Humid Heat Stress and Preterm Birth Risk in Brazil

Abstract

Climatic conditions of humid heat stress, characterized by prolonged periods of high temperature and elevated humidity, can influence reproductive health, yet remain understudied in tropical settings. We estimated the association between exposure to combined high temperature and high relative humidity and the occurrence of preterm birth in Brazil during the warm months (January–March and October–December) of 2023. We integrated daily municipal-level meteorological data (BRDW-GD) with live birth records (SINASC), defining humid heat stress as simultaneous exposure to temperatures above 35 °C and relative humidity above 50% within a 30-day window preceding delivery. Within this window, we assessed whether pregnant individuals experienced 10, 7, 5, or 3 days under these conditions. Effects were estimated using logistic regression, adjusting for maternal and newborn characteristics, and stratified by major Brazilian regions. Results revealed substantial regional heterogeneity. Between October and December, a protective effect was observed in the Northern region, whereas the Northeast, Southeast, and Midwest regions exhibited increased risk. During the summer months (January–March), this pattern reversed: the Southeast showed a protective effect, while the North demonstrated elevated risk. At the national level, the associations were positive but of small magnitude.

Keywords: preterm birth; climate; humidity; maternal health; Brazil; regions

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1. Introduction

Climate change represents one of the greatest global challenges of our time, with impacts that go beyond environmental boundaries and directly affect human health and well-being. In the context of maternal and perinatal health, maternal mortality, and fetal deaths, the effects of climatic changes have become particularly relevant and concerning. Rising temperatures, changes in precipitation patterns, and the increasing frequency of extreme weather events, such as heatwaves and floods, have been associated with adverse outcomes among pregnant individuals and newborns.

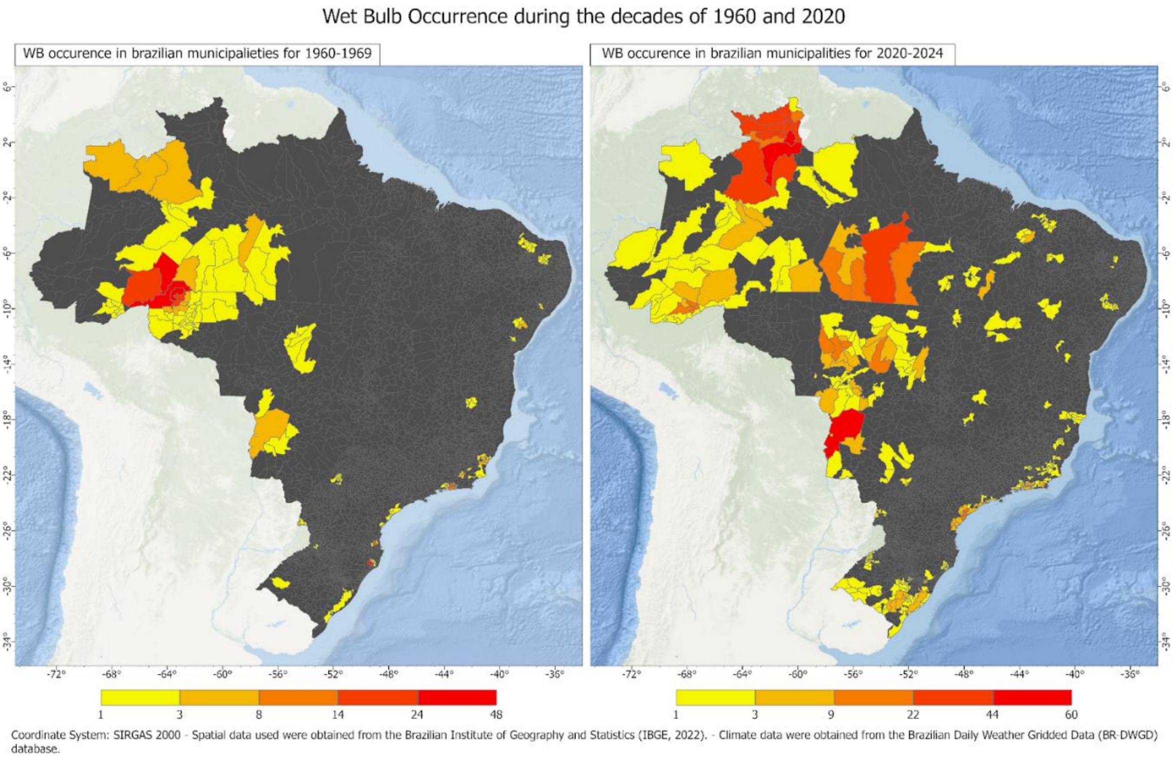
Recent studies indicate that exposure to high temperatures during pregnancy is correlated with an increased risk of complications, including preterm birth, stillbirth, and other adverse neonatal outcomes (Darrow et al., 2024; Chersich et al., 2020; Bátiz et al., 2022). Furthermore, higher temperatures and reduced rainfall may intensify exposure to air pollutants, which in turn affect reproductive health and contribute to obstetric complications. These impacts tend to be more severe in regions with limited infrastructure and among socially vulnerable populations, exacerbating health inequalities.

