

Preplanned Studies

Disparities of Heatwave-Related Preterm Birth in Climate Types — China, 2012–2019

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Summary

What is already known about this topic?

An association between prenatal heatwave exposure and the risk of preterm birth was found. However, the disparities in heatwave-related preterm birth across different climate types have not been examined.

What is added by this report?

This nationwide case-crossover study investigated the association between heatwave exposure and preterm birth across different Köppen-Geiger climate types. Among pregnant women residing in the arid-desert-cold climate type, exposure to compound heatwaves was found to be associated with a significantly higher risk of preterm birth [adjusted odds ratios (AORs) ranged from 1.55 [95% confidence interval (CI): 1.21–1.97] to 2.11 (95% CI: 1.35–3.31)]. In contrast, among pregnant women residing in the tropical monsoonal climate type, exposure to daytime-only heatwaves was associated with an increased risk of preterm birth [AORs ranged from 1.25 (95% CI: 1.03–1.51) to 1.37 (95% CI: 1.05–1.77)].

What are the implications for public health practice?

Specific interventions should be implemented in China to mitigate the risk of preterm birth related to heatwaves, particularly for pregnant women residing in arid-desert-cold and tropical monsoonal climates.

Recent systematic reviews have identified a need for studies investigating the association between high temperatures and preterm birth (PTB) across different climate types (1–2). Previous research has suggested that the association between extreme heat and PTB may vary depending on the climate (3–4), and there is also variability in the definition of heatwaves used in different studies (5). Furthermore, recent studies have revealed differences in the dominant subtypes of heat episodes across regions in China (6). To enhance our understanding of this topic, we conducted a large, nationally representative case-crossover study using

data from China's national maternal surveillance system encompassing 5,446,088 participants from 2012 to 2019. Our study aimed to examine the risk of PTB associated with 18 different definitions of heatwaves in various climate types according to the Köppen-Geiger classification. Our findings indicate that pregnant women in the arid-desert-cold climate type faced a higher risk of PTB when exposed to compound heatwaves, while those in the tropical monsoonal climate type experienced an increased risk with daytime-only heatwaves. These results provide valuable evidence for the development of targeted strategies for heat-PTB prevention in China, taking into account the disparities in heatwave-related PTB among different climate types.

We obtained data on singleton live births from China's National Maternal Near Miss Surveillance System (NMNMSS) for the period between January 1, 2012, and December 31, 2019, as data for 2020–2022 were not available during the study period. The data included information from 438 health facilities in 325 counties or districts across China. We applied four exclusion criteria and extracted a final analytic sample of 5,446,088 births in the warm season (April to October), as described elsewhere (7). The NMNMSS was approved by the Ethics Committee of West China Second University Hospital, Sichuan University, China (Protocol ID: 2012008), and adhered to the principles of the Declaration of Helsinki. The ethical approval (Protocol ID: 2012008) also authorized the use of NMNMSS data for subsequent studies, including the current study, on maternal health.

We defined PTB as births occurring before 37 completed weeks of gestation. To assign climate types for eligible birth records, we used the addresses of the delivery health facilities for each pregnant woman, as residential addresses were not available in the NMNMSS. Climate types were classified based on the updated Köppen-Geiger climate classification. We obtained climate classification data from the 1 km global Köppen-Geiger raster product for the time

period 1981–2010 from Climatologies at high resolution for the earth's land surface areas (CHELSA) (8). Daily maximum temperature (Tmax), minimum temperature (Tmin), relative humidity, and fine particulate matter levels with an aerodynamic diameter less than or equal to 2.5 (PM_{2.5}) were extracted. To assign exposure, we calculated the mean grid from a zone with a 25-km radius around each pregnant woman's delivery address. Detailed information on the calculation method can be found elsewhere (7). We defined 18 types of heatwaves, categorized into three distinct types: daytime-only (Tmax exceeds thresholds only), nighttime-only (Tmin exceeds thresholds only), and compound (both Tmax and Tmin exceed thresholds). We used six indexes, namely 75th-D2, 75th-D3, 75th-D4, 90th-D2, 90th-D3, and 90th-D4, which represent periods of equal to or more than two, three, or four consecutive days above the daily temperature thresholds at the 75th or 90th percentiles. (Supplementary Material, available in <https://weekly.chinacdc.cn/>).

