Disproportionate climate burden of rising temperature on low birth weights in a health-compromised nation

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Summary

Background: Warming temperatures add to the global health burden, with profound implications for vulnerable populations including pregnant women and newborns. Low birth weight is a major neonatal health issue in Pakistan leading to neonatal mortality and impaired long-term health. This study assessed the impact of extreme temperatures on low birth weights, developed heat vulnerability index at district-level, identified high-risk subgroups, estimated heat-attributable burden, and projected future risks.

Methods: We constructed a space-time series study using national survey data from 2008–2017 across Pakistan. Distributed-lag nonlinear models within a generalised linear mixed-effects framework accounted for provincial variation. We modelled nonlinear and lagged associations between temperature and low birth weights using quadratic functions, and model-averaged predictions addressed uncertainty. Province-level risk estimates combined with district-level indicators, such as live births, child mortality, poverty index, and heat index, developed the heat vulnerability index.

Findings: The study included 85,017 participants, with 15,920 (18·72%) infants identified as having low birth weights. Heat-related risks for low birth weights varied across provinces, with relative risks ranging from 1·30 (1·07–1·57, 95% confidence interval) to 1·74 (1·16–2·59). The heat-related population attributable fraction ranged from 8·95 to 10·91%, translating to 1·12 million heat-related low birth-weight cases over the study period. Projections estimate that heat-related population attributable fractions will increase by 1·23–2·36% by the 2060s. Subgroup analysis showed that the risk of heat-related low birth weight was associated with hazardous air pollution, women with both lower or higher education, and those living in urban areas. Women in southern Punjab, northern Baluchistan, and Sindh faced the highest risks.

Interpretation: Our findings identify Pakistan's districts most vulnerable to heat-related low birth weight and highlight contributing factors. These insights can drive targeted interventions to mitigate risks. The study advances understanding of global impacts of rising temperatures, particularly in resource-limited and high-risk settings.

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Keywords: child health, climate change, extreme heat, global health, heat-related population attributable fraction, heatwaves, infants, pregnant women, relative risk

Introduction

Rising temperatures and the increased frequency of extreme heat due to climate change present a major threat to global health. These impacts are more pronounced in low- and middle-income and resource-limited settings. In South Asia, heatwaves are now 45 times more likely than in the pre-industrial era, with temperatures 0·85°C higher due to climate change, making it one of the most vulnerable regions globally (1). Pakistan, already facing socio-economic and health challenges, is among the countries most affected by climate change (2). The country has experienced an increase in extreme weather events — heatwaves, floods, and droughts — attributed to shifting climate patterns.

Extreme heat disproportionately affects marginalised populations, including pregnant women who are more at risk due to poverty, malnutrition, limited healthcare access, and resource scarcity (3). With a neonatal mortality rate of 41 deaths per 1,000 live births and 19–32% of infants born low birth weight, Pakistan bears one of the highest burdens (4). Low birth weight is a leading cause of neonatal mortality and is linked to long-term health impairments such as stunted growth and cognitive deficits (4).

Pregnant women are particularly vulnerable to heat-related complications due to physiological susceptibility and limited access to healthcare (5). Seasonal variation in birth outcomes suggests that temperature extremes affect the maternal biological and behavioural responses. Research on temperature effects on birth outcomes is abundant in high-income countries with robust birth registries, but such studies are scarce in low-resource settings like Pakistan, where populations are more vulnerable to climate-related impacts.

In addition to heat, worsening air pollution in Pakistan's urban centres has emerged as a large health concern, especially for pregnant women and newborns (6). As of 2023, Pakistan ranks as the fourth most-polluted country globally, with air pollution reducing life expectancy by 3·9 years (7). Although air pollution is not the primary focus of our study, we accounted for it as a confounding factor due to its impact on maternal and neonatal health.

Pakistan presents a good opportunity to investigate heat impacts on resource-limited and marginalised communities. The nation is highly susceptible to climate change impacts and faces compounded challenges including growing population, limited healthcare infrastructure, widespread poverty, and socio-political instability. These overlapping vulnerabilities highlight the urgency of localised evidence to inform targeted interventions and policies. Our study provides comprehensive evidence on heat exposure, socio-economic disparities, and maternal health in Pakistan, offering insights to mitigate climate-related health inequities both nationally and in other low-resource settings.

Our objective is to assess extreme weather's impact on low birth weight in Pakistan, identify high-risk areas and subgroups, and project future risks under two climate-change scenarios. We aims to provide temperature-specific risk estimates at a provincial scale and develop a district-level heat vulnerability index to guide targeted interventions and policies. By integrating maternal health and environmental datasets within a robust statistical framework, we generate insights into climate variability and low birth weight in Pakistan, with implications in other low- and middle-income countries.

Research in context

Evidence before this study

The body of research on the impacts of rising temperatures and heat exposure on health outcomes, particularly maternal and child health, is expanding rapidly. Current evidence strongly suggests that the risk of low birth weight is associated with heat exposure. However, most of this evidence originates from high-income countries, while only a few recent studies have explored the impacts of heat on birth weights in resource-limited and vulnerable settings. In particular, Pakistan experiences major challenges in maternal and child health, ranking among the worst globally for these indicators. Pakistan is also one of the most severely affected by climate change, experiencing frequent heatwaves, floods, and droughts. Despite this vulnerability, only two studies to date have examined the relationship between heat exposure and low birth weight in Pakistan — one focusing on a single district and one providing national-scale estimates through global analyses. There is therefore a major research gap at both national and local scales to inform targeted intervention strategies and identify high-risk factors.

Added value of this study

Our study starts to fill this gap by providing both national and regional evidence for the association between heat exposure and low birth weight in Pakistan. This is a challenging endeavour where comprehensive national datasets are often unavailable. While studies in low- and middle-income countries frequently rely on Demographic and Health Surveys and Multiple Indicator Cluster Surveys, these datasets have limitations, including inconsistent data collection, missing data, and until recently, the absence of some data such as the exact day of birth. Neither are spatial coordinates provided for most datasets from Pakistan. Despite these constraints, our study used robust methodologies to produce provincial-level, long-term risk estimates for the relationship between heat and low birth weights. We also downscaled these estimates to develop a district-level heat vulnerability index for low birth weights, enabling the identification of high-risk areas.

In addition to leveraging Demographic and Health Surveys and Multiple Indicator Cluster Surveys, we integrated multiple global and national datasets, including air pollution indices, poverty indices, and mortality rates, to account for a wide range of factors influencing low birth weights. Furthermore, we provided projections of future risks for low birth weights under different climate-change scenarios, offering valuable insights for policymakers and public health stakeholders to design targeted interventions that enhance resilience in vulnerable regions.

Implications of all the available evidence

This study provides context-specific evidence from Pakistan, identifying the country's vulnerability to climate change and warming temperatures, thereby enabling the design and implementation of targeted interventions. Pakistan's maternal and child health outcomes are poorer than those in countries of similar socio-economic status and challenges. For example, Pakistan's maternal mortality rate is 319 per 100,000 live births, compared to 124 in similar countries; the neonatal mortality rate is 41 per 1,000 live births, compared to 20 per 1,000 elsewhere. Limited healthcare access and widespread socioeconomic inequalities are among the largest contributors to these disparities.

By introducing interventions in high-risk areas with economic constraints, improvements in maternal and child health outcomes can be achieved. This goal aligns directly with the country's Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being), SDG 10 (Reduced Inequalities), and SDG 13 (Climate Action).

Pakistan's National Action Plan for climate change is hindered by economic constraints, inadequate institutional coordination, and challenges in resource mobilisation. In such a resource-constrained environment, studies like ours can play a pivotal role in guiding the development of cost-effective, targeted interventions. For example, leveraging successful existing programs, such as the Lady Health Workers program, could provide an efficient platform for delivering necessary health and climate-related information to women in vulnerable regions. The development of a district-level heat vulnerability index provides a replicable framework for identifying high-risk areas and designing targeted interventions, which can be applied in other low- and middle-income countries experiencing climate-related health challenges.

Methods

Data Sources

Health and socio-economic data

We compiled data from 11 surveys done between 2010–2020, including Pakistan Demographic Health Surveys (DHS) (8) and UNICEF Multi-Indicator Cluster Surveys (MICS) (9), covering maternal and child health, socio-economic status, and demographics. We defined low birth weight as ≤ 2·5 kg or based on maternal recall of the baby being "smaller than average." While recall is subjective and prone to bias, there is 86% agreement with measured birth weights (10). We did sensitivity analyses to assess associations of heat with birth weights and birth sizes individually. Data sources, cleaning, and processing are detailed in Supplementary Table S1.