In a recent study, Darrow et al. (2024) examined the association between heatwaves and increased rates of preterm and early-term births in the United States. The authors analyzed daily rates of preterm and early-term births following heatwave episodes in a nationwide study spanning 25 years. They used birth registration data from 1993 to 2017 for the 50 most populous metropolitan areas in the country, alongside daily temperature data. The results demonstrated a positive association between heatwaves and daily rates of preterm and early-term births, with stronger associations observed when considering four consecutive days in which mean temperatures exceeded the local 97.5th percentile prior to delivery. Notably, rates of premature and early-term births increased after heatwaves, especially among socioeconomically disadvantaged groups.

Combined exposure to heat and high humidity constitutes a particularly important environmental stressor in tropical and subtropical regions, although its effects on reproductive health remain underestimated. Unlike metrics based solely on-air temperature, wet-bulb temperature (Tw) (Stull, 2011) reflects the role of humidity in the body's ability to dissipate heat: the higher the humidity, the lower the efficiency of evaporative cooling, even in the absence of extreme heat (Grundstein et al., 2024; Baldwin et al., 2023). During pregnancy, this climatic condition demands physiological adaptations, such as increased cardiac output, hemodynamic changes, and higher water requirements, which reduce thermal tolerance and make pregnancy particularly sensitive to prolonged periods of heat and high humidity (Chersich et al., 2023; Preston et al., 2020). These episodes can lead to dehydration, chronic heat stress, inflammatory or infectious responses, plausible pathways for triggering preterm labor.

Over recent decades, some regions of Brazil have nearly doubled the number of days with elevated wet-bulb temperatures, with the Midwest region showing the greatest increase, as illustrated in Figure 1. Wet-bulb temperature, which combines the effects of air temperature and relative humidity, is widely used to assess thermal comfort and human heat stress (Stull, 2011). This indicator is essential to understanding health risks: a wet-bulb temperature of 35 °C corresponds approximately to an air temperature of 45 °C with 50% relative humidity, resulting in a perceived temperature close to 71 °C.

Figure 1: Frequency of occurrence of wet-bulb temperature (Tw) equal to or exceeding 35 °C during the 1960s (a) and the 2020s (b) across Brazilian municipalities.



Source: Authors' estimates based on Xavier's dataset, updated within the scope of the Climaterna Project in 2024.

This alarming increase in the number of days with elevated wet-bulb temperatures in Brazil over recent decades underscores the importance of accounting for the interaction between heat and humidity when assessing the climatic impacts on maternal and perinatal health. Despite advances in heat-related research, the persistence of high humidity remains understudied, particularly in countries with substantial climatic diversity such as Brazil.

In this study, we represent this condition using a metric approximating wet-bulb temperature (Tw), which we refer to as "humid heat stress," defined as the combined exposure to temperatures above 35 °C and relative humidity above 50%. Accordingly, this study examines how humid heat stress relates to preterm birth in Brazil during the two warmest periods of the year (January–March and October–December), integrating daily climate and birth data and exploring differences across the country's major regions. The aim of this analysis is to determine whether exposure to humid heat stress in the days preceding delivery is associated with preterm birth among pregnant individuals in Brazil, as well as to identify potential regional variations in this effect.