In this multisite study, a space-time-stratified case-crossover design was used to examine the relationship between heatwave events and PTB. This design allowed each participant to serve as her own control and compared exposure on case days to control days (7). Time-invariant individual level confounders, as well as long-term and seasonal trends, were controlled for in the design. Conditional logistic regression models were employed to assess the association between heatwave events and PTB. The models were adjusted for the moving average of relative humidity and PM_{2.5} in the last gestational week (lag06), calculated across the time window, using a natural cubic spline with 3 *df*. The analysis explored the variation in climate zones using an interaction term between the heatwave exposure variable and the category variable for climate types. The reference group for this analysis was the tropical monsoonal (Am) climate type. The significance of the interaction term was tested using a two-sided *P*-value of <0.05. Each of the three types of heatwave definitions and six indexes were modeled individually. Additionally, the lag effects of the final week prior to delivery were investigated. We estimated the odds ratio employing the maximized model goodness of fit in the seven lag days (lag0, lag1, lag2, lag3, lag4, lag5, lag6) for each heatwave definition (9).

All analyses were performed using R software (version 4.1.1, R Project for Statistical Computing, Vienna, Austria). The “survival” package (version

3.2.11) and the “splines” package (version 4.1.1) were employed for conducting the conditional logistic regression analysis.

In the final analytic sample, which included a total of 5,446,088 participants, we observed coverage of 10 different Köppen-Geiger climate types. These types encompassed two tropical [Tropical-monsoon (Am) and Tropical-savannah (Aw)], two arid [Arid-steppe-cold (BSk) and Arid-desert-cold (BWk)], three temperate [Temperate-fully humid-hot summer (Cfa), Temperate-dry winter-hot summer (Cwa), and Temperate-dry winter-warm summer (Cwb)], and three cold [Cold-fully humid-hot summer (Dfa), Cold-dry winter-hot summer (Dwa), and Cold-dry winter-warm summer (Dwb)] climate types (Supplementary Table S1, available in <https://weekly.chinacdc.cn/>). The majority of participants (68.93%) resided in temperate climate types (Table 1). The rate of PTB did not vary significantly among tropical, arid, temperate, and cold climate types (Table 1). However, pregnant women living in tropical climate types experienced higher exposure to compound and nighttime heat waves during the study period. Conversely, women in arid climate types experienced less exposure to compound heat waves (Table 2).

Pregnant women in arid BWk climate type endure a higher risk of PTB {adjusted odds ratio (AOR) range, 1.55 [95% confidence interval (CI): 1.21–1.97] to 2.11 (95% CI: 1.35–3.31)} than tropical Am climate type during exposure to compound heat waves in the 90th-D3 and 90th-D4 indexes (Figure 1). When exposed to daytime-only heat waves, pregnant women in tropical Am climate type also face a higher risk of PTB [AOR range, 1.25 (95% CI: 1.03–1.51) to 1.37 (95% CI: 1.05–1.77)] than other climate types in the 75th-D2, 75th-D3, 90th-D3, and 90th-D4 indexes. The risk of PTB for pregnant women in arid BWk climate type is associated with exposure to nighttime-only heat waves in the 90th-D4 index [AOR, 1.23 (95% CI: 1.00–1.51)], with no significant difference compared with tropical Am pregnant women.

DISCUSSION

In our nationwide study examining the relationship between heat waves and PTB across ten different climate types as classified by the Köppen-Geiger system, we observed varying associations. Specifically, among pregnant women exposed to daytime-only heat waves, those residing in the tropical Am climate type faced an elevated risk of PTB [AOR range, 1.25 (95%

TABLE 1. Climate zonal characteristics of participants.

Characteristic		Participants, <i>n</i>	Preterm births, <i>n</i> (%) [†]	Sampled sites (health facilities), <i>n</i>	Sampled counties, <i>n</i> [§]
Total		5,446,088	310,384 (5.70)	438	325
Climate type and descriptions*					
A	Tropical	134,653	7,606 (5.65)	11	8
	Am Tropical-monsoon	57,221	2,685 (4.69)	6	4
	Aw Tropical-savannah	77,432	4,921 (6.36)	5	4
B	Arid	777,351	45,465 (5.85)	82	63
	BSk Arid-steppe-cold	640,730	38,082 (5.94)	66	52
	BWk Arid-desert-cold	136,621	7,383 (5.40)	16	11
C	Temperate	3,754,084	216,811 (5.78)	267	191
	Cfa Temperate-fully humid-hot summer	2,147,735	129,056 (6.01)	145	106
	Cwa Temperate-dry winter-hot summer	1,455,039	78,931 (5.42)	108	77
	Cwb Temperate-dry winter-warm summer	151,310	8,824 (5.83)	14	8
D	Cold	780,000	40,502 (5.19)	78	65
	Dfa Cold-fully humid-hot summer	42,162	2,633 (6.24)	4	2
	Dwa Cold-dry winter-hot summer	648,889	35,134 (5.41)	58	48
	Dwb Cold-dry winter-warm summer	88,949	2,735 (3.07)	16	15