Environmental data

We obtained monthly gridded meteorological data (2008–2017) from Copernicus ERA5-Land (9×9 km resolution), including mean temperature (°C), precipitation (m), and dew point (°C) (11). We estimated the heat index using the `weathermetrics` R package (12). We sourced mean monthly $PM_{2\cdot5}$ concentrations ($\mu g\ m^{-3}$) from the Atmospheric Composition Analysis Group (11-km resolution) (13). We aggregated district-level environmental variables to the provincial level using arithmetic means.

Study design

Space-time series design

We applied a space-time series design to analyse long-term, delayed, and non-linear associations between monthly mean temperatures and low birth weights at the provincial level. We addressed spatial non-independence using generalised linear mixed-effects models with random intercepts and captured temporal delays in temperature effects through a distributed-lag non-linear framework (14). We calculated weighted averages across models to derive coefficients and variance matrices. This approach effectively resolved uncertainties, data sparsity, sampling gaps, and potential missingness inherent in survey-based datasets.

Data aggregation

We linked monthly health and environmental data by province, month, and year. We analysed the data at the provincial level to address zero inflation in district-level data and capture regional trends. We aggregated low birth weight cases and environmental variables monthly, using temporal indicators (month and year of birth) to compensate for the absence of exact birth dates in the survey data.

Analysis

Modelling framework

We modelled the association between monthly mean temperature exposure and low birth weights using generalised linear mixed-effects models with a negative binomial error distribution to account for overdispersion. We included random intercepts to account for provinces-level non-independence. We modelled the exposure-response relationship using linear and quadratic functions (polynomial degree = 2) and specified a lag of seven months (polynomial degree = 1) to capture long-term lagged effects during pregnancy. The selection of the lag period was informed by existing studies (15) and further validated in sensitivity analysis.

We adjusted for $PM_{2 \cdot 5}$, maternal education, wealth index, humidity and precipitation in six different models. We compared models based on Akaike's information criterion (AIC), with model weights used to predict model-averaged risks at specific percentiles. We imputed missing data for education and wealth index using the `mice` package in R (16). Table S2 and Fig. S1, Supplementary Materials present details on model comparisons and handling of missing data.

Subgroup analyses

We did subgroup analyses based on: **maternal education**: low (no education or primary) *versus* high (secondary or higher), **wealth index**: low (poorest, poorer, and middle) *versus* high (richer and richest), **air quality**: $PM_{2 \cdot 5} < 25$ μg m^{-3} ('fair') *versus* $PM_{2 \cdot 5} \geq 25$ μg m^{-3} ('poor/hazardous'), and **region type**: urban *versus* rural. We estimated subgroup-specific risks using model-averaged coefficients and crossbasis functions and reported results for specific temperature percentiles.

Heat vulnerability index

We developed a district-level heat vulnerability index to identify high-risk regions by incorporating indicators for exposure, sensitivity, and adaptive capacity (17). We assessed environmental exposure using district-level average heat index (derived from mean temperature and humidity) and $PM_{2 \cdot 5}$ concentration over the study period. We represented sensitivity with under-five mortality rates and total live births, while the multidimensional poverty index captured adaptive capacity, reflecting socio-economic vulnerabilities. We integrated estimates of province-specific relative risk to establish empirical relationships between heat exposure and health outcomes. To ensure comparability, we scaled and centred variables (mean = 0, SD = 1). Supplementary Materials, Fig. S3, provide further details on index construction, scaling methods, and uncertainty modelling.

Temperature-related population attributable fractions

We estimated the population attributable fraction of low birth-weight cases attributable to temperature exposure under current and future climate scenarios. For the baseline (2008–2017), we used observed mean temperature data from ERA5-Land. For future projections (2048–2057 and 2068–2077), we applied projected mean temperature increases obtained from the World Bank's Climate Change Knowledge Portal (climateknowledgeportal.worldbank.org). The scenarios included Shared Socio-Economic Pathways (SSP) SSP2-4.5 ('intermediate' greenhouse-gas emissions) and SSP5-8.5 ('very high' greenhouse-gas emissions) (18).

For each scenario, we calculated the median temperature over the entire study period to represent population acclimatisation. We defined heat exposure as temperatures above the median, and cold exposure as temperatures below the median. We calculated population attributable fractions as:

$$100\frac{r_{\mathrm{dln}}-1}{r_{\mathrm{dln}}}\,\mathrm{P} \qquad \text{[eq 1]}$$

where r_{dln} = mean relative risk derived from distributed lag nonlinear models associated with exposure over the study period, and P = proportion of days classified as heat or cold exposure. We applied Monte Carlo simulations (1,000 iterations) to incorporate uncertainty in risk estimates. We calculated the confidence limits for the $2{\cdot}5^{\text{th}}$ and $97{\cdot}5^{\text{th}}$ percentiles of the simulated population attributable fractions.

Sensitivity analysis

We did sensitivity analysis based on birth weights and birth size, different lag periods, and different exposure and lag degrees. Further details on sensitivity analysis are provided in Supplementary Materials (Table S5).

Software and tools

We did all data preprocessing and analyses in R (version 4.1.0; R Core Team 2024) with the `dlnm` (19), `glmmTMB` (20), and `MuMIn` (21) packages, and visualisation with `ggplot2` (22). All code and data are available at doi:10.5281/zenodo.14373384.

Role of funding source

No funding source.

Results

After cleaning and preprocessing the data, we retained 85,017 records from mothers who provided birth weight or size information for their most recent child born within the last five years during the study period. Among these, 15,920 children had a low birth weight (≤ 2·5 kg) or were reported smaller than average in size at birth. By extrapolating to the national level and using an average birth rate of 29·69 per 1,000 population (from 2008 to 2017) and annual total population estimates (23), we calculated that approximately 60.15 million babies were born in Pakistan between 2008 and 2017 (mean = 6.01 million per year), of which 18·72% (~ 11·26 million) had low birth weight.

Nearly three-quarters (74·65%) of participants had primary or no education, 13·47% had completed secondary education, and 11·87% had attained higher education (Table 1). About one-third (29·01%) of participants belonged to the 'poorer/poorest' wealth category, 12.57% were in the middle-income group, and 23·79% were classified as 'richer/richest' (Table 1). The median temperature during the study period was 19·5 °C, and the median air pollution concentration was 44·8 μg m^{-3} (Table 1).

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The graphical analysis of monthly trends for low birth weight, mean temperature, precipitation, humidity, and air pollution ($PM_{2·5}$) revealed that cases of low birth weight are higher during hotter months when temperatures, humidity, and precipitation are highest (Fig. 1).