2. Data and Methods

Live birth data from the Brazilian Live Birth Information System (SINASC) for the year 2023 were used and integrated with daily meteorological data on air temperature and relative humidity from the Brazilian Daily Weather Gridded Data (BR-DWGD), both made available by the Climaterna platform (Soares et al., 2025). The year 2023 was selected because it was the warmest year ever recorded in Brazil, marked by nine heatwave events throughout the year (INMET, 2024).

Exposure to humid heat stress was defined as days with air temperature above 35 °C and relative humidity above 50%. To assess the temporal association between exposure and outcome, 30-day windows preceding delivery were considered, within which the accumulation of 3, 5, 7, or 10 days of exposure to humid heat conditions was evaluated. Analyses were stratified by region, focusing on the warm seasons: summer (January–March) and spring (October–December).

Preterm birth was classified according to gestational age at delivery into the following categories: extreme preterm (<32 completed weeks), moderate preterm (32–33 weeks), late preterm (34–36 weeks), and overall preterm (<37 weeks).

Logistic regression models were fitted for each geographic region (North, Northeast, South, Southeast, and Midwest) and for Brazil as a whole. Analyses were adjusted for potential maternal confounders: age, education level, parity, marital status, and race/ethnicity. Adjusted odds ratios (aORs) and 95% confidence intervals were estimated, with statistical significance set at $p<0.05$.

3. Preliminary Results

The adjusted logistic regression analysis revealed distinct regional patterns in the association between exposure and the outcome, with substantial variation in both the magnitude and direction of effects across Brazil's regions.

During the spring and early summer months (October to December), pronounced regional heterogeneity was observed. The North region stood out for exhibiting a consistent and statistically significant protective effect across all exposure windows. For 3 days of exposure within the 30-day pre-delivery window, the adjusted odds ratio (aOR) was 0.822 (95% CI: 0.739–0.915; p = 0.0003), indicating an approximately 18% reduction in the odds of preterm birth. This protective effect remained robust in the 5-day window (aOR: 0.854; 95% CI: 0.780–0.936; p < 0.0001), 7-day window (aOR: 0.888; 95% CI: 0.818–0.963; p = 0.0043), and 10-day window (aOR: 0.926; 95% CI: 0.862–0.995; p = 0.0363).

The other regions showed positive associations with the outcome. The Northeast exhibited the most consistent and robust positive associations, with an aOR of 1.126 (95% CI: 1.083–1.172; p<0.0001) for 3 days of exposure, with similar magnitudes across all exposure windows (ranging from 1.103 to 1.126), indicating an approximate 10–13% increase in the odds of the outcome. The South region presented an aOR of 1.085 (95% CI: 1.024–1.151; p=0.0059) for 3 days of exposure; however, associations were not statistically significant for the 7-day (p=0.1606) and 10-day windows (p=0.7744), suggesting greater sensitivity to short-term exposure. The Southeast showed more modest yet consistent positive associations, with aORs ranging from 1.051 to 1.069 across exposure windows, all statistically significant (p<0.001).

The Midwest displayed a distinct pattern, with no significant association in the 3-day window (aOR: 1.050; 95% CI: 0.895–1.231; p=0.5495), but significant positive associations emerged for longer exposure durations: 5 days (aOR: 1.172; 95% CI: 1.058–1.297; p=0.0023), 7 days (aOR: 1.169; 95% CI: 1.073–1.274; p=0.0003), and 10 days (aOR: 1.102; 95% CI: 1.025–1.185; p=0.0082), suggesting a cumulative effect of exposure in this region.

In the first quarter of the year, a substantial reversal of association patterns was observed compared to the October–December period, indicating a marked seasonality of effects. The Southeast, which had previously demonstrated positive associations, displayed a robust and consistent protective effect across all exposure windows. For 3 days of exposure, the aOR was 0.884 (95% CI: 0.850–0.919; p<0.0001), corresponding to an approximately 12% reduction in the odds of preterm birth. This protective effect remained stable across 5-day (aOR: 0.875; 95% CI: 0.838–0.913; p<0.0001), 7-day (aOR: 0.880; 95% CI: 0.839–0.923; p<0.0001), and 10-day windows (aOR: 0.891; 95% CI: 0.842–0.943; p=0.0001), demonstrating remarkable consistency regardless of exposure duration.