* Climate types and descriptions followed the updated Köppen-Geiger climate classification.

[†] Percentages are calculated from participants' number of all singleton births during the warm season (April to October) in China in each category of climate types.

[§] Two sampled counties covered both arid BSk and cold Dwa climate types.

CI: 1.03–1.51) to 1.37 (95% *CI*: 1.05–1.77)]. Additionally, for pregnant women exposed to compound heat waves, those living in the arid BWk climate type experienced a higher risk of PTB [AOR range, 1.55 (95% *CI*: 1.21–1.97) to 2.11 (95% *CI*: 1.35–3.31)].

Previous studies have examined the association between extreme heat exposure during pregnancy and PTB. These studies exploring associations in the last week before delivery have observed stronger associations in hot-dry/mixed-dry climate zones in the US, with a relative risk of 1.057 (95% *CI*: 1.030–1.083), and in comparative hot areas of China, with an AOR of 1.069 (95% *CI*: 1.010–1.132) (3,10). Another study conducted in China found AORs of 2.48 (95% *CI*: 2.37–2.59), 1.62 (95% *CI*: 1.36–1.93), and 1.39 (95% *CI*: 1.33–1.46) for PTB in temperate, tropical, and subtropical zones (4), respectively, when exposed to extreme heat throughout the entire pregnancy. Studies mentioned above reported climatic zonal disparities; meanwhile, the AOR of PTB was higher with extreme heat exposure during the entire pregnancy than in the last week before delivery. In comparison to the risk of PTB associated with exposure to heat waves nationwide in China, AORs ranging from 1.02 (95% *CI*: 1.00–1.03) to 1.04

(95% *CI*: 1.01–1.07) for compound heat waves and AORs ranging from 1.03 (95% *CI*: 1.01–1.05) to 1.04 (95% *CI*: 1.01–1.08) for daytime-only heat waves (7), our findings provide further evidence of higher associations in specific climate types compared to nationwide estimates.

The association between acute prenatal exposure and PTB is still unclear. Heat-induced PTB can occur due to heat-related dehydration, impaired body temperature regulation, and cardiovascular changes (11–12). Differences in the impact of heat on health across geographic regions may be explained by physiological adaptations and adaptive capacities at the individual and community levels, including behavioral, infrastructure, and technological adaptations (3,13–14). Our research suggests that lower levels of physiological, behavioral, and technological adaptations in arid climates and during daytime-only heat waves in tropical regions may contribute to the observed findings. Further investigation into the climatic variations of heat-induced PTB could shed light on the underlying mechanisms and inform the development of adaptation services to reduce risks for pregnant women exposed to extreme temperatures.

Our study has several strengths. First, we used finer domains to determine localized heat extremes by

TABLE 2. Summary of climate zonal heat waves in the warm season during 2012–2019.