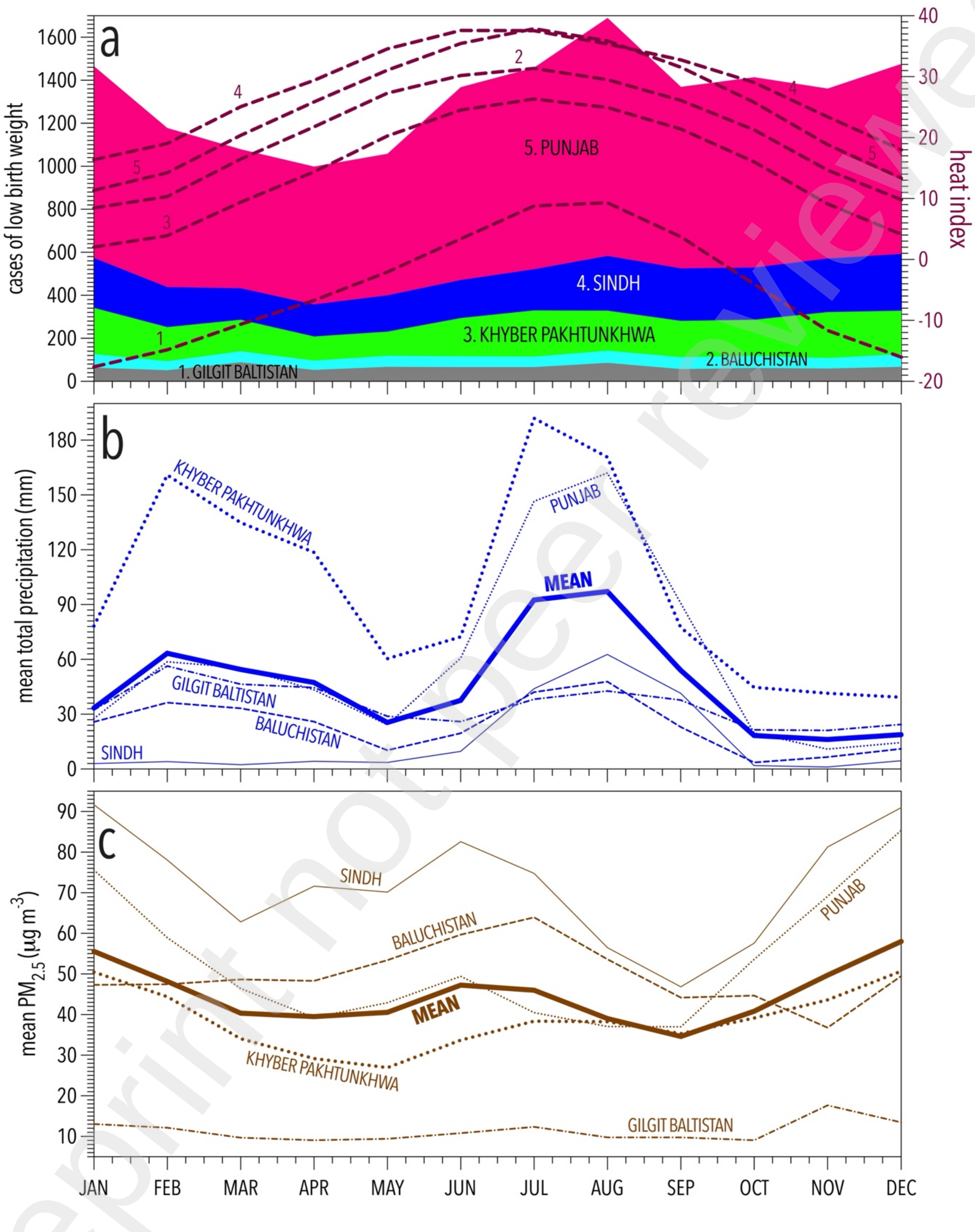

Figure 1. Monthly trends of (a) cases of low birth weight along with average heat index, (b) average precipitation, and (c) average particulate matter ($PM_{2.5}$) concentration.

Province-level exposure-response association between temperature and low birth weights

We observed a strong positive association between low birth weight and heat exposure across all provinces (Fig. 2). The relative risk estimates range from 1·30 (1·07–1·57, 95% confidence bounds) to 1·48 (1·11–1·97) at moderate heat (90th percentile), and from 1·37 (1·09–1·73) to 1·74 (1·16–2·59) at extreme heat (99th percentile), compared to the median reference temperature (Fig. 2). In contrast, we found no evidence of a relationship between the risk of low birth weight and cold exposure for all provinces except Gilgit Baltistan. In our findings, heat exposure had an impact; therefore, the results and discussions primarily emphasise the effects of heat. We present province-specific risk estimates for all provinces in Table S3 Supplementary materials.

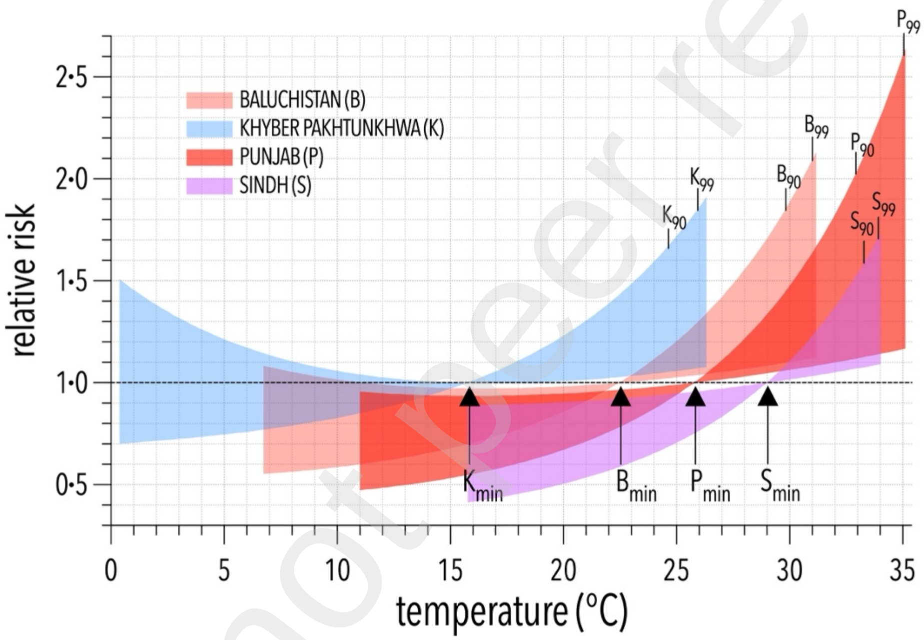

Figure 2. Exposure-response association between counts of low birth weight and mean temperature (with 95% confidence bounds). Arrows indicate the minimum risk, while province-level letters (B = Baluchistan, K = Khyber Pakhtunkhwa, P = Punjab, S = Sindh) and vertical lines represent the 90th, and 99th percentiles for relative risk estimation.

Our stratified subgroup analysis indicates that higher air pollution exacerbates the risk of low birth weight during hot conditions 2·11 (1·23–3·64). Women with primary or no education had a 1·99 (1·20–3·30) relative risk of delivering low birth weight infants during extreme heat. Women with secondary or higher education also had an increased risk of low birth weight associated with extreme weather exposure (2·36; 1·18–4·74) (Table 2).

Similarly, women from both high and low wealth groups had a high risk of low birth weight linked to extreme heat 2·03 (1·21–3·41) and 7·06 (1·68–29·68), respectively. The results with wide confidence intervals should be interpreted with caution. There was also an elevated heat-related risk among women in urban (2·22; 1·24–3·96) *versus* rural areas (2.02; 1·21–3·37) (Table 2).

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District-level heat vulnerability index

The heat vulnerability index map (Fig. 3) illustrates the spatial distribution of heat vulnerability for low birth weights across Pakistan's provinces and districts. The map highlights that districts in southern Punjab, northern Baluchistan, and Sindh exhibit the highest vulnerability, indicating a greater risk of heat-related low birth weights in these regions. These areas are likely influenced by higher heat exposure and compounding socio-economic and environmental conditions such as poverty and air pollution. In contrast, northern regions such as Gilgit Baltistan and parts of Khyber Pakhtunkhwa had lower vulnerability due to their cooler climates.

