additional heating degrees there was a 5-min daily reduction in MVPA. For every additional 10 cooling degrees, there was a 17-min reduction in MVPA.
Gubbels (2010)[24]	• Weather conditions (sunny with clear skies or rainy) and outdoor temperature recorded per observation day	• Social environment group size and others' short verbal messages for promoting/discouraging activity, assessed by the OSRAC-P • The presence of activity opportunities, assessed by the EPAO instrument	• PA intensity (assessed by the OSRAC-P: mean activity intensity during the observation periods [15 s] was assessed on a scale from 1 [sedentary] to 5 [highly active]).	• No association was found between natural environment and PA intensity.
Mueller (2001)[25]	• Altitude: 0–600 m, 600–1200 m and >1200 m; • Relief of terrain: <30 m, 30–100 m and >100 m • Rainfall: <3000 mm/year and ≥3000 mm/year • Rainfall deficit: none/irregular and moderate to severe	NA	• Establishing standard normal *z*-scores for the three nutritional/growth indicators: length-for-age, weight-for-age and weight-for-length	• The environmental factors altitude, relief and climatic seasonality were found to be significantly correlated with growth (children from higher altitudes were short but heavier, whereas those living in areas with more seasonal climates were

TABLE 3 (Continued)

First author (year)[a]	Measures of natural environmental factors	Other environmental factors adjusted for in the model	Detailed measures of weight-related outcomes	Results of weight-related outcomes
	• Seasonality: none, moderate and high • Risk of inundation: no, seasonal, permanent or tidal flooding (others)			taller. High relief was generally linked with impaired growth). • Differences in diet and, to a lesser extent, environment were the main determining factors of among population differences. • Living in very steep terrain is connected with a higher energy expenditure and therefore with a need for more and/or higher quality food. • Altitude may act as a surrogate of other (unknown) factors that influence growth.
Peyer (2016)[26]	• Annual number of unhealthy air quality days due to ozone and fine particulate matter	• Built environment (% of postal codes in county with health food outlets, number of liquor stores per 10 000 population, access to recreational facilities)	• Overweight/obesity (BMI ≥ 85th percentile on the 2000 U.S. CDC growth charts) • Obesity (BMI ≥ 95th percentile on the 2000 U.S. CDC growth charts)	• Inconsistent and weak correlations were found for the physical environment (average $r = -0.17$), with significant associations evident only in 2011 and 2012.

Abbreviations: BMI, body mass index; CDC, Center for Disease Control and Prevention; EPAO, the Environment and Policy Assessment and Observation; MVPA, moderate-vigorous physical activity; NA, not applicable; OSRAC-P, observational system for recording physical activity in children—preschool version; PA, physical activity; SOPLAY, the system for observing play and leisure activity in youth.

important diseases that are restricted in their distribution by altitude, such as malaria.[39]

There are some limitations in this review that need to be noted, in order to guide and recommend future directions. First, the natural environmental factors include many correlated indicators such as precipitation, temperature, wind speed and altitude. Meanwhile, the measures of the natural environmental factors vary across studies. For example, the natural environmental factors could be measured by comprehensive (e.g., thermal comfort[40]) or component indicators (e.g., wind speed) and by objective (e.g., sensors, climate stations, satellite observation and GIS[23]) or subjective (e.g., parent feelings[22]) methods. Handing this problem needs a consistent reporting guideline and checklist for spatial data and methods in epidemiology.[41] Second, most of the selected studies were cross-sectional, rather than longitudinal studies, which is not strong enough to draw a conclusion of the causal association between the two subjects. Moreover, the quality assessment showed that the total scores of most included studies were below 10 and of moderate quality. Given that the development of advanced spatial, earth observation and big data approaches has enabled the rapid and accurate quantification of natural environmental factors to be combined with follow-up health data, more longitudinal studies should be designed.[42–45] Furthermore, the population samples in the new longitudinal studies should be tested by statistical power.[46] Third, as known, using different methods to determine the associations between two variables may lead to different associations. Among the included studies, various statistical technologies were used (e.g., mixed model regression[23] and hierarchical Bayesian spatial models[25]), also with different confounding factors (socio-demographic and/or physical environmental) controlled for, which may result in uncertainties and affect the comparability of the associations revealed among those studies. Finally, we failed to conduct meta-analyses and stratified analyses because of the limited number and various characteristics of the included studies. It is necessary to conduct stratified analyses in the future, due to the differences in the obesogenic effects of natural environmental factors on different subgroups by, for example, age, gender and race.[47]

The recent increased frequency, magnitude and persistence of cold- and warm-season weather extremes is often attributed to the amplification (i.e., increasingly north–south or south–north, rather than west–east) and/or stalling of upper-tropospheric flow in the form of the ridges and troughs in the mid-latitude Rossby waves, which are intertwined with the polar front jet stream (PFJ).[48,49] Kelnosky et al.[50] found increased tornado frequency associated with the PFJ in Southeast (United States) Tornado Alley, but the persistence of such extreme events has also been attributed to Arctic amplification—the warming of polar areas at increased rates compared with tropical areas.[51–54] All these factors will affect obesity in not only children but also all-age populations.[55] Therefore, the topic of this study is increasingly needed to be investigated by novel study designs and more natural environmental data from multiple sources.

5 | CONCLUSIONS

Climate change is a global issue, but its impact on population health is locally based. This systematic review revealed a rather mixed association between the natural environment and weight-related behaviours/outcomes among children and adolescents. We recognize that inclement weather may only represent a reduced potential for being physically active outdoors, rather than a prohibiting factor. Moreover, compensating increased PA indoors could be feasible. The latter needs to be measured by combining outdoor and indoor PA to design more longitudinal studies and strengthen the causality of this association between natural environmental factors such as inclement weather and childhood obesity. The stakeholders need more research on the influence of the natural environmental factors on PA, in order to help to design more effective interventions and strategies for preventing childhood obesity.

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CONFLICT OF INTEREST

We declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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