Köppen-Geiger Climate Types													
Heatwave definitions*													
Tropical				Arid				Temperate				Cold	
Types	Indexes	Cut off Tmax† (°C)	Cut off Tmin† (°C)	Heatwave days/site/ year§ (%)	Cut off Tmax† (°C)	Cut off Tmin† (°C)	Heatwave days/site/ year§ (%)	Cut off Tmax† (°C)	Cut off Tmin† (°C)	Heatwave days/site/ year§ (%)	Cut off Tmax† (°C)	Cut off Tmin† (°C)	Heatwave days/site/ year§ (%)
Daytime- only heat wave	75th-D2	32.98	17.95	18.50 (8.64)	26.25	18.13	26.40 (12.34)	29.54	17.96	22.53 (10.53)	25.59	17.47	22.57 (10.55)
	75th-D3	32.98	17.95	11.92 (5.57)	26.25	18.13	15.84 (7.40)	29.54	17.96	14.07 (6.57)	25.59	17.47	12.75 (5.96)
	75th-D4	32.98	17.95	8.48 (3.96)	26.25	18.13	9.17 (4.28)	29.54	17.96	9.16 (4.28)	25.59	17.47	7.63 (3.57)
	90th-D2	33.88	19.50	13.34 (6.23)	28.24	19.57	13.23 (6.18)	31.24	19.35	12.85 (6.01)	27.64	18.84	11.35 (5.30)
	90th-D3	33.88	19.50	8.20 (3.83)	28.24	19.57	6.87 (3.21)	31.24	19.35	7.16 (3.35)	27.64	18.84	5.65 (2.64)
Nighttime- only heat wave	90th-D4	33.88	19.50	5.58 (2.61)	28.24	19.57	3.64 (1.70)	31.24	19.35	4.03 (1.88)	27.64	18.84	2.79 (1.30)
	75th-D2	32.98	17.95	36.16 (16.90)	26.25	18.13	26.55 (12.41)	29.54	17.96	21.09 (9.85)	25.59	17.47	22.38 (10.46)
	75th-D3	32.98	17.95	23.99 (11.21)	26.25	18.13	14.93 (6.98)	29.54	17.96	11.88 (5.55)	25.59	17.47	11.85 (5.54)
	75th-D4	32.98	17.95	16.74 (7.82)	26.25	18.13	8.95 (4.18)	29.54	17.96	6.66 (3.11)	25.59	17.47	6.14 (2.87)
	90th-D2	33.88	19.50	23.35 (10.91)	28.24	19.57	12.67 (5.92)	31.24	19.35	11.35 (5.30)	27.64	18.84	10.21 (4.77)
Compound heat wave	90th-D3	33.88	19.50	14.65 (6.84)	28.24	19.57	6.55 (3.06)	31.24	19.35	6.03 (2.82)	27.64	18.84	4.76 (2.23)
	90th-D4	33.88	19.50	8.78 (4.10)	28.24	19.57	3.28 (1.53)	31.24	19.35	3.08 (1.44)	27.64	18.84	2.17 (1.02)
	75th-D2	32.98	17.95	49.45 (23.11)	26.25	18.13	20.25 (9.46)	29.54	17.96	30.77 (14.38)	25.59	17.47	22.36 (10.45)
	75th-D3	32.98	17.95	41.01 (19.16)	26.25	18.13	14.07 (6.57)	29.54	17.96	23.76 (11.10)	25.59	17.47	15.31 (7.15)
	75th-D4	32.98	17.95	35.34 (16.51)	26.25	18.13	9.62 (4.49)	29.54	17.96	17.44 (8.15)	25.59	17.47	9.96 (4.65)
Compound heat wave	90th-D2	33.88	19.50	19.44 (9.09)	28.24	19.57	4.39 (2.05)	31.24	19.35	9.66 (4.52)	27.64	18.84	5.67 (2.65)
	90th-D3	33.88	19.50	13.94 (6.52)	28.24	19.57	2.33 (1.09)	31.24	19.35	6.47 (3.02)	27.64	18.84	2.88 (1.34)
	90th-D4	33.88	19.50	11.42 (5.34)	28.24	19.57	1.31 (0.61)	31.24	19.35	4.25 (1.98)	27.64	18.84	1.59 (0.74)

* 18 definitions of heat waves with three types, daytime-only (only daily maximum temperature exceeds thresholds), nighttime-only (only daily minimum temperature exceeds thresholds), and compound (both daily maximum and minimum temperature exceeds thresholds) heat waves, and six indexes, 75th-D2, 75th-D3, 75th-D4, 90th-D2, 90th-D3, and 90th-D4 (periods equal to or more than two, three, or four consecutive days above the daily thresholds of temperature as 75th or 90th percentiles).

† Tmax, daily maximum temperature; Tmin, daily minimum temperature.

§ Percentages are calculated using 214 days in the warm season (April to October) as the denominator.