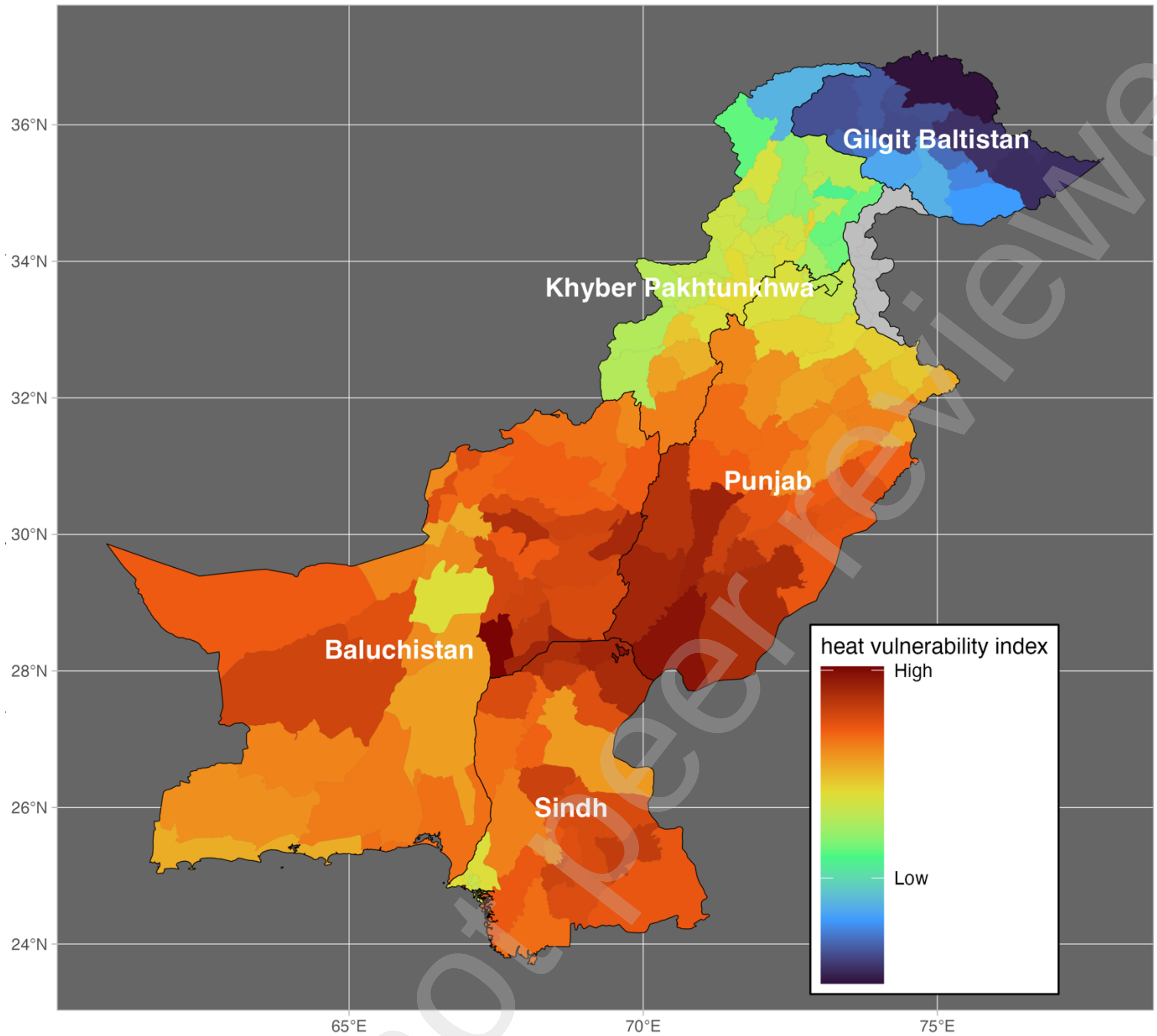


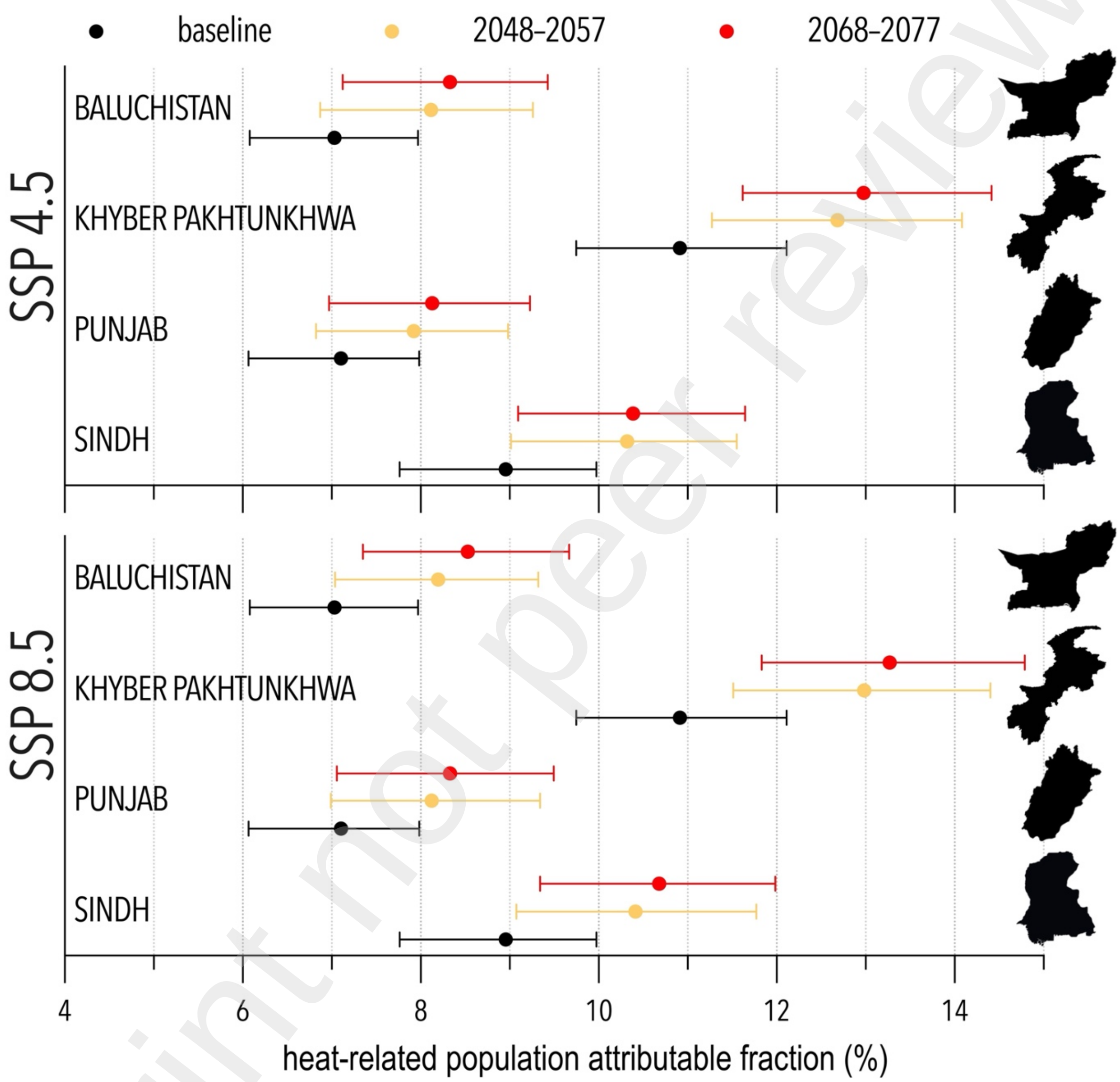
Figure 3. District-level spatial patterns of the heat vulnerability index of low birth weights associated with heat.

Current and projected population attributable fraction of heat-related low birth weights

The analysis of the population attributable fraction revealed regional variation in temperature-related impacts on low birth weight under current and future climate scenarios (Fig. 4; Table S4). In Baluchistan, the heat-related population attributable fraction increased from 8·95% (7·76–9·97) during the baseline period to 10·68% (9·35–11·98) under SSP5-8.5 for 2068–2077, representing an increase of 1·73% by the 2060s under a high-emissions scenario. Similarly, Khyber Pakhtunkhwa experienced an increase in the heat-related population attributable fraction from 7·10% (6·07–7·98) at baseline to 8·33% (7·06–9·50) under SSP5-8.5 for 2068–2077, showing an increment of 1·23% by the 2060s.

Punjab had the highest increase in the heat-related population attributable fraction, rising from 10·91% (9·75–12·11) at baseline to 13·27 (11·83–14·79) under SSP5-8.5 for 2068–2077, with an increase of 2·36% by the 2060s. In Sindh, the heat-related population attributable fraction increased from 7·03%

317 (6·08–7·97) at baseline to 8·53% (7·35–9·67) under SSP5-8.5 for 2068–2077 (increasing by 1·50% by
318 the 2060s). These findings underscore the intensifying impacts of heat under high-emissions scenarios,
319 highlighting regional disparities in vulnerability to temperature-related risks on low birth weight.



320

321 **Figure 4**. Heat-related population attributable fraction (%) with 95% confidence intervals by province for climate-
322 projection scenarios SSP 4.5 (upper panel) and SSP 8.5 (lower panel).

Discussion

Our study highlights the impact of heat exposure on low birth weight in Pakistan, emphasising the health implications of rising temperatures and compounded vulnerabilities in resource-limited settings. Pakistan stands out for having some of the worst maternal and child-health outcomes among low- and middle-income countries with similar socio-economic status (24). Climate change and extreme temperature conditions further exacerbate this vulnerability. Dimitrova et al. (25) highlighted that Pakistan (along with Mali, Sierra Leone, and Nigeria) experiences a disproportionately high burden of neonatal mortality linked to temperature fluctuations, with > 160 temperature-related neonatal deaths per 100,000 live births. Similarly, Zu et al. (26) estimated the temperature-related burden of low birth weight across several countries, reporting the greatest reduction in birth weight — -257g (-498·06 to -17·15g) — among children in Pakistan.

