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RESEARCH

Spatial and Temporal Patterns in Childhood and Adolescent Asthma Hospitalisations in Queensland, Australia: A 20-Year Ecological Study Across Climate Zones

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ABSTRACT

Objectives: To examine spatial, temporal and seasonal patterns in childhood and adolescent asthma hospitalisations across Queensland, and assess variation in hospitalisation risk by age and sex across climate regions.

Design: A retrospective, population-based ecological study using area-level administrative data from hospital admissions.

Setting: All public and private hospitals in Queensland, Australia, 1 January 2000–31 December 2019.

Participants: Children and adolescents aged 0–19 years who were admitted to hospital with a principal diagnosis of asthma.

Main Outcome Measures: Age-standardised admission rates and relative risks (RRs) from spatial models; temporal patterns from time-series analysis; spatial variation from mapping; age-, sex- and climate zone-specific risks.

Results: Hospitalisations among children aged 0–4 years declined from 48.1% (1640 admissions) in 2000 to 23.2% (721 admissions) in 2019, whereas proportions in older age groups increased. Seasonal peaks occurred in May, June and February, with male patients showing a stronger February peak and female patients maintaining higher risks into July. Hot desert regions had the highest RRs, rising from 3.73 (95% credible interval [CrI], 3.71–3.74) in 2000–2001 to 9.37 (95% CrI, 9.28–9.47) in 2009–2010, then declining to 2.37 (95% CrI, 2.37–2.38) in 2018–2019. Hot semi-arid and tropical savanna regions showed persistently elevated risks (hot semi-arid: RR, 1.86–3.75; tropical savanna: RR, 1.81–4.58). Three temporal phases were evident statewide: an early lower-risk period (2000–2002), a higher-risk period (2002–2012) and a later reduction (2012–2019), with most RRs between 0.5 and 1.5. Seasonality was strongest in hot desert zones (seasonal strength, 0.519) and weakest in tropical savanna zones (0.063).

Conclusions: Childhood and adolescent asthma hospitalisations in Queensland exhibit significant spatiotemporal variation, with burden shifting from younger to older children, and climate-specific risks, although observed reductions in the youngest age group may partly reflect diagnostic and hospital admission practice changes. Higher asthma risks in arid and tropical savanna regions underscore the need for geographically tailored services and planning. These findings suggest that targeted public health strategies might help reduce asthma burden in vulnerable communities.

JEL Classification: Respiratory tract diseases, Environment and public health, Pediatric medicine, Statistics, epidemiology and research design, Health services administration

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Plain Language Summary

The known:

Childhood and adolescent asthma hospitalisations exhibit seasonal variation, differing by sex and age group.

The new:

Over the past two decades, Queensland's asthma hospitalisation burden has shifted from children aged 0–4 years to older age groups. Asthma risk shows latitude-dependent patterns, with arid (hot desert, hot semi-arid) and tropical savanna regions consistently exhibiting the highest relative risks despite low population densities.

The implications:

These findings highlight the need for targeted early warning systems and asthma management strategies that consider demographic and geographic differences.

1 | Introduction

Asthma is a common chronic respiratory condition that affects children and adolescents worldwide [1] and imposes a considerable burden on health care systems and families [2]. In Australia, the prevalence of asthma among young people remains high at about 10% [3].

Although previous spatial studies in Australia have revealed regional variation in asthma prevalence [4], most relied on cross-sectional data, which limits detection of persistent risks or evolving patterns [5]. One Queensland study reported seasonal peaks in emergency asthma visits with latitude-dependent variation; however, it spanned only 6 years and aggregated data by hospital networks rather than by patient residential location and climate zones, restricting detection of broader environmental patterns [6]. Spatial and temporal analyses can offer insight into how risk shifts over time and whether elevated burdens persist in specific regions [7, 8].

Queensland's integrated medical records provide an ideal context for investigating statewide, longitudinal patterns in asthma hospitalisations. As Australia's second-largest state, Queensland accounts for 20% of the national population [9], with children and adolescents comprising about 25% of residents [10]. The state encompasses diverse climate conditions from tropical north to subtropical south, with population concentrated in subtropical regions where several areas report high childhood asthma prevalence [11]. To systematically examine climate's role in asthma risk, this study applied the Köppen–Geiger climate classification system [12], which categorises regions based on temperature and precipitation patterns and provides a robust framework for assessing hospitalisation risk across environmental contexts (Figure S1 and Table S1). Building on our previous national prevalence survey that identified climate zone differences in childhood and adolescent asthma [4], we focus on Queensland hospital admissions (2000–2019) to characterise spatial and temporal patterns by age and sex across Köppen–Geiger climate zones. Our aim is to translate prevalence-based signals into admission-focused evidence on when, where and in which groups risks are higher, to inform targeted prevention and service planning.

2 | Methods

2.1 | Data Source

This ecological study utilised weekly hospitalisation data (1 January 2000–31 December 2019) for children and adolescents aged 0–19 years from all public and private hospitals in Queensland, Australia. The study is reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) [13] guidelines for observational studies (Text S1). Asthma hospitalisations were defined as admissions with a principal diagnosis of asthma (International Classification of Diseases, 10th Revision, Australian Modification [ICD-10-AM] J45); emergency presentations not resulting in admission were excluded. Sex was recorded as a binary biological variable (females and males) and, given the study population of children, is reported as male patients and female patients. Geographic identifiers used Statistical Local Areas (SLA) or Statistical Areas Level 2 (SA2) (Figure 1), with admissions assigned to patients' usual residence. Age-standardised rates were calculated using the 2001 Australian standard population [14].

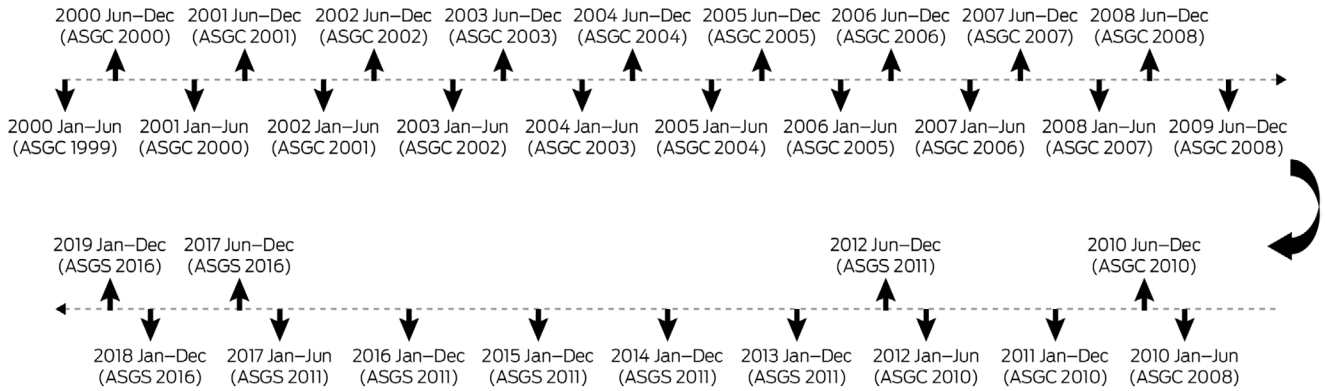

FIGURE 1 | Flowchart of the data collection timeline and corresponding geographic boundary versions for Queensland Health data (2000–2019). ASGC, Australian Standard Geographical Classification; ASGS, Australian Statistical Geography Standard.

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2.2 | Statistical Analysis

Analysis covered temporal, spatial and climate-based components: (i) time series decomposition to describe long-term changes and seasonal patterns, (ii) spatial modelling using Bayesian methods to estimate geographic variations in relative risk and (iii) climate zone comparisons to examine environmental associations.

2.2.1 | Time Series Analysis

Weekly hospitalisation data were aggregated to monthly counts for temporal analysis by overall, age group, sex and climate zone. Monthly counts were decomposed into trend and seasonal components using seasonal-trend decomposition via Loess. Seasonal strength was quantified and the trend component significance assessed with Mann–Kendall tests.