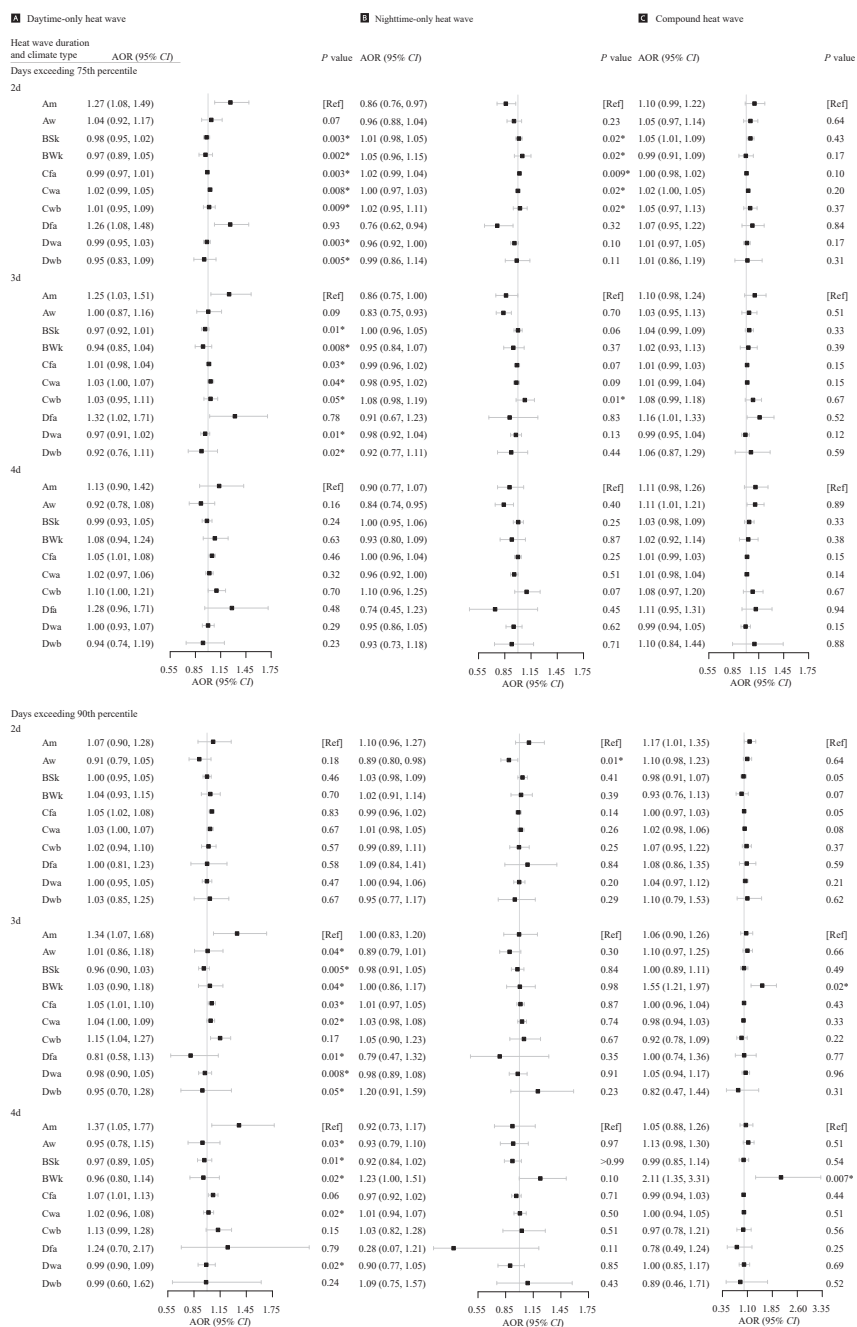


FIGURE 1. AORs of preterm birth associated with heat waves during the last week before delivery among climate types.

Note: 18 definitions of heat waves with three types, daytime-only (only daily maximum temperature exceeds thresholds), nighttime-only (only daily minimum temperature exceeds thresholds), and compound (both daily maximum and minimum temperature exceeds thresholds) heat waves, and six indexes, 75th-D2, 75th-D3, 75th-D4, 90th-D2, 90th-D3, and 90th-D4 (periods equal to or more than two, three, or four consecutive days above the daily thresholds of temperature as 75th or 90th percentiles). Climate types and descriptions followed the updated Köppen-Geiger climate classification. All models adjusted moving average of relative humidity and $PM_{2.5}$ in the last gestational week (lag06), calculated across the time window, using a natural cubic spline with 3 *df*. We examined the climate zonal variation with an interaction term of heatwave exposure variable and climate types' category variable.