Conversely, the North region, which had demonstrated protective effects during October–December, showed a complete reversal of this pattern, with significant positive associations across all windows during January–March. Adjusted odds ratios increased progressively with longer exposure durations: 1.199 (95% CI: 1.093–1.315; p=0.0001) for 3 days, 1.242 (95% CI: 1.114–1.384; p=0.0001) for 5 days, 1.247 (95% CI: 1.102–

1.411; p=0.0004) for 7 days, and 1.289 (95% CI: 1.113–1.492; p=0.0007) for 10 days—indicating up to a 29% increase in the odds of preterm birth for the 10-day exposure window.

The Northeast and South regions maintained positive associations in both seasonal periods, although with slightly different magnitudes. In the Northeast, aORs ranged from 1.121 to 1.141 during January–March, comparable to those observed during the previous period (1.103 to 1.126). In the South, a similar pattern of positive associations was observed, with an aOR of 1.132 (95% CI: 1.073–1.194; p<0.0001) for 3 days of exposure, increasing progressively to 1.159 (95% CI: 1.065–1.261; p=0.0006) for 10 days, suggesting a more pronounced cumulative effect during this season.

The Midwest region displayed a distinct pattern in the first quarter, with no statistically significant associations in the 3-, 5-, and 7-day exposure windows (p>0.05), but a significant positive association emerged for the 10-day window (aOR: 1.143; 95% CI: 1.008–1.297; p=0.0376), reinforcing the hypothesis of a cumulative exposure effect in this region.

At the national level, a significant positive association was observed across all exposure windows for both seasonal periods. From October to December, national aORs ranged from 1.033 (95% CI: 1.011–1.055; p=0.0028) for 10 days of exposure to 1.050 (95% CI: 1.029–1.072; p<0.0001) for 7 days, with relatively stable effect sizes across exposure durations. During January to March, estimates were slightly higher, ranging from 1.021 (95% CI: 0.995–1.047; p=0.1092) for 5 days to 1.056 (95% CI: 1.021–1.091; p=0.0013) for 10 days, although the 5-day association did not reach statistical significance.

The magnitude of associations generally increased with longer exposure windows in most regions, particularly in the North during January–March and in the Midwest across both periods, suggesting a potential cumulative effect. However, some regions, such as the South during October–December, showed a loss of statistical significance in longer windows, possibly indicating a greater relevance of acute exposures or dilution of effect when non-exposure days are included.

These findings reveal a complex interplay between regional factors, seasonality, and exposure timing, including a reversal in the direction of effects between seasonal periods in at least two regions (North and Southeast). This emphasizes the need to consider geographically and temporally specific contexts when interpreting results and designing intervention strategies.

TABLE 1 - Adjusted odds ratios for the association between pre-delivery exposure and outcome by region, exposure window, and season, Brazil, 2023

Region	Yea r	Number of days exposed (30-day window prior to delivery)	Month	OR	aOR (95% CI)	p-value
North	2023	3 days	10, 11, 12	0.8222	0.739-0.915	0.0003***
Northeast	2023	3 days	10, 11, 12	1.126	1.083-1.172	0.0000***
South	2023	3 days	10, 11, 12	1.085	1.024-1.151	0.0059**
Southeast	2023	3 days	10, 11, 12	1.051	1.013-1.089	0.0076**
Midwest	2023	3 days	10, 11, 12	1.050	0.895-1.231	0.5495
Brazil	2023	3 days	10, 11, 12	1.049	1.027-1.071	0.0000***
North	2023	5 days	10, 11, 12	0.854	0.780-0.936	0.0000***
Northeast	2023	5 days	10, 11, 12	1.117	1.074-1.162	0.0000***
South	2023	5 days	10, 11, 12	1.060	0.991-1.134	0.0915*
Southeast	2023	5 days	10, 11, 12	1.066	1.032-1.101	0.0001***
Midwest	2023	5 days	10, 11, 12	1.172	1.058-1.297	0.0023**
Brazil	2023	5 days	10, 11, 12	1.049	1.028-1.071	0.0000***
North	2023	7 days	10, 11, 12	0.888	0.818-0.963	0.0043**
Northeast	2023	7 days	10, 11, 12	1.126	1.082-1.171	0.0000***
South	2023	7 days	10, 11, 12	1.062	0.977-1.154	0.1606
Southeast	2023	7 days	10, 11, 12	1.069	1.035-1.104	0.0001***
Midwest	2023	7 days	10, 11, 12	1.169	1.073-1.274	0.0003***
Brazil	2023	7 days	10, 11, 12	1.050	1.029-1.072	0.0000***
North	2023	10 days	10, 11, 12	0.926	0.862-0.995	0.0363*
Northeast	2023	10 days	10, 11, 12	1.103	1.060-1.148	0.0000***
South	2023	10 days	10, 11, 12	1.017	0.908-1.139	0.7744
Southeast	2023	10 days	10, 11, 12	1.066	1.027-1.107	0.0008***