2.2.2 | Spatial Analysis

Spatial analyses were conducted using fiscal-year data from 2000–2001 to 2018–2019, with each year defined as 1 June to 31 May. Age-standardised hospitalisation rates were derived for each area using the 2001 Australian standard population. Relative risks (RRs) were estimated with Intrinsic Conditional Autoregressive (ICAR) models in R-INLA [15]. RR represents the ratio of observed to expected hospitalisations in each area after adjusting for age and spatial effects. Values above 1.0 indicate higher-than-expected risk, whereas values below 1.0 indicate lower-than-expected risk. The ICAR model smooths these estimates by incorporating information from neighbouring areas, and 95% credible intervals (CrIs) were calculated to quantify statistical uncertainty around each RR estimate (Text S2).

2.2.3 | Subgroup and Sensitivity Analyses

Age-specific analyses were conducted separately for each age group, with rate differences assessed using Kruskal–Wallis tests followed by post hoc Dunn tests. Sex-specific spatial models were fitted independently for male patients and female patients. Two sensitivity analyses were undertaken: excluding the 0–4 years group to assess diagnostic uncertainty impact, and including both ICD-10-AM J45 and J46 codes to evaluate severe presentations. Further breakdown by J45 subcodes was not undertaken due to sparse data.

2.2.4 | Climate Zone Analysis

Geographic areas were classified using Köppen–Geiger climate zones (version 2) [12]. SLA/SA2 units were assigned to climate zones by maximum area overlap, with zone-level summaries calculated using zonal statistics on risk surfaces. Between-zone differences were evaluated using Kruskal–Wallis tests with H statistics reported, followed by Bonferroni-corrected pairwise comparisons. Latitudinal gradients were assessed through spatial regression of Kriging-predicted values against latitude coordinates, with linear regression models fitted annually to evaluate north–south changes over time. Kriging-predicted values represent standardised spatial risk estimates relative to the state mean (baseline = 0), where negative values indicate below-average risk and positive values indicate above-average risk compared with Queensland's overall hospitalisation pattern.

Additional details are provided in the Supporting Information (Text S3 and Figure S2). Analyses were conducted using R version 4.3.0 (packages INLA, spdep, sf and forecast) and ArcGIS Pro 3.4.0.

2.3 | Ethics Statement

This study was approved by the Children's Health Queensland Hospital and Health Service Human Research Ethics Committee (HREC/21/QCHQ/80236, 21/10/2022) and the Queensland University of Technology Human Research Ethics Committee (LR 2024–7972–17208).

3 | Results

3.1 | Population Distribution and Patterns

Asthma hospitalisation patterns showed significant variation by age and sex (Figure 2, Figures S2–S4 and Table S2). The proportion of hospitalised patients aged 0–4 years declined from 48.1% (1640 hospitalisations) in 2000 to 23.2% (721 hospitalisations) in 2019, while the proportion of hospitalised patients in the older age groups increased. Male patients had higher hospitalisation rates than female patients at ages 0–4, 5–9 and 10–14 years, whereas female patients had higher rates than male patients at 15–19 years.

3.2 | Seasonal Patterns of Asthma Hospitalisation

Seasonal decomposition revealed seasonal patterns that varied by age group and climate zone, with overall peaks in May–June and lows in December–January (Figures 2–5, Figures S5 and S6 and Tables S3 and S4). Age-specific analysis showed asthma hospitalisations among children aged 0–4 years peaked in May, those among children aged 5–9 years in May to June with secondary February peaks, while adolescents aged 15–19 years uniquely showed June as the primary hospitalisation peak. Seasonal effects decreased substantially with age. By sex, male patients had higher seasonal amplitude with pronounced May–June and February peaks, whereas female patients showed broader winter patterns extending into July; both sexes had troughs in November–January. Climate zone analysis indicated significant seasonal variation in all regions ($p < 0.001$). BWh (hot desert) zones had the strongest seasonality (seasonal strength, 0.519) with September peaks, while Aw (tropical savanna) zones had the weakest (0.063) with May peaks; tropical and subtropical zones showed varied peak timing.

3.3 | Risk Variation by Age Group and Sex

Asthma hospitalisation risk patterns showed marked age-specific heterogeneity in both spatial and temporal dimensions (Figure S7). The 0–4 and 5–9 years age groups consistently exhibited the highest asthma rates (hospitalisations per 100,000

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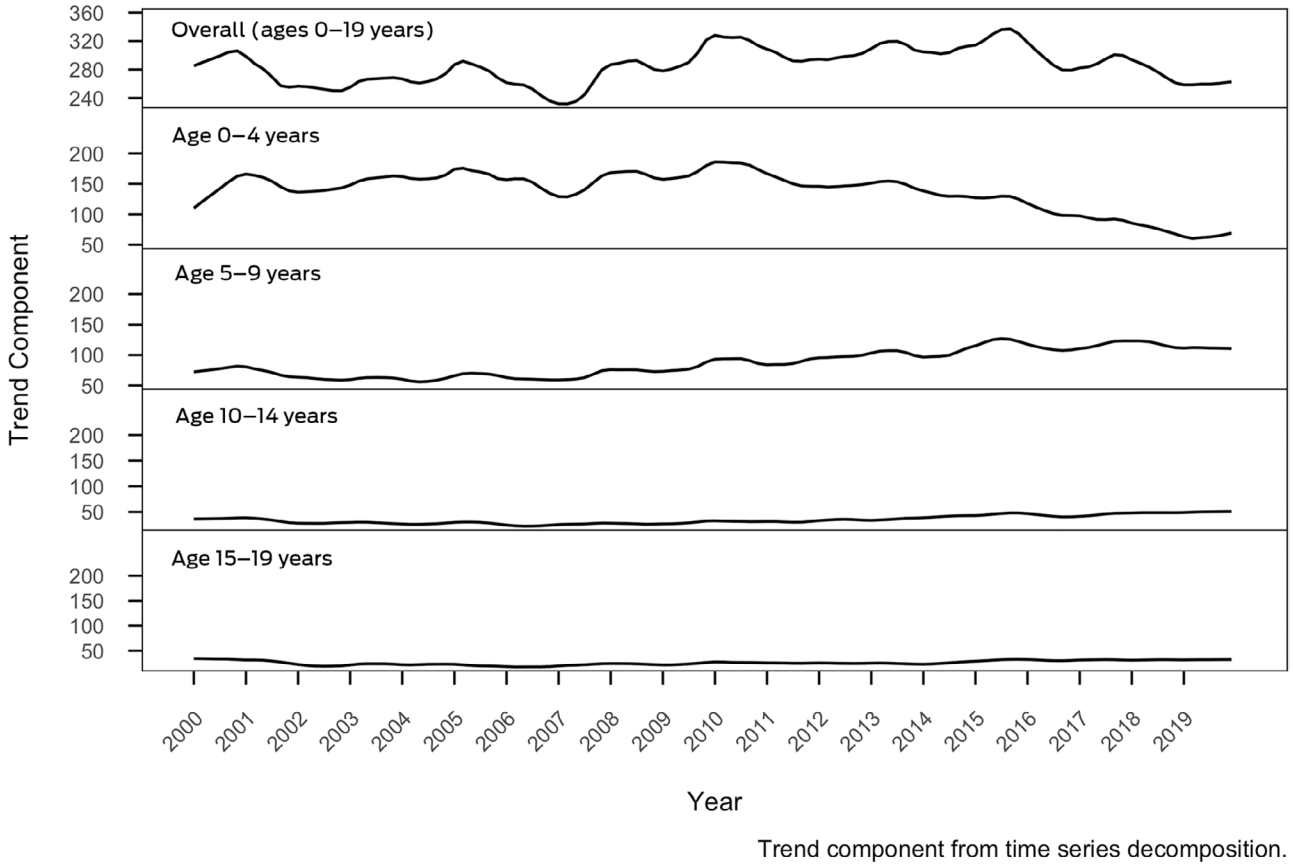

FIGURE 2 | Trend component of monthly asthma hospitalisations by age group in Queensland, 2000–2019. Sharp seasonal transitions reflect natural patterns in the raw data.

population), with persistent high-risk areas in scattered inland regions and southeastern coastal areas. The 10–19 years age group showed the lowest rates, with most areas below 500 cases per 100,000 population except during 2006–2011.