These statistics underscore the intersection of climate vulnerability and systemic healthcare challenges in Pakistan, highlighting that heat exposure is not just an environmental issue, but also a social determinant of health that disproportionately impacts marginalised populations. Our study builds on this evidence, providing detailed insights into the risk of low birth weights associated with heat (30–70%), identifying contributing factors, pinpointing high-risk areas, and estimating future population attributable fractions. This localised analysis informs targeted interventions and adaptation strategies for regions facing severe climate-related health challenges.

We found that women with both primary and secondary/higher education are vulnerable to the effects of extreme heat (27). Similarly, women from both higher and lower-income households have a high risk of low birth weights. This counterintuitive vulnerability could be attributed to several factors, including a lack of adaptation to extreme heat in urbanised environments where the urban heat-island effect is pronounced. Frequent power outages are common in Pakistan and can worsen the effects of heat exposure, even in households equipped with air conditioning (28). In wealthier households, medical interventions such as elective C-sections and other obstetric procedures, might increase physical stress in pregnant women, making them more susceptible to heat-related complications (29). Sedentary lifestyles, often associated with wealthier populations, might further impair thermoregulation, making it more difficult to cope with extreme temperatures (27).

We identified that Punjab was the most vulnerable to heat-related low birth weights. The heat vulnerability index revealed that districts in lower Punjab, southern Sindh, and northern Baluchistan are the most at risk. These regions are among the hottest in Pakistan and face substantial risks from climate change. The spatial analysis underscores the importance of prioritising these areas for public health interventions, providing local health authorities with scientific evidence to inform resource allocation and health policies. We estimated that 8·95 to 10·91% of low birth-weight cases in Pakistan were attributable to hot conditions across various provinces. Based on this estimate, if approximately 11·26 million children were born with low birth weight in Pakistan from 2008 to 2017, an average of 1·12 million cases can be attributed to hot weather conditions. These estimates are projected to increase by 1·23–2·36% in high-emissions scenarios by the 2060s. The estimates suggest that high temperatures are a major threat to progress in maternal health and could widen social and health inequalities in low- and middle-income countries.

We did not observe an association between cold exposure and low birth weight, except for Gilgit-Baltistan, a region with a harsh tundra climate and severe winters. The area's high altitude, extreme cold, and limited healthcare access during winter likely contribute to this finding. Further research is needed to understand the combined impacts of heat, glacier melting, flooding, and landslides in these terrains and their interaction with maternal and child health to guide adaptation strategies.

Pakistan's vulnerability is intensified by its rapidly growing population, young average age, and cultural barriers limiting women's autonomy and access to prenatal care. Political instability, civil unrest, and periodic terrorism further strain the country's capacity to prioritise public health. Limited healthcare infrastructure and research resources hinder the development of adaptive strategies to address climate-related health impacts. Together, these factors create a backdrop of socio-economic fragility, heightening the vulnerability of pregnant women and newborns to adverse health outcomes, including low birth weight. Addressing the intersection of climate change and maternal health requires comprehensive strategies that integrate climate adaptation and mitigation with strengthening health systems, promoting gender equality, and building community resilience. Collaborative efforts at the global, regional, and national scales are essential to mitigate the impact of climate change on maternal health and to achieve sustainable development goals.

Educational programs should inform pregnant women about heat risks and mitigation strategies, while the government must improve access to prenatal check-ups and maternal healthcare services. Investments in prenatal and postnatal care in high-risk areas are necessary for enhancing maternal and child health. Tailored early warning systems can alert pregnant women and healthcare providers to heatwaves through mobile networks, local media, and antenatal care centres. Lady Health Workers and non-governmental organisations should promote heat adaptation, hydration, and support access to cooling facilities. Collaborations with the Pakistan Meteorological Department and telecommunication companies can extend outreach via mobile apps, voice messages, and community networks.

As climate change progresses, it will be necessary to develop and test adaptation strategies to understand and improve the vulnerabilities of pregnant women in urban and rural areas to heat-related health risks. Continuous monitoring and evaluation of these strategies will be essential to ensure their effectiveness over time. With the heat vulnerability maps developed, high risk areas can be specifically targeted for interventions, optimising the allocation of resources and improving outcomes for the most vulnerable populations.

Limitations

We used data from Pakistan's Demographic and Health Surveys and Multiple Indicator Cluster Surveys, representative of national maternal and child health indicators. However, these datasets have limitations: (1) The lack of exact childbirth dates required monthly data aggregation, which might de-emphasise short-term temperature peaks, even though the approach effectively captures broader temporal patterns. Aggregated data also enable reliable long-term burden estimation, aligning with the principles of Basagaña and Ballester (30). (2) Missing spatial coordinate required aggregation at monthly and provincial scales, accounting for regional variation while addressing data sparsity. To complement this, we developed a district-level heat vulnerability index to identify high-risk areas for targeted interventions. (3) We addressed inherent variability and gaps in survey data using weighted coefficients from multiple models and random intercepts for provinces. (4) Birth size, a crude measure used alongside birth weight, can introduce biases. (5) We excluded data from the 2017–2018 Pakistan Demographic and Health Survey to avoid redundancy and overlap with the 2018 Multi-Indicator Cluster Surveys. (6) Gridded meteorological data served as a proxy for exposure, capturing local trends but lacking individual-level spatial and temporal precision. Monthly averages might obscure variability and household factors influencing low birth weight.

The study's aggregated nature limits control over individual-level confounders, so we encourage caution when interpreting the relationships observed as causal. Including spatial coordinates and precise childbirth dates in Pakistan's Multi-Indicator Cluster Surveys, along with robust maternal and child health data systems, are essential. Improved data collection will enhance understanding of environmental impacts on health and support more targeted interventions.

Conclusions

Pregnant women in Pakistan face a heightened risk of delivering infants of low birth weight following exposure to extreme temperatures, with percent risk varying among provinces from 30 to 70%. Around 8·95 to 10·91% of cases of low birth weights are attributable to heat and are projected to increase by 1·2 to 2·36% for climate projections to the 2060s. Regions in southern Punjab, northern Sindh, and Baluchistan have the highest risks.

Addressing this issue requires the development, implementation, and rigorous evaluation of comprehensive intervention strategies. These approaches must be multifaceted, leveraging collaboration between researchers, government agencies, and local communities. Enhancing and adapting existing strategies will be essential for improving health outcomes and protecting maternal and child health in the future.

Contributors

SHF: Conceptualisation, Data Curation, Formal Analysis, Methodology, Visualisation, Project Administration, Writing-original draft preparation. CJAB: Formal Analysis, Methodology, Visualisation, Writing-reviewing and editing. ZAB: Validation, Writing-reviewing and editing. PB: Validation, Writing-reviewing and editing. JKD: Validation, Writing-reviewing and editing. SM: Conceptualisation, Validation, Writing-reviewing and editing. ZSL: Conceptualisation, Validation, Funding Acquisition, Writing-reviewing and editing

Declaration of interests

We declare no competing interests.

Data Sharing

All relevant R code and data for the analyses and results available at doi:10.5281/zenodo.14373384.