Midwest	2023	10 days	10, 11, 12	1.102	1.025-1.185	0.0082**
Brazil	2023	10 days	10, 11, 12	1.033	1.011-1.055	0.0028***
North	2023	3 days	1, 2, 3	1.199	1.093-1.315	0.0001***
Northeast	2023	3 days	1, 2, 3	1.128	1.082-1.176	0.0000***
South	2023	3 days	1, 2, 3	1.132	1.073-1.194	0.0000***
Southeast	2023	3 days	1, 2, 3	0.884	0.850-0.919	0.0000***
Midwest	2023	3 days	1, 2, 3	0.991	0.927-1.060	0.7910
Brazil	2023	3 days	1, 2, 3	1.028	1.005-1.051	0.0165*
North	2023	5 days	1, 2, 3	1.242	1.114-1.384	0.0001***
Northeast	2023	5 days	1, 2, 3	1.121	1.072-1.173	0.0000***
South	2023	5 days	1, 2, 3	1.103	1.039-1.171	0.0014**
Southeast	2023	5 days	1, 2, 3	0.875	0.838-0.913	0.0000***
Midwest	2023	5 days	1, 2, 3	1.044	0.960-1.135	0.3168
Brazil	2023	5 days	1, 2, 3	1.021	0.995-1.047	0.1092
North	2023	7 days	1, 2, 3	1.247	1.102-1.411	0.0004***
Northeast	2023	7 days	1, 2, 3	1.121	1.067-1.177	0.0000***
South	2023	7 days	1, 2, 3	1.117	1.041-1.199	0.0021***
Southeast	2023	7 days	1, 2, 3	0.880	0.839-0.923	0.0000***
Midwest	2023	7 days	1, 2, 3	1.095	0.992-1.209	0.0726
Brazil	2023	7 days	1, 2, 3	1.029	1.000-1.059	0.0472*
North	2023	10 days	1, 2, 3	1.289	1.113-1.492	0.0007***
Northeast	2023	10 days	1, 2, 3	1.141	1.080-1.204	0.0000***
South	2023	10 days	1, 2, 3	1.159	1.065-1.261	0.0006***
Southeast	2023	10 days	1, 2, 3	0.891	0.842-0.943	0.0001***
Midwest	2023	10 days	1, 2, 3	1.143	1.008-1.297	0.0376*
Brazil	2023	10 days	1, 2, 3	1.056	1.021-1.091	0.0013**

Source: Logistic regression analysis conducted by the authors using the Climaterna database (Soares, C. F., et al., 2024). Available at: https://doi.org/10.25824/redu/ZE4IJM.

4. Discussion

The findings of this study indicate that exposure to humid heat stress is associated with preterm birth in Brazil, with substantial variation across regions and seasons. The reversal of effects observed between the North and Southeast regions, as well as the differing effect magnitudes across exposure windows, underscores the complexity of the relationship between climate and reproductive health and highlights the need for more in-depth investigation.

Considering these preliminary results, the next phase of this research will aim to expand the analyses to better understand the underlying mechanisms and assess the robustness of the associations. Future work will incorporate methods with stronger causal inference, such as regression discontinuity designs, and will explore alternative exposure definitions, interactions with socio-environmental variables, and heterogeneity by maternal characteristics.

Deepening these analyses is essential to determine whether the observed effects are persistent, causal, and meaningful for maternal health surveillance strategies in the context of accelerating climate change. Thus, this study does not conclude with the results presented here but rather represents an initial step in an ongoing effort to integrate climatic and epidemiological evidence into public policy planning.

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