Temporally, the 0–4 years age group had the highest age-standardised RR (ASRR) for asthma at baseline, ranging from 1.25 (95% CrI, 1.20–1.31) to 1.16 (95% CrI, 1.11–1.22) during 2000–2009, then declined steadily to 0.98 (95% CrI, 0.91–1.05) in 2018–2019 (Figure 6, Table S5). The 5–9 years age group showed increasing ASRR from about 0.82–0.96 in early years to 1.04 (95% CrI, 0.99–1.10) in 2018–2019. The 10–14 and 15–19 years age groups maintained ASRR below 1.0 throughout most of the study period.

From 2000–2001 to 2018–2019, spatial distribution of asthma admissions displayed marked sex differences (Figure S8). Female patients exhibited a higher relative risk than male patients in early years, particularly in central-south and northern regions, with these high-risk areas gradually diminishing after 2012. Male patients showed more persistent and widespread elevated risk than female patients, especially across inland and southern areas.

3.4 | Statewide Spatial and Temporal Risk Patterns

Kriging analysis revealed three evolutionary phases in asthma admissions (Figure 7). The early phase (2000–2002) showed low overall risk with localised high-risk areas in southwestern regions. The middle phase (2002–2012) exhibited the highest asthma risk with widespread high-risk coverage across southwestern, northwestern and northern regions, with relative risk values reaching >4.5. The southeastern inland region also showed significant hotspot areas during 2006–2011.

The late phase (2012–2019) was characterised by substantial risk reduction for asthma admissions. From 2012 to 2013 onwards, most regions entered a low-risk state (RR, 0.5–1.5), representing a shift towards baseline or protective profiles. The northeastern coastal region occasionally showed localised risk hotspots.

Kriging-predicted values revealed a significant latitudinal gradient in asthma admissions ($p<0.001$), shifting over time from negative gradients (decreasing risk south to north) to positive, with the strongest correlations in 2015–2016 ($r=0.475$) and 2011–2012 ($r=0.400$) (Table S6). Sensitivity analyses produced consistent results (Figures S9–S11).

3.5 | Comparative Risk Across Climate Zones

Between 2000 and 2019, the RR of asthma admissions varied significantly between climate zones, showing spatial and temporal heterogeneity (Figure 8, Table S7). Arid regions (hot desert and BSh [hot semi-arid]) and tropical savanna climates consistently exhibited the highest RR for asthma admissions. In hot desert areas, RR increased from 3.73 (95% CrI, 3.71–3.74) in 2000–2001 to annual peaks of about 4.00–9.37 during 2002–2008, with a peak of 9.37 (95% CrI, 9.28–9.47) in

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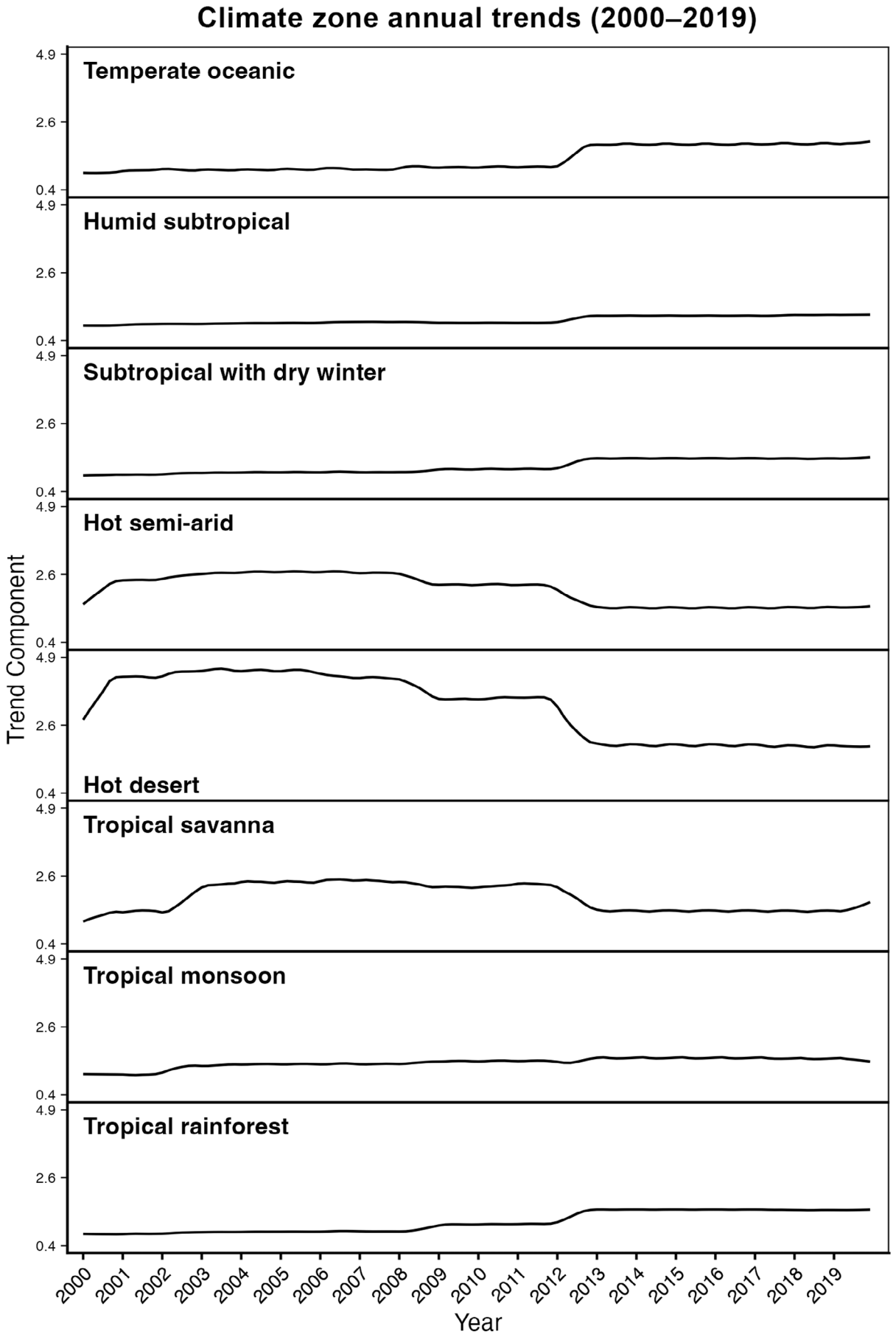

FIGURE 3 | Legend on next page.

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FIGURE 3 | Trend component of monthly asthma hospitalisations by climate zone in Queensland, 2000–2019. Af, Tropical rainforest; Am, Tropical monsoon; Aw, Tropical savanna; BSh, Hot semi-arid; BWh, Hot desert; Cfa, Humid subtropical; Cfb, Temperate oceanic; Cwa, Subtropical with dry winter.