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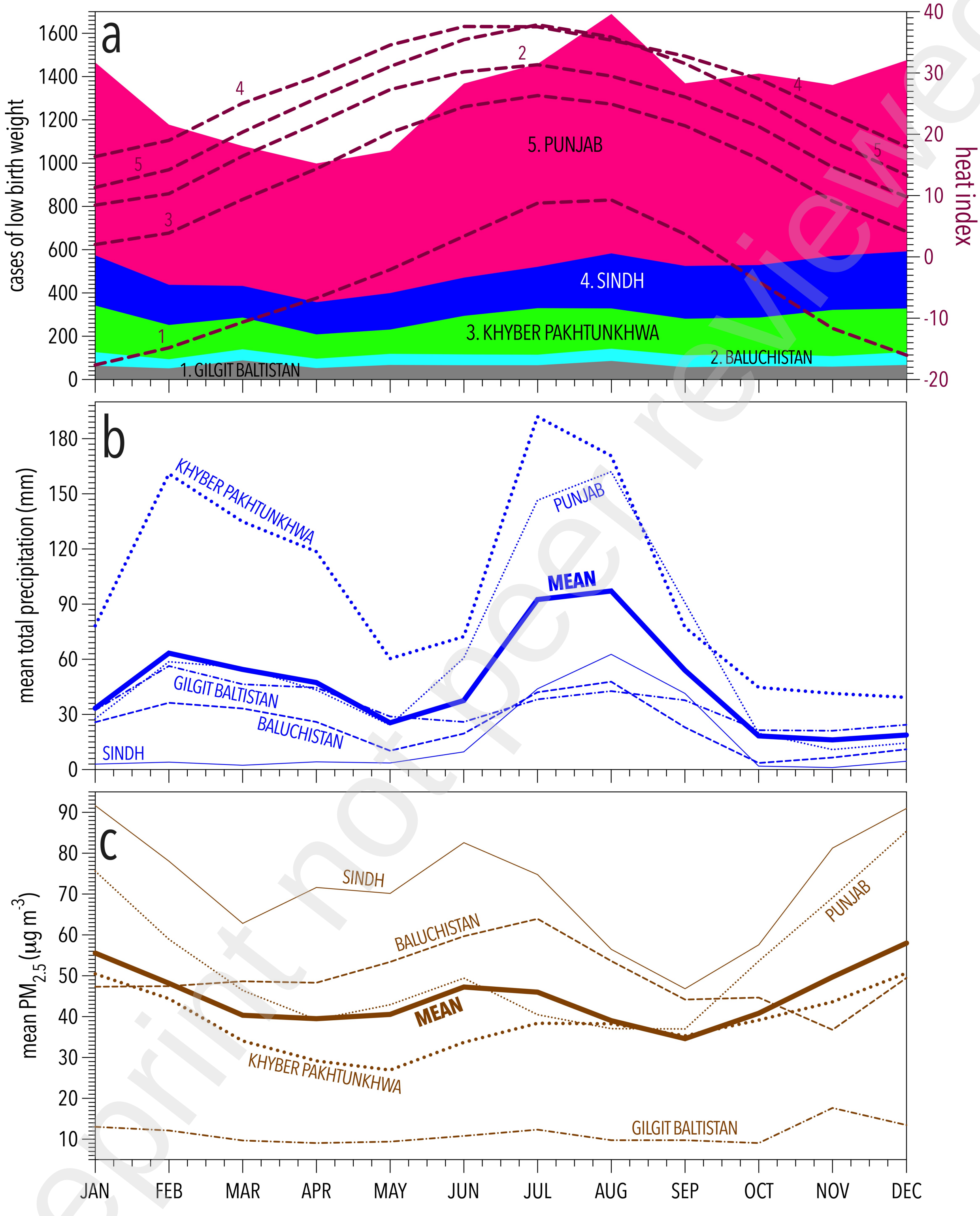
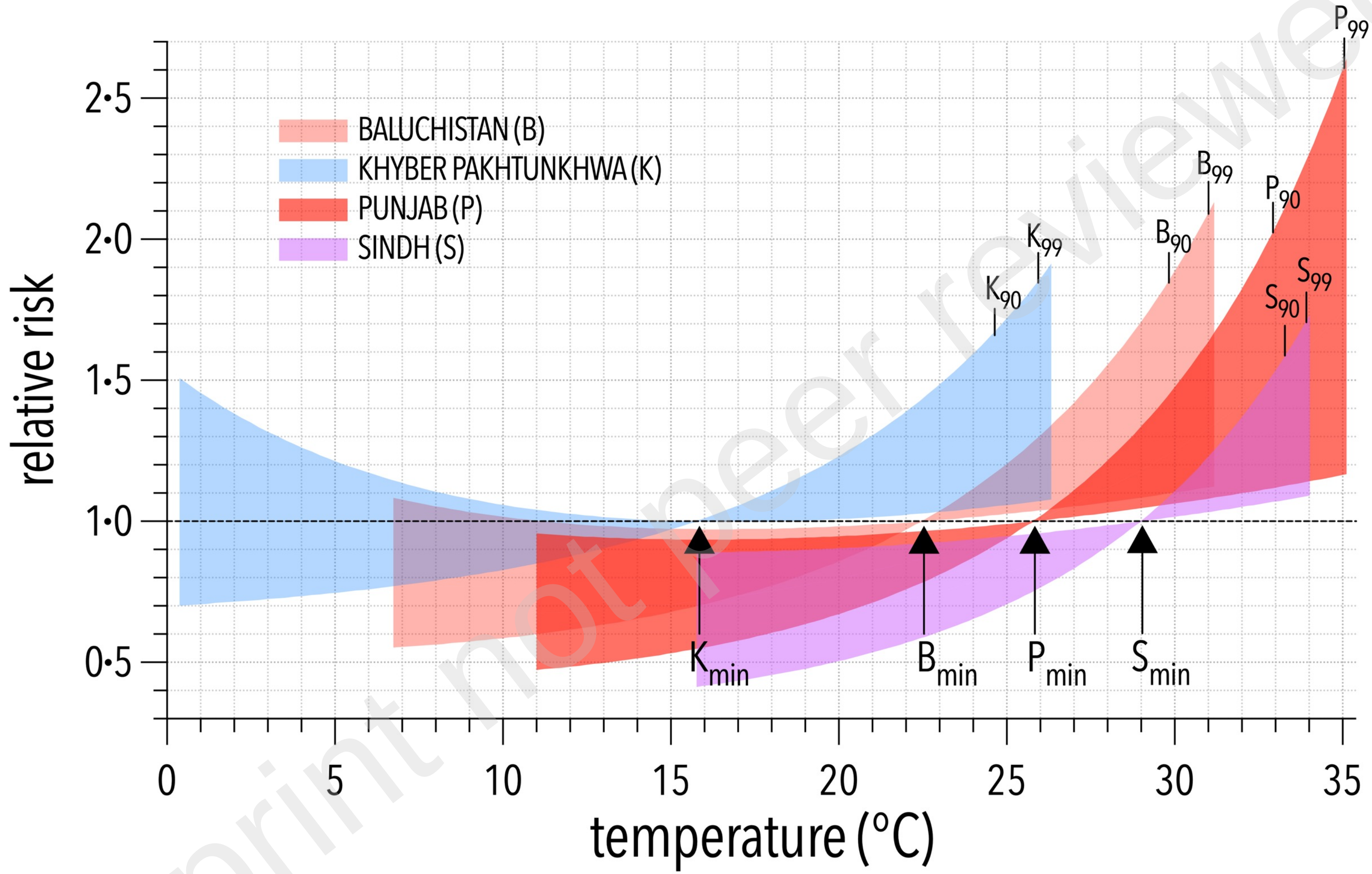
References