Abbreviation: Ref=reference; AOR=adjusted odds ratios; CI=confidence interval; Am=Tropical-monsoon; Aw=Tropical-savannah; BSk=Arid-steppe-cold; BWk=Arid-desert-cold; Cfa=Temperate-fully humid-hot summer; Cwa=Temperate-dry winter-hot summer; Cwb=Temperate-dry winter-warm summer; Dfa=Cold-fully humid-hot summer; Dwa=Cold-dry winter-hot summer; Dwb=Cold-dry winter-warm summer.

* Statistically significant.

utilizing the 25-km radius surrounding each health facility. This allowed us to accurately assess temperature distribution and percentiles. Additionally, we incorporated considerations for human climate adaptation in various climate types by utilizing the temperature distribution from the recent climate state period (1981–2010) as a reference for defining threshold values in each domain. Second, we conducted an analysis of the disparities in heat wave-related preterm births across different climate types. We examined 18 different definitions of heat waves and utilized a comprehensive national sampling database that covered ten diverse climate types. Our findings contribute to the global heat-PTB studies using unified climate classification.

The study has certain limitations that should be acknowledged. First, the study only obtained the delivery hospital addresses of pregnant women from the NMNMSS database. The climate type for each pregnant woman was determined based on the addresses of the delivery health facilities. Although efforts were made to reduce misclassification by calculating the mean grid from a 25-km radius around each address, there may still be potential exposure misclassification. Second, this study is exploratory in nature, specifically investigating the associations between heat waves and PTB in different climate types. Further research is needed to validate these findings.

In conclusion, this study conducted at a national level found that pregnant women residing in arid BWk climate types were at a higher risk of PTB when exposed to compound heat waves during the final week before delivery. Similarly, in tropical regions with an Am climate type, exposure to daytime-only heat waves was associated with an increased risk of PTB. These findings underscore the need for the implementation of heat-PTB prevention strategies that take into account the climate disparities between regions.

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REFERENCES

- Chersich MF, Pham MD, Areal A, Haghighi MM, Manyuchi A, Swift CP, et al. Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths: systematic review and meta-analysis. *BMJ* 2020;371:m3811. <http://dx.doi.org/10.1136/bmj.m3811>.
- Zhang YQ, Yu CH, Wang L. Temperature exposure during pregnancy and birth outcomes: an updated systematic review of epidemiological evidence. *Environ Pollut* 2017;225:700–12. <http://dx.doi.org/10.1016/j.envpol.2017.02.066>.
- Sun SZ, Weinberger KR, Spangler KR, Eliot MN, Braun JM, Wellenius GA. Ambient temperature and preterm birth: a retrospective study of 32 million US singleton births. *Environ Int* 2019;126:7–13. <http://dx.doi.org/10.1016/j.envint.2019.02.023>.
- Wang YY, Li Q, Guo YM, Zhou H, Wang QM, Shen HP, et al. Ambient temperature and the risk of preterm birth: a national birth cohort study in the mainland China. *Environ Int* 2020;142:105851. <http://dx.doi.org/10.1016/j.envint.2020.105851>.
- Kent ST, McClure LA, Zaitchik BF, Smith TT, Gohlke JM. Heat waves and health outcomes in Alabama (USA): the importance of heat wave definition. *Environ Health Perspect* 2014;122(2):151–8. <http://dx.doi.org/10.1289/ehp.1307262>.
- Chen Y, Zhai PM. Revisiting summertime hot extremes in China during 1961–2015: overlooked compound extremes and significant changes. *Geophys Res Lett* 2017;44(10):5096–103. <http://dx.doi.org/10.1002/2016GL072281>.
- Guo YF, Chen PR, Xie YX, Wang YP, Mu Y, Zhou RB, et al. Association of daytime-only, nighttime-only, and compound heat waves with preterm birth by urban-rural area and regional socioeconomic status in China. *JAMA Netw Open* 2023;6(8):e2326987. <http://dx.doi.org/10.1001/jama.2023.26987>.