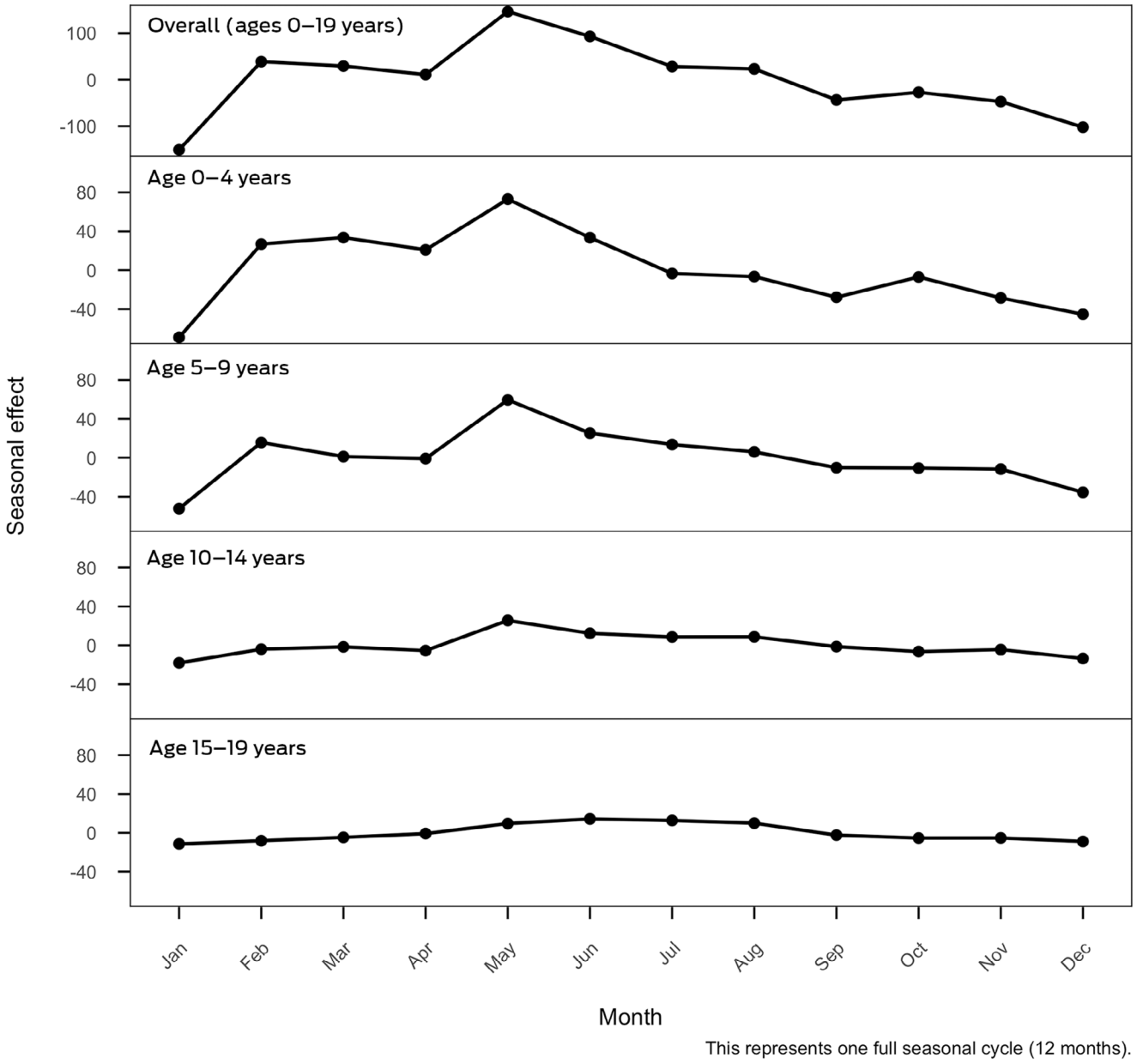

FIGURE 4 | Seasonal component of monthly asthma hospitalisations (1-year cycle) overall and by age group in Queensland, 2000–2019.

2009–2010, then declined to about 2.27–2.44, including 2.37 (95% CrI, 2.37–2.38) in 2018–2019. Asthma admission in hot semi-arid and tropical savanna regions remained elevated, with peak RRs of 3.75 and 4.58, respectively, before declining in later years.

Af (tropical rainforest) and Cfb (temperate oceanic) zones generally maintained asthma admission RRs at or below 1.0 through most of the study period. The tropical rainforest zone was largely protective against asthma admissions (e.g., RR, 0.71–1.12 before 2012) but increased recently (to about RR, 1.53–2.10), while Cfa (humid subtropical) remained relatively stable. Notable increases were observed in Am (tropical monsoon) zones in the late phase (to RR, 2.08–2.36 in 2017–2019).

Kruskal–Wallis tests revealed statistically significant differences in asthma admissions across climate zones in all study years ($p < 0.001$) (Table S8).

4 | Discussion

This study provides the first comprehensive analysis of long-term spatial and temporal patterns in childhood and adolescent

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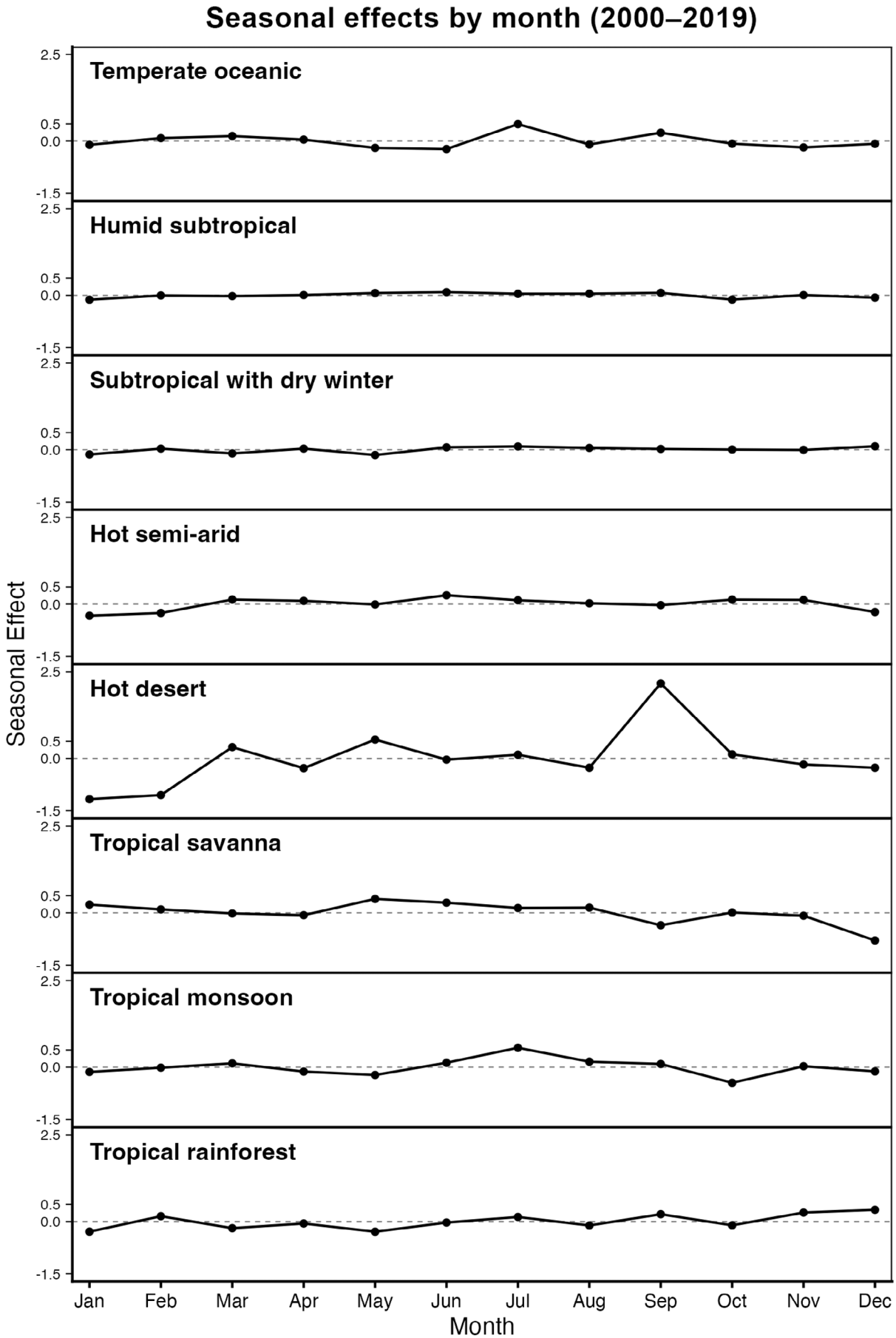

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FIGURE 5 | Seasonal component of monthly asthma hospitalisations (1-year cycle) by climate zone in Queensland, 2000–2019. Af, Tropical rainforest; Am, Tropical monsoon; Aw, Tropical savanna; BSh, Hot semi-arid; BWh, Hot desert; Cfa, Humid subtropical; Cfb, Temperate oceanic; Cwa, Subtropical with dry winter. Dashed horizontal line indicates no seasonal effect.