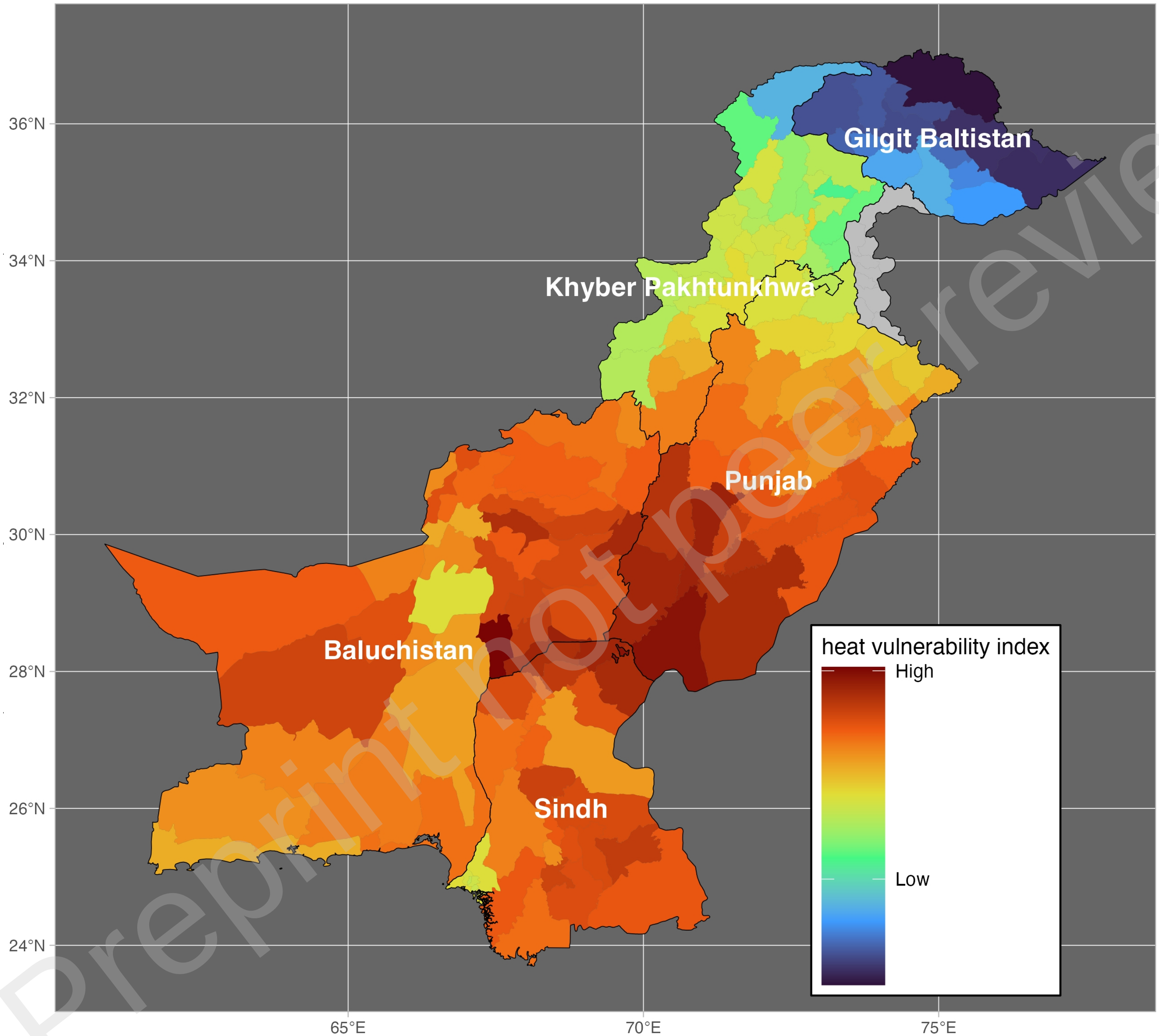
1. World Weather Attribution. Climate change made the deadly heatwaves that hit millions of highly vulnerable people across Asia more frequent and extreme. 2024. Available from: https://www.worldweatherattribution.org/climate-change-made-the-deadly-heatwaves-that-hit-millions-of-highly-vulnerable-people-across-asia-more-frequent-and-extreme.
2. Eckstein D, Künzel V, Schäfer L. Global Climate Risk Index 2021: Who suffers most from extreme weather events? Weather-related loss events in 2019 and 2000-2019. Germanwatch. 2021. Available from: https://www.germanwatch.org/en/cri.
3. Islam M, Ali S, Majeed H, et al. Drivers of stunting and wasting across serial cross-sectional household surveys of children under 2 years of age in Pakistan: potential contribution of ecological factors. Am J Clin Nutr. 2025;35:S0002-9165(25)00003-6. https://doi.org/10.1016/j.ajcnut.2025.01.003
4. Nisar YB, Dibley MJ. Determinants of neonatal mortality in Pakistan: secondary analysis of Pakistan Demographic and Health Survey 2006–07. BMC Public Health. 2014;14:1-12. https://doi.org/10.1186/1471-2458-14-663
5. Shankar K, Hwang K, Westcott JL, et al. Associations between ambient temperature and pregnancy outcomes from three South Asian sites of the Global Network Maternal Newborn Health Registry: a retrospective cohort study. BJOG. 2023;130:124-33. https://doi.org/10.1111/1471-0528.17616
6. Anwar A, Ayub M, Khan N, Flahault A. Nexus between air pollution and neonatal deaths: a case of Asian countries. Int J Environ Res Public Health. 2019;16(21):4148. https://doi.org/10.3390/ijerph16214148
7. Lee K, Greenstone M. Annual update: Air Quality Life Index. 2021. Available from: https://aqli.epic.uchicago.edu/wp-content/uploads/2021/08/AQLI_2021-Report.EnglishGlobal.pdf
8. Demographic Health Program. DHS overview. The DHS Program website. Funded by USAID. [Internet]. [cited 2024 Feb 9]. Available from: http://www.dhsprogram.com.
9. UNICEF. Multiple indicator cluster surveys. [Internet]. 2024 [cited 2024 Feb 9]. Available from: https://www.mics.unicef.org/surveys.
10. Acharya P, Adhikari S, Adhikari TB. Mother's perception of size at birth is a weak predictor of low birth weight: evidence from Nepal Demographic and Health Survey. PLoS One. 2023;18(1):e0280788. https://doi.org/10.1371/journal.pone.0280788
11. Muñoz-Sabater J, Dutra E, Agustí-Panareda A, et al. ERA5-Land: a state-of-the-art global reanalysis dataset for land applications. Earth Syst Sci Data. 2021;13(9):4349-83. https://doi.org/10.5194/essd-13-4349-2021
12. Anderson GB, Bell ML, Peng RD. Methods to calculate the heat index as an exposure metric in environmental health research. Environ Health Perspect. 2013;121(10):1111-9. https://doi.org/10.1289/ehp.1206273
13. Van Donkelaar A, Hammer MS, Bindle L, et al. Monthly global estimates of fine particulate matter and their uncertainty. Environ Sci Technol. 2021;55(22):15287-300. https://doi.org/10.1021/acs.est.1c05309
14. Gasparrini A, Armstrong B, Kenward MG. Distributed lag non-linear models. Stat Med. 2010;29(21):2224-34. https://doi.org/10.1002/sim.3940
15. Nyadanu SD, Tessema GA, Mullins B, Chai K, Yitshak-Sade M, Pereira G. Critical windows of maternal exposure to biothermal stress and birth weight for gestational age in Western Australia. Environ Health Perspect. 2023;131(12):127017. https://doi.org/10.1289/ehp12660
16. van Buuren S, Groothuis-Oudshoorn K. mice: multivariate imputation by chained equations in R. J Stat Softw. 2011;45(1):1-67. doi:10.18637/jss.v045.i03. https://doi.org/10.18637/jss.v045.i03

17. Bao J, Li X, Yu C. The construction and validation of the heat vulnerability index: a review. Int J Environ Res Public Health. 2015;12(7):7220-34. http://doi.org/10.3390/ijerph120707220
18. Intergovernmental Panel on Climate Change (IPCC). Summary for policymakers. In: Climate Change 2021: The Physical Science Basis. Cambridge University Press; 2021. p. 3-32. https://doi.org/10.1017/9781009157896.001
19. Gasparrini A. Distributed lag linear and non-linear models in R: the package dlnm. J Stat Softw. 2011;43(8):1. https://doi.org/10.18637/jss.v043.i08
20. Brooks ME, Kristensen K, van Benthem KJ, et al. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R J. 2017;9(2):378-400. https://doi.org/10.32614/RJ-2017-066
21. Bartoń K. MuMIn: Multi-model inference. R package version 1.48.4. CRAN.R-project.org/package=MuMIn; 2024. Available from: https://cran.r-project.org/web/packages/MuMIn/MuMIn.pdf
22. Wickham H. ggplot2: Elegant graphics for data analysis. Springer-Verlag; 2016. Available from: https://cran.r-project.org/web/packages/MuMIn/MuMIn.pdf
23. United Nations Children's Fund (UNICEF). Maternal and newborn health disparities in Pakistan. 2024. Available from: https://data.unicef.org/wp-content/uploads/country_profiles/Pakistan/country%20profile_PAK.pdf.
24. Aziz A, Saleem S, Nolen TL, et al. Why are the Pakistani maternal, fetal and newborn outcomes so poor compared to other low and middle-income countries? Reprod Health. 2020;17:1-12. https://doi.org/10.1186/s12978-020-01023-5
25. Dimitrova A, Mengel M, Gasparrini A, Lotze-Campen H, Gabrysch S. Temperature-related neonatal deaths attributable to climate change in 29 low-and middle-income countries. Nat Commun. 2024;15(1):5504. https://doi.org/10.1038/s41467-024-49890-x
26. Zhu Z, Zhang T, Benmarhnia T, et al. Estimating the burden of temperature-related low birthweight attributable to anthropogenic climate change in low-income and middle-income countries: a retrospective, multicentre, epidemiological study. Lancet Planet Health. 2024;8(12):e997-1009. https://doi.org/10.1016/S2542-5196(24)00242-0
27. Conte Keivabu R, Cozzani M. Extreme heat, birth outcomes, and socioeconomic heterogeneity. Demography. 2022;59(5):1631-54. https://doi.org/10.1215/00703370-10174836
28. ABC News. South Asian heatwave: Heatwave hits India and Pakistan as power stations struggle to secure coal supply. 2022 Apr 30 [cited 2025 Jan 17]. Available from: https://www.abc.net.au/news/2022-04-30/south-asian-heatwave/101027906
29. Mumtaz S, Bahk J, Khang YH. Rising trends and inequalities in cesarean section rates in Pakistan: Evidence from Pakistan Demographic and Health Surveys, 1990-2013. *PLoS One.* 2017;12(10):e0186563. https://doi.org/10.1371/journal.pone.0186563
30. Basagaña X, Ballester J. Unbiased temperature-related mortality estimates using weekly and monthly health data: a new method for environmental epidemiology and climate impact studies. Lancet Planet Health. 2024;8(10):e766-77. https://doi.org/10.1016/S2542-5196(24)00212-2