- org/10.1001/jamanetworkopen.2023.26987.
8. Climatologies at high resolution for the earth's land surface areas. 1 km global Köppen–Geiger climate classification for present and future. <https://chelsa-climate.org/1-km-global-koppen-geiger-climate-classification-for-present-and-future/>. [2021-11-18].
 9. Richardson DB, Cole SR, Chu HT, Langholz B. Lagging exposure information in cumulative exposure-response analyses. *Am J Epidemiol* 2011;174(12):1416 – 22. <http://dx.doi.org/10.1093/aje/kwr260>.
 10. Guo TJ, Wang YY, Zhang HG, Zhang Y, Zhao J, Wang Y, et al. The association between ambient temperature and the risk of preterm birth in China. *Sci Total Environ* 2018;613-614:439 – 46. <http://dx.doi.org/10.1016/j.scitotenv.2017.09.104>.
 11. Bouchama A, Abuyassin B, Lehe C, Laitano O, Jay O, O'Connor FG, et al. Classic and exertional heatstroke. *Nat Rev Dis Primers* 2022;8(1):8. <http://dx.doi.org/10.1038/s41572-021-00334-6>.
 12. Ebi KL, Capon A, Berry P, Broderick C, de Dear R, Havenith G, et al. Hot weather and heat extremes: health risks. *Lancet* 2021;398(10301):698 – 708. [http://dx.doi.org/10.1016/S0140-6736\(21\)01208-3](http://dx.doi.org/10.1016/S0140-6736(21)01208-3).
 13. Basagaña X, Michael Y, Lensky IM, Rubin L, Grotto I, Vadislavsky E, et al. Low and high ambient temperatures during pregnancy and birth weight among 624,940 singleton term births in Israel (2010–2014): an investigation of potential windows of susceptibility. *Environ Health Perspect* 2021;129(10):107001. <http://dx.doi.org/10.1289/EHP8117>.
 14. Hondula DM, Balling RC, Vanos JK, Georgescu M. Rising temperatures, human health, and the role of adaptation. *Curr Clim Change Rep* 2015;1(3):144 – 54. <http://dx.doi.org/10.1007/s40641-015-0016-4>.

SUPPLEMENTARY MATERIAL

Definition of Heat Waves

We used a three-step process to calculate daily binary variables indicating heatwave day of 18 definitions (three types in six indexes) of heat waves within each health facility's 25 km radius domain during the study period 2012–2019. Firstly, we collected daily Tmax and Tmin for the study period from 1981–2010 and 2012–2019. Second, we calculated daily thresholds, either the 75th or 90th percentile of Tmax or Tmin, within each health facility's 25 km radius domain, using the reference period of 1981–2010. Third, we identified daily indicators for 18 different heatwave definitions for each domain during the study period from 2012–2019.

Daily thresholds were determined using a reference period of 1981–2010. To calculate the thresholds, we considered a window of seven days before and seven days after the target day, resulting in a set of 15 temperature values for each day in each year of the reference period. This generated a total of 450 temperature values, which were used as the reference windows for each day. Percentiles were then calculated for each set of 450 values to establish the daily thresholds.

$$TX_d = \bigcup_{y=1981}^{2010} \bigcup_{i=d-7}^{d+7} Tmax_{y,i}$$

$$TN_d = \bigcup_{y=1981}^{2010} \bigcup_{i=d-7}^{d+7} Tmin_{y,i}$$

For a given day d in a grid cell, the threshold, TX_d and TN_d are defined as the 75th, or 90th percentile of daily maximum or minimum temperature, centered on a 15-day window (seven days prior and seven days later to a specific day) in the reference period 1981–2010, which has 15 multiply 30 equals to 450 samples.

Where \bigcup denotes the union of 450 sample sets for the given day d ;

$Tmax_{y,i}$ is the daily Tmax of the day i in the year y ;

$Tmin_{y,i}$ is the daily Tmin of the day i in the year y .

SUPPLEMENTARY TABLE S1. Climate types of sampled sites of NMNMSS in 30 PLADs and representative cities

No	PLADs	Climate types			Representative cities	
1	Anhui	C	Cfa	Hefei	Wuhu	Anqing
2	Anhui	C	Cwa	Huainan	Fuyang	Suzhou
3	Beijing	B, D	BSk, Dwa	Beijing		
4	Chongqing	C	Cfa, Cwa	Chongqing		
5	Fujian	C	Cfa	Fuzhou	Sanming	Zhangzhou
6	Gansu	B	BSk	Lanzhou	Pingliang	Qingyang
7	Gansu	B	BWk	Baiyin		
8	Gansu	D	Dwb	Pingliang		
9	Gansu	C	Cwa	Longnan		
10	Guangdong	C	Cfa	Shaoguan	Meizhou	Qingyuan
11	Guangdong	C	Cwa	Foshan	Maoming	Jieyang
12	Guangxi	C	Cwa	Nanning	Beihai	Fangchenggang
13	Guangxi	C	Cfa	Liuzhou	Guilin	Wuzhou
14	Guizhou	C	Cfa	Guiyang	Zunyi	Tongren
15	Guizhou	C	Cwa	Guiyang	Bijie	
16	Guizhou	C	Cwb	Liupanshui	Qianxinan	
17	Hainan	A	Aw	Haikou	Sanya	
18	Hainan	A	Am	Qionghai	Ding'an	
19	Hebei	B	BSk	Shijiazhuang	Xingtai	Baoding