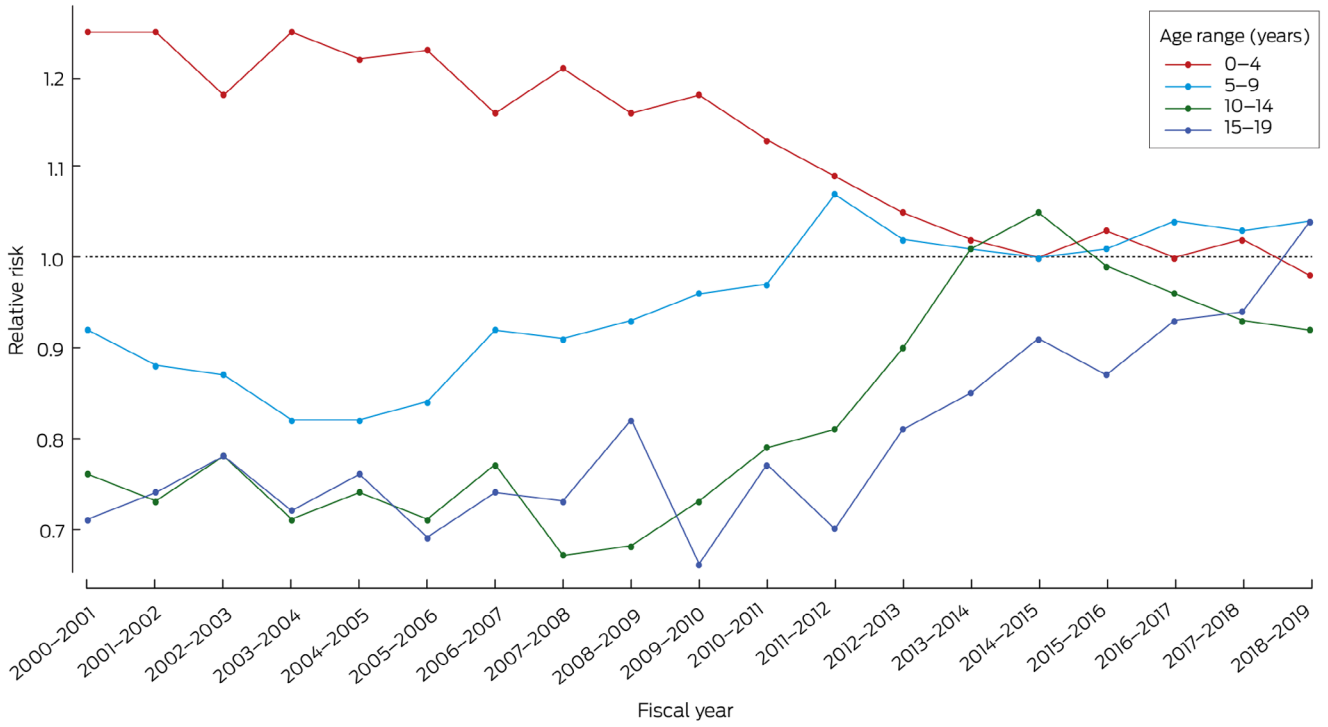

FIGURE 6 | Distribution of age-specific relative risk across fiscal years in Queensland.

asthma hospitalisations across Queensland, incorporating age, sex, seasonality and climate zones. Strong seasonal patterns emerged with May–June peaks across most age groups, and adolescents aged 15–19 years uniquely showed June as the primary peak. Over 20 years, age distribution shifted notably from highest burden in 0–4-year-olds to increased rates among older age groups, with male patients having higher rates in early childhood and female patients having higher rates among adolescents. Spatial analysis revealed three evolutionary phases: early low-risk (2000–2002), middle high-risk (2002–2012) and late substantial risk reduction (2012–2019). Arid climate zones consistently exhibited the highest relative risks, while tropical rainforest zones showed protective effects.

Asthma hospitalisations in Queensland exhibited distinct seasonal patterns by age-specific triggers and climate zones. These patterns align with cooler-month circulation of respiratory viruses [16] and cold air-induced bronchoconstriction [17]. This differs from Australian temperate regions, where peaks occur in February and November [18], likely reflecting different climate conditions and triggers. Climate zone analysis revealed hot desert zones showed the strongest seasonality and tropical savanna zones the weakest.

Age-specific asthma hospitalisation patterns reveal distinct seasonal variations, with younger children (0–4 years) showing peaks in May–June, while school-aged children show additional peaks coinciding with school terms, likely reflecting increased viral transmission through social interactions [19, 20]. Sex differences were observed, with male patients showing stronger February peaks possibly due to increased allergen exposure, while female patients exhibited more sustained winter hospitalisation rates [21].

Beyond these seasonal triggers, age-specific asthma hospitalisation rates evolved over time, possibly reflecting shifts in physiological development, health policy and lifestyle behaviours. In the early 2000s, asthma hospitalisation rates were highest among children aged 0–4 years, likely due to immature immune systems and increased vulnerability to respiratory infections and allergens [22]. However, targeted public health interventions, including early screening, maternal–child health services and community support programmes, may have contributed to the decline in this age group [23]. Childhood vaccination programmes, particularly influenza vaccination, also mitigated infection-related exacerbations [24].

Asthma management strategies evolved during the study period. Successive guideline updates (Global Initiative for Asthma 2002, 2006, 2014; *Australian Asthma Handbook* 2014, 2019) [1, 25] strengthened inhaled corticosteroid use, introduced control-based frameworks and promoted stepwise treatment approaches. Implementation of written asthma action plans, asthma-friendly school initiatives and greater availability of reliever inhalers supported earlier recognition and management,