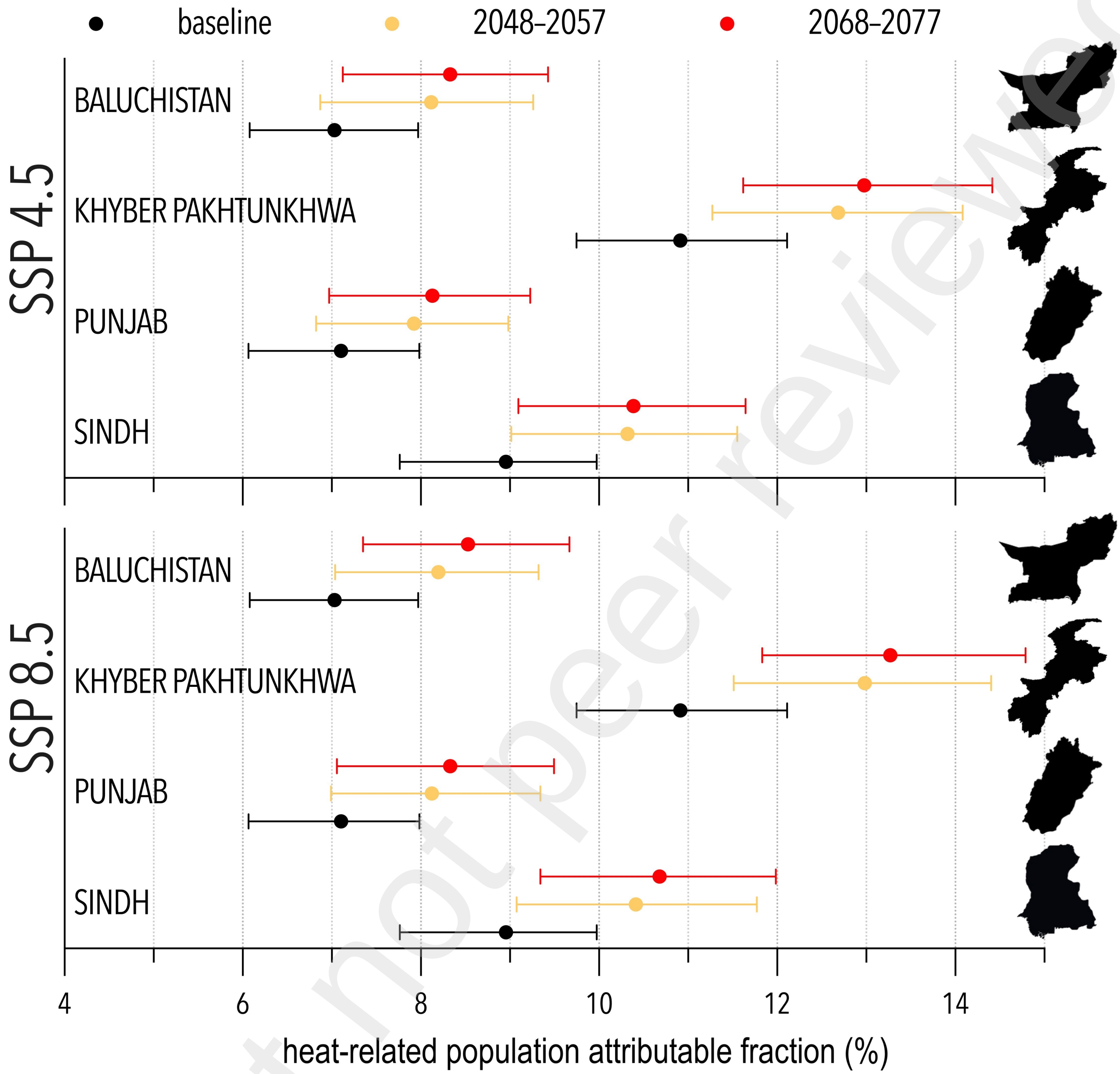

a
cases of low birth weight
heat index
5. PUNJAB
4. SINDH
3. KHYBER PAKHTUNKHWA
2. BALUCHISTAN
1. GILGIT BALTISTAN
b
mean total precipitation (mm)
KHYBER PAKHTUNKHWA
PUNJAB
MEAN
GILGIT BALTISTAN
BALUCHISTAN
SINDH
c
mean $PM_{2.5}$ ($\mu g\ m^{-3}$)
SINDH
BALUCHISTAN
PUNJAB
MEAN
KHYBER PAKHTUNKHWA
GILGIT BALTISTAN
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC



BALUCHISTAN (B)
KHYBER PAKHTUNKHWA (K)
PUNJAB (P)
SINDH (S)
relative risk
temperature (°C)
2·5
2·0
1·5
1·0
0·5
0
5
10
15
20
25
30
35
K_{90}
K_{99}
B_{90}
B_{99}
P_{90}
P_{99}
S_{90}
S_{99}
K_{min}
B_{min}
P_{min}
S_{min}



Gilgit Baltistan
Khyber Pakhtunkhwa
Punjab
Baluchistan
Sindh
heat vulnerability index
High
Low
36°N
34°N
32°N
30°N
28°N
26°N
24°N
65°E
70°E
75°E



baseline
2048–2057
2068–2077
SSP 4.5
SSP 8.5
BALUCHISTAN
KHYBER PAKHTUNKHWA
PUNJAB
SINDH
4
6
8
10
12
14
heat-related population attributable fraction (%)

Table 1. Prevalence of low birth weight, socio-demographic status, and environmental conditions in Pakistan from 2008 to 2017 (n = 85,017).

Demographic and socioeconomic variables			
Variable	**%**	**variable**	**%**
prevalence / 100 cases (n = 15,920)	18·72		
education		**mother Age**	
primary or no education (%)	74·65	15–29	59·37
secondary (%)	13·47	30–39	35·53
higher (%)	11·87	40–49	5·11
wealth index		**Province**	
poor	29·01	Baluchistan	3·95
middle	12·57	Gilgit Baltistan	4·98
rich	23·79	Khyber Pakhtunkhwa (including FATA)	13·02
region		Punjab	62·31
rural	66·69	Sindh	15·74
urban	33·31		
Environmental variables			
variables	**median (range)**	**variable**	**median (range)**
mean temperature (^{o}C)	19·5 (-20·0–35·1)	**humidity (%)**	54·3 (18·9–80·2)
air pollution $PM_{2·5}$ (µg m^{-3})	44·8 (4·5–123·9)	**precipitation (mm)**	46·60 (0·03–427)

Table 2. Relative risk estimates (with 95% confidence bounds) of low birth weight linked to heat and cold across heat-index percentile ranges.

Subgroup	**risk estimates (90th Percentile)**	**risk estimates (99th Percentile)**
air quality status		
fair (< 25 µg m^{-3})	0·80 (0·51–1·27)	0·98 (0·53–1·80)
poor–hazardous (≥ 25 µg m^{-3})	1·78 (1·17–2·71)	2.11 (1·23–3·64)
education Status		
primary or no education	1·70 (1·15–2·50)	1·99 (1·20–3·30)
secondary or above	1·69 (1·04–2·76)	2·36 (1·18–4·74)
wealth Status		
low	1·72 (1·15–2·58)	2·03 (1·21–3·41)
high	4·54 (1·50–13·71)	7·06 (1·68–29·63)
type of region		
urban	1·94 (1·20–3·14)	2·22 (1·24–3·96)
rural	1·74 (1·16–2·62)	2·02 (1·21–3·37)