Continued

No	PLADs	Climate types		Representative cities		
20	Hebei	D	Dwa	Tangshan	Qinhuangdao	Handan
21	Heilongjiang	D	Dwa	Harbin	Qiqihar	
22	Heilongjiang	D	Dwb	Jiamusi	Mudanjiang	Shuangyashan
23	Henan	C	Cwa	Zhengzhou	Kaifeng	Luoyang
24	Henan	D	Dwa	Anyang		
25	Henan	B	BSk	Jiyuan		
26	Hubei	C	Cfa	Wuhan	Xiangyang	Jingmen
27	Hubei	C	Cwa	Shiyan	Yichang	Enshi
28	Hunan	C	Cfa	Changsha	Zhuzhou	Xiangtan
29	Inner Mongolia	B	BSk	Huhhot	Ordos	Bayan Nur
30	Inner Mongolia	D	Dwa	Huhhot	Hinggan	
31	Inner Mongolia	D	Dwb	Hulun Buir		
32	Jiangsu	C	Cfa	Nanjing	Wuxi	Nantong
33	Jiangsu	C	Cwa	Xuzhou	Lianyungang	Yancheng
34	Jiangxi	C	Cfa	Nanchang	Jingdezhen	Pingxiang
35	Jilin	D	Dwa	Changchun	Jilin	Siping
36	Jilin	D	Dwb	Jilin	Baishan	Yanbian
37	Jilin	B	BSk	Baicheng		
38	Liaoning	D	Dwa	Shenyang	Dalian	Fushun
39	Liaoning	B	BSk	Chaoyang		
40	Ningxia	B	BWk	Yinchuan	Shizuishan	Wuzhong
41	Ningxia	B	BSk	Wuzhong	Guyuan	Zhongwei
42	Ningxia	D	Dwb	Guyuan		
43	Qinghai	B	BSk	Xining	Hainan	
44	Qinghai	D	Dwb	Haidong		
45	Shaanxi	C	Cwa	Xi'an	Baoji	Hanzhong
46	Shaanxi	B	BSk	Weinan	Yulin	
47	Shandong	D	Dwa	Jinan	Weifang	Weihai
48	Shandong	C	Cwa	Yantai	Rizhao	
49	Shanghai	C	Cfa	Shanghai		
50	Shanxi	B	BSk	Taiyuan	Jincheng	Shuozhou
51	Shanxi	D	Dwa	Yangquan	Changzhi	Yuncheng
52	Sichuan	C	Cwa	Chengdu	Zigong	Deyang
53	Sichuan	C	Cwb	Liangshan		
54	Tianjing	B, D	BSk, Dwa	Tianjing		
55	Xinjiang	D	Dfa	Urumqi	Lli	
56	Xinjiang	B	BSk	Urumqi	Changji	Lli
57	Xinjiang	B	BWk	Turpan	Bayingol	Kizilsu Krigiz
58	Yunnan	C	Cwb	Kunming	Qujing	
59	Yunnan	C	Cwa	Yuxi	Puer	Wenshan
60	Zhejiang	C	Cfa	Hangzhou	Ningbo	Wenzhou

Abbreviation: NMNMSS=National Maternal Near Miss Surveillance System; PLADs=provincial level administration divisions; A=Tropical; Am=Tropical-monsoon; Aw=Tropical-savannah; B=Arid; BSk=Arid-steppe-cold; BWk=Arid-desert-cold; C=Temperate; Cfa=Temperate-fully humid-hot summer; Cwa=Temperate-dry winter-hot summer; Cwb=Temperate-dry winter-warm summer; D=Cold; Dfa=Cold-fully humid-hot summer; Dwa=Cold-dry winter-hot summer; Dwb=Cold-dry winter-warm summer.