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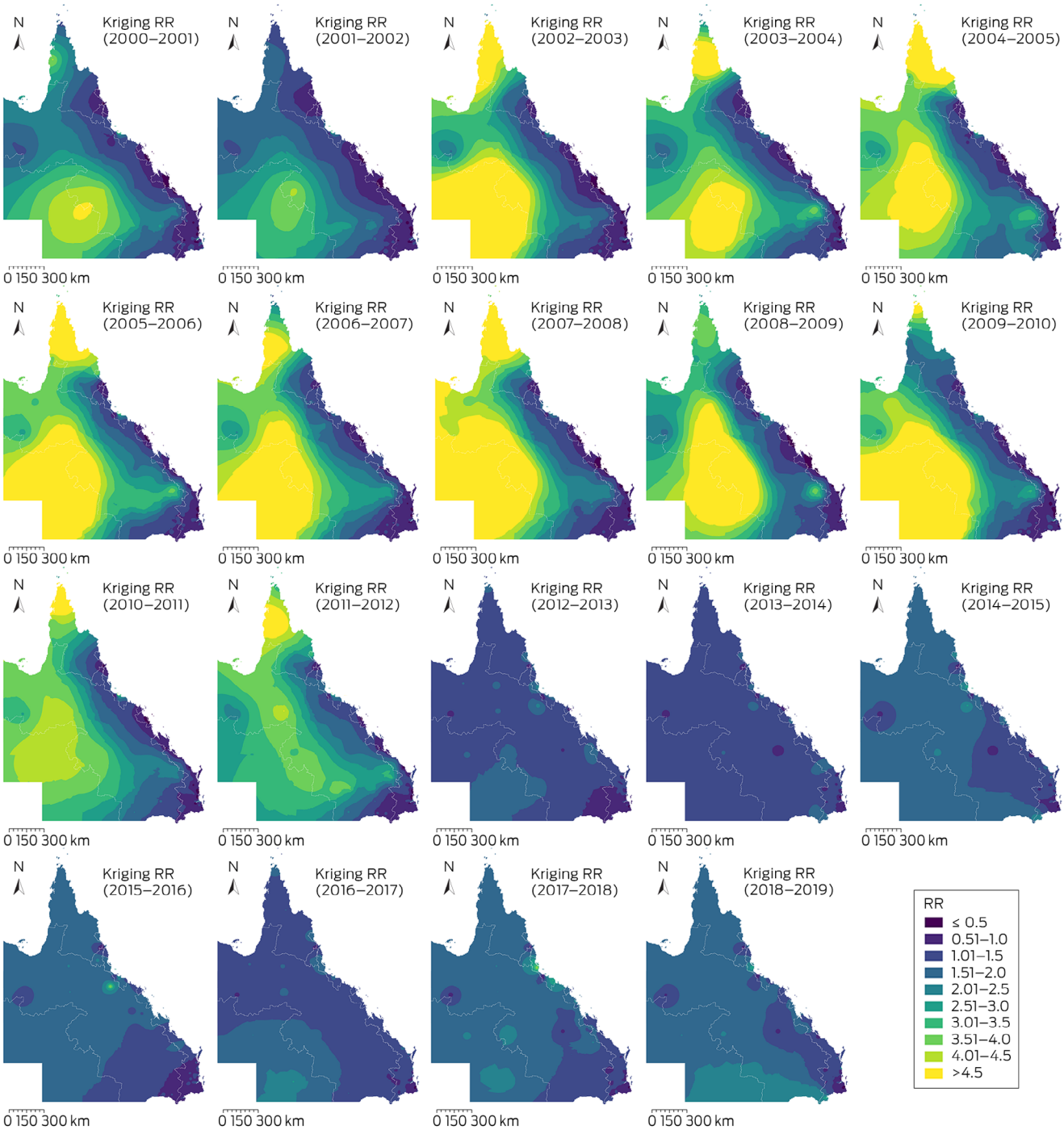

FIGURE 7 | Kriging–Smoothed relative risk (RR) of asthma among children and adolescents in Queensland for fiscal years based on the standard population distribution for ages 0–19 years. The white grid lines represent the climate zone.

consistent with post-2012 declines in hospitalisations, although causal attribution cannot be made. For 0- to 4-year-olds, part of the apparent decline is also likely to reflect diagnostic transfer (e.g., viral-induced wheeze or reactive airways disorder) and the wider use of short-stay units that may alter recording of asthma admission rates over time [26]. In contrast, school-aged children (5–9 and 10–14 years) showed increased rates in recent years, possibly due to greater outdoor activities and environmental trigger exposure [27, 28]. Adolescents (15–19 years) experienced upticks coinciding with rising e-cigarette use, a known exacerbating factor [29]. These emerging risk factors underscore the dynamic interplay between biological, environmental and public health determinants in shaping age-specific asthma changes.

Geographic variation in asthma hospitalisation across Queensland was shaped by environmental, climatic and structural factors. Spatial risk patterns exhibited three evolutionary phases: early low-risk (2000–2002), with localised high-risk areas in southwestern inland regions; middle high-risk (2002–2012), characterised by widespread coverage across multiple regions; and late phase (2012–2019), marked by substantial risk reduction statewide. These changes likely reflect environmental

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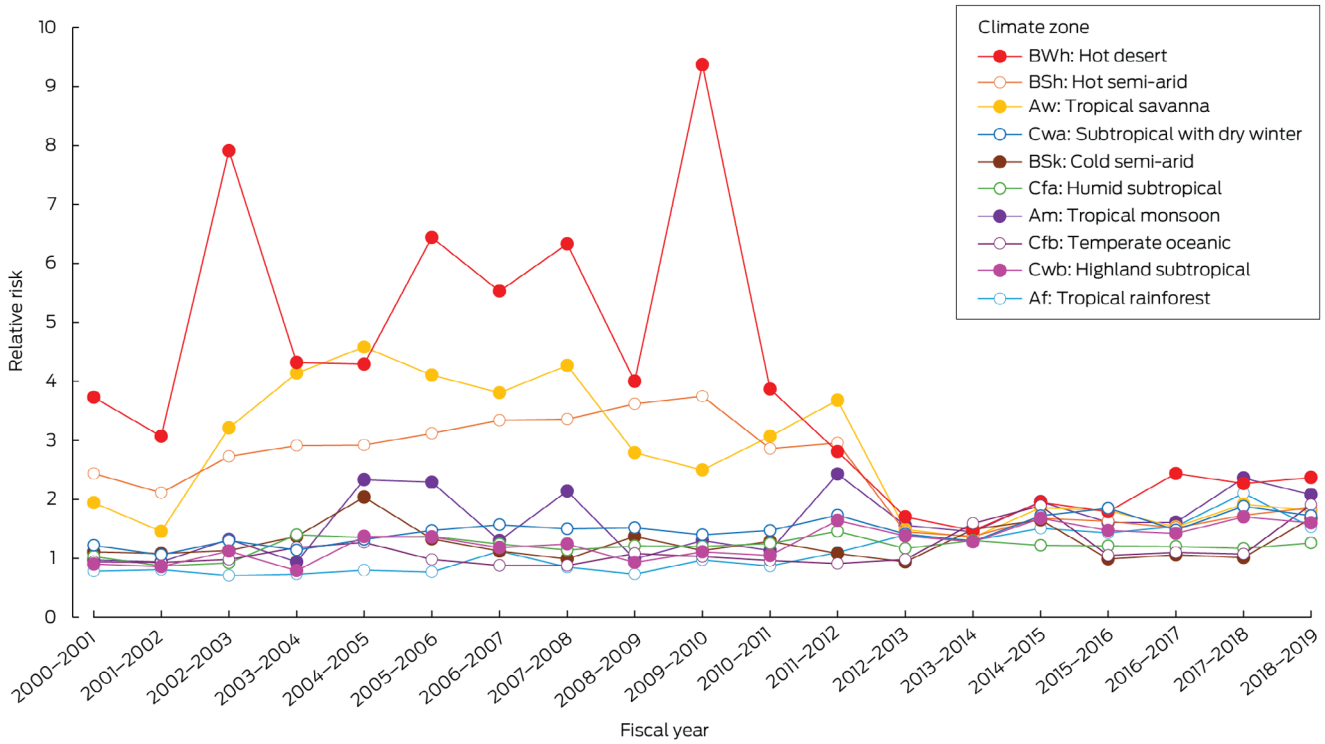

FIGURE 8 | Distribution of asthma relative risk (RR) by climate zones across fiscal years in Queensland.

exposures, population distributions and health care access variations. The fluctuating latitudinal gradients likely reflect alternating dominance of coastal versus inland climatic influences, with negative gradients indicating higher southern (coastal) risk and positive gradients indicating higher northern (inland) risk, modulated by local demographic and environmental vulnerabilities.

Asthma hospitalisation risk varied substantially across climate zones, with consistently elevated risks in arid and semi-arid regions (hot desert and hot semi-arid) likely due to increased airborne dust and particulate matter from dry conditions and soil disturbance [30, 31]. In contrast, tropical rainforest zones generally showed lower risk, while monsoonal areas maintained stable low risks until experiencing increases in recent years, possibly reflecting changing environmental conditions and demographic shifts.

These spatial patterns reflect demographic and structural factors. Queensland is characterised by densely populated coastal cities and sparsely inhabited inland regions [32]. In remote and rural communities, limited health care infrastructure, transport barriers and reduced access to asthma management services likely contribute to persistently elevated risks [32, 33]. Research shows asthma risk rises from inner-city to outer suburbs, where incidence nearly doubles [34], while children and adolescents in hotspot zones often reside in areas with high social vulnerability, marked by socio-economic disadvantages and related social determinants of health, such as household composition and disability, housing conditions and access to transportation [35].

This admissions-based study extends our previous national prevalence survey [4] within the same climate zone framework. Broad patterns are consistent, with higher levels in arid regions and clear sex differences. Key differences include that admission patterns do not fully align with national prevalence hotspots, and tropical rainforest regions show lower hospitalisations in most years. These divergences likely reflect differences between admissions and self-reported prevalence, including severity thresholds, care-seeking behaviour and variation in disease management.

These findings provide an evidence base to inform policy planning, particularly for resource allocation and targeted interventions. By highlighting spatial, demographic and seasonal variations, the study supports the development of climate-responsive strategies to reduce asthma-related health disparities in Queensland [36]. Examples include targeted seasonal preparedness and climate zone-specific health promotion. Climate-specific risk patterns could guide targeted public health messaging. Nevertheless, these historical patterns might not reliably predict future changes, given changing climate conditions and evolving health care practices.

5 | Limitations

This study has limitations. First, it relies on hospitalisation data, which might underestimate asthma burden, as milder episodes managed through primary care or self-medication are not captured. Environmental variables were excluded due to methodological constraints. Outcome misclassification is possible: over time, diagnostic transfer (e.g., wheeze/reactive airways disorder) and expanding use of short-stay units may have redirected some acute episodes away from inpatient asthma codes. Statewide linkage to emergency department and short-stay encounters was unavailable, so we could not assess the

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magnitude of this effect. This would tend to reduce inpatient rates in 0- to 4-year-olds. Geographic boundary changes over time precluded consistent environmental exposure alignment and multivariate modelling. This means observed patterns may be confounded by unmeasured environmental factors, potentially affecting the effect of climate zones on hospitalisation risk. Climate-driven allergen shifts have been shown in southeastern Australia [37], but comparable data are lacking for Queensland, limiting adjustment for regional exposures.

Socio-economic status indicators, widely used to explain asthma disparities [38], were excluded due to inconsistent geographic unit definitions over the study period to avoid spatial misclassification. Although Indigenous populations carry disproportionately high respiratory disease burden [36], separate analyses for these groups were not included.

Due to geospatial data incompatibility, population data for 2009 and 2011 were derived from preceding year estimates, potentially introducing minor temporal misalignment. The Köppen climate classification provides relatively coarse spatial resolution, which may obscure finer-scale environmental influences. As an ecological study, findings reflect area-level associations rather than individual-level risk and causal inferences cannot be drawn. Climate zones as exposure proxies may lead to misclassification and potential modifiable areal unit effects. In addition, our data lack individual patient identifiers, preventing distinction between new admissions and readmissions. Research from New South Wales found children aged 2–4 years had the highest asthma readmission rates [39], suggesting that the high hospitalisation burden we observed in the 0–4 years group may include both incident cases and repeat admissions for children with severe disease. Temporal aggregation and spatial smoothing might have obscured extremes. Unmeasured area-level confounders, including health care access, care-seeking behaviour, admission pathways and environmental exposures, may contribute to observed variation.

Intra-annual patterns in asthma presentations vary between viral-induced wheeze and allergic asthma associated with (pollen) allergen exposure [40]. Finally, inclusion of children aged 0–4 years, despite diagnostic uncertainty in < 3-year-olds, was considered appropriate given the ecological focus and significant respiratory burden in this age group. Sensitivity analysis excluding this cohort produced broadly consistent patterns, supporting the robustness of main findings.

6 | Conclusion

Findings show spatiotemporal heterogeneity in childhood and adolescent asthma hospitalisations across Queensland from 2000 to 2019 related to climate zones. The burden shifted from younger to older children over time, with three distinct phases: early low-risk, middle high-risk and late risk reduction. Arid regions consistently showed elevated risks while tropical rainforest zones showed protective effects. The climate zone-specific patterns and spatial clustering suggest potential for geographically targeted, climate-responsive interventions to reduce health disparities in childhood and adolescent asthma care across Queensland.

Author Contributions

Jialu Wang: writing – original draft, visualisation, conceptualisation, data curation, software, investigation, formal analysis, methodology, resources, validation. **Javier Cortes-Ramirez:** conceptualisation, data curation, methodology, resources, writing – review and editing. **Janet Davies:** conceptualisation, writing – review and editing. **Wenbiao Hu:** conceptualisation, methodology, writing – review and editing, supervision.

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Disclosure

Not commissioned; externally peer reviewed.

Conflicts of Interest

Janet Davies has conducted research on diagnostics in collaboration with Abionic SA, Switzerland, supported by the National Foundation for Medical Research Innovation with co-contribution from Abionic. Outside the scope of this study, her research has been supported by in-kind services or materials from Sullivan Nicolaides Pathology (Queensland), Abacus Dx (Australia), Stallergenes (France), Stallergenes Greer (Australia), Swisens (Switzerland), Kenelec (Australia) and ThermoFisher (Sweden); investigator-initiated contracted research grant from Bayer Healthcare LLC USA, as well as cash or in kind contributions from Partner Organisations for the National Health and Medical Research Council AusPollen Partnership Project (GNT1116107), Australasian Society Clinical Immunology Allergy, Asthma Australia; Stallergenes Australia; Bureau of Meteorology, Commonwealth Scientific Industrial Research Organisation, Federal Office of Climate and Meteorology Switzerland. Queensland University of Technology owns patents relevant to grass pollen allergy diagnosis (US PTO 14/311944 issued, AU2008/316301 issued) for which Janet Davies is an inventor. She is the Executive Lead, Repository and Discovery Pillar and Co-Chair of the Respiratory Allergy Stream for the Australian National Allergy Centre of Excellence. All other authors declare no competing interests.

Data Availability Statement

This study did not generate original data.

References

1. Global Initiative for Asthma, *2022 GINA Main Report* (GINA, 2022), https://ginasthma.org/wp-content/uploads/2022/07/GINA-Main-Report-2022-FINAL-22-07-01-WMS.pdf.

13265377, 2026, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.5694/mja2.70145 by Kate Steyn - National Health And Medical Research Council , Wiley Online Library on [25/02/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

2. K. Ahmad, R. Khanam, E. Kabir, and H. Jürges, "The Healthcare Cost Burden of Asthma in Children: A Longitudinal Population-Based Study," *Value in Health* 26 (2023): 1201–1209.

3. Australian Institute of Health Welfare, *Asthma* (AIHW, 2024), https://www.aihw.gov.au/reports/chronic-respiratory-conditions/asthma.

4. J. Wang, J. Cortes-Ramirez, and W. Hu, "Geographic Trends in Asthma Risk Among Children and Adolescents Across Climate Zones in Australia, 2004–2018," *Advances in Climate Change Research* 16 (2025): 613–622.

5. J. Wang, J. Cortes-Ramirez, T. Gan, J. M. Davies, and W. Hu, "Effects of Climate and Environmental Factors on Childhood and Adolescent Asthma: A Systematic Review Based on Spatial and Temporal Analysis Evidence," *Science of the Total Environment* 951 (2024): 175863.

6. M. Simunovic, J. Boyle, P. Baker, B. Erbas, and J. M. Davies, "Spatiotemporal Characteristics of Asthma Emergency Department Presentations in Diverse Geographical and Climatic Regions, Queensland, Australia," *Emergency Medicine Australasia* 33 (2021): 623–630.

7. J. Cortes-Ramirez, K. Mengersen, L. Morawska, P. Sly, P. Jagals, and D. Wraith, "The Hospitalisation Risk of Chronic Circulatory and Respiratory Diseases Associated With Coal Mining in the General Population in Queensland, Australia," *Science of the Total Environment* 949 (2024): 174989.

8. J. Cortes-Ramirez, J. D. Wilches-Vega, B. Caicedo-Velasquez, O. M. Paris-Pineda, and P. D. Sly, "Spatiotemporal Hierarchical Bayesian Analysis to Identify Factors Associated With COVID-19 in Suburban Areas in Colombia," *Heliyon* 10 (2024): e30182.

9. Australian Bureau of Meteorology, *3101.0—Australian Demographic Statistics, Mar 2018* (ABS, 2018), https://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/3101.0Main%20Features1Mar%202018.

10. Australian Bureau of Statistics, *National, State and Territory Population* (ABS, 2024), https://www.abs.gov.au/statistics/people/population/national-state-and-territory-population/sep-2024.

11. J. R. Khan, R. Lingam, L. Owens, et al., "Social Deprivation and Spatial Clustering of Childhood Asthma in Australia," *Global Health Research and Policy* 9 (2024): 22.

12. H. E. Beck, T. R. McVicar, N. Vergopolan, et al., "High-Resolution (1 Km) Köppen-Geiger Maps for 1901–2099 Based on Constrained CMIP6 Projections," *Scientific Data* 10 (2023): 724.

13. E. Von-Elm, D. G. Altman, M. Egger, S. J. Pocock, P. C. Gøtzsche, and J. P. Vandenbroucke, "The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: Guidelines for Reporting Observational Studies," *Lancet* 370 (2007): 1453–1457.

14. Australian Bureau of Statistics, *3101.0—Australian Demographic Statistics, Mar 2013* (ABS, 2013), https://www.abs.gov.au/ausstats/abs@.nsf/Lookup/3101.0Feature+Article1Mar%202013.

15. J. Besag, J. York, and A. Mollié, "Bayesian Image Restoration, With Two Applications in Spatial Statistics," *Annals of the Institute of Statistical Mathematics* 43 (1991): 1–20.

16. Queensland Health, *Queensland Weekly Influenza and Respiratory Syncytial Virus (RSV)—Surveillance Report* (Queensland Health, 2023), https://www.health.qld.gov.au/__data/assets/pdf_file/0009/1220400/influenza-rsv-qld.pdf.

17. M. D'Amato, A. Molino, G. Calabrese, L. Cecchi, I. Annesi-Maesano, and G. D'Amato, "The Impact of Cold on the Respiratory Tract and Its Consequences to Respiratory Health," *Clinical and Translational Allergy* 8 (2018): 20.

18. J. D. Silver, M. F. Sutherland, F. H. Johnston, et al., "Seasonal Asthma in Melbourne, Australia, and Some Observations on the Occurrence of Thunderstorm Asthma and Its Predictability," *PLoS One* 13 (2018): e0194929.

19. A. Beigelman and L. B. Bacharier, "Early-Life Respiratory Infections and Asthma Development: Role in Disease Pathogenesis and Potential Targets for Disease Prevention," *Current Opinion in Allergy and Clinical Immunology* 16 (2016): 172–178.

20. H. J. Zar, F. Cacho, T. Kootbodien, et al., "Early-Life Respiratory Syncytial Virus Disease and Long-Term Respiratory Health," *Lancet Respiratory Medicine* 12 (2024): 810–821.

21. M. Simunovic, J. Boyle, B. Erbas, P. Baker, and J. M. Davies, "Airborne Grass Pollen and Thunderstorms Influence Emergency Department Asthma Presentations in a Subtropical Climate," *Environmental Research* 236 (2023): 116754.

22. N. Mthembu, P. Ikwegbue, F. Brombacher, and S. Hadebe, "Respiratory Viral and Bacterial Factors That Influence Early Childhood Asthma," *Frontiers in Allergy* 2 (2021): 692841.

23. N. Rehman, M. Morais-Almeida, and A. C. Wu, "Asthma Across Childhood: Improving Adherence to Asthma Management From Early Childhood to Adolescence," *Journal of Allergy and Clinical Immunology. In Practice* 8 (2020): 1802–1807.e1.

24. E. Vasileiou, A. Sheikh, C. Butler, et al., "Effectiveness of Influenza Vaccines in Asthma: A Systematic Review and Meta-Analysis," *Clinical Infectious Diseases* 65 (2017): 1388–1395.

25. National Asthma Council Australia, *Australian Asthma Handbook* (National Asthma Council Australia, 2024), https://www.nationalasthma.org.au/health-professionals/australian-asthma-handbook.

26. M. Simunovic, B. Erbas, J. Boyle, P. Baker, and J. M. Davies, "Characteristics of Emergency Patients Admitted to Hospital With Asthma: A Population-Based Cohort Study in Queensland, Australia," *Emergency Medicine Australasia* 33 (2021): 1027–1035.

27. M. Hauptman and W. Phipatanakul, "The School Environment and Asthma in Childhood," *Asthma Research and Practice* 1 (2015): 12.

28. V. M. McDonald, G. Archbold, T. Beyene, et al., "Asthma and Landscape Fire Smoke: A Thoracic Society of Australia and New Zealand Position Statement," *Respirology* 28 (2023): 1023–1035.

29. X. Li, Y. Zhang, R. Zhang, F. Chen, L. Shao, and L. Zhang, "Association Between e-Cigarettes and Asthma in Adolescents: A Systematic Review and Meta-Analysis," *American Journal of Preventive Medicine* 62 (2022): 953–960.

30. Queensland Government, *Queensland's Extended Wet and Dry Periods, Australian Rainfall Periods (April to March) Relative to Historical Records 1889–2024* (Queensland Government, 2024), https://data.longpaddock.qld.gov.au/static/posters/WetDryDroughtPoster.pdf.

31. Queensland Government, *State of the Environment Report 2020, Particulate Concentrations* (Queensland Government, 2021), https://www.stateoftheenvironment.detsi.qld.gov.au/pollution/air-quality/particulate-concentrations.

32. Australian Institute of Health Welfare, *Rural and Remote Health* (AIHW, 2024), https://www.aihw.gov.au/reports/rural-remote-australians/rural-and-remote-health.

33. M. Deshpande, W. E. Zahnd, L. Bandy, J. Lorenson, and A. Fifer, "Spatial Analysis of Disparities in Asthma Treatment Among Adult Asthmatics," *Research in Social & Administrative Pharmacy: RSAP* 15 (2019): 1145–1153.

34. E. Cameron, J. Mo, and C. Yu, "A Health Inequality Analysis of Childhood Asthma Prevalence in Urban Australia," *Journal of Allergy and Clinical Immunology* 154 (2024): 285–296.

35. J. R. Grunwell, C. Opolka, C. Mason, and A. M. Fitzpatrick, "Geospatial Analysis of Social Determinants of Health Identifies Neighborhood Hot Spots Associated With Pediatric Intensive Care Use for Life-Threatening Asthma," *Journal of Allergy and Clinical Immunology. In Practice* 10 (2022): 981–991.e1.

13265377, 2026, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.5694/mja2.70145 by Kate Steyn - National Health And Medical Research Council , Wiley Online Library on [25/02/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

36. D. M. Shifti, M. H. Al Imam, D. Maresco-Pennisi, et al., "Emergency Department Presentations Related to Asthma and Allergic Diseases in Central Queensland, Australia: A Comparative Analysis Between First Nations Australians and Australians of Other Descents," *BMJ Open* 15 (2025): e091482.

37. Q. Xie, A. Huete, C. C. Hall, et al., "Satellite-Observed Shifts in C3/C4 Abundance in Australian Grasslands Are Associated With Rainfall Patterns," *Remote Sensing of Environment* 273 (2022): 112983.

38. E. Uphoff, B. Cabieses, M. Pinart, M. Valdes, J. M. Anto, and J. Wright, "A Systematic Review of Socioeconomic Position in Relation to Asthma and Allergic Diseases," *European Respiratory Journal* 46 (2015): 364–374.

39. M. M. Rashid, N. Hu, J. R. Khan, et al., "The High Burden of Asthma Readmission Among Australian Children: A Population-Based Cohort Study," *Respirology (Carlton, Vic.)* 30 (2025): 871–881.

40. B. Erbas, S. C. Dharmage, M. L. K. Tang, et al., "Do Human Rhinovirus Infections and Food Allergy Modify Grass Pollen-Induced Asthma Hospital Admissions in Children?," *Journal of Allergy and Clinical Immunology* 136 (2015): 1118–1120.e2.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** mja270145-sup-0001-supinfo.pdf.

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