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Country-level impact of climate change on maternal and newborn health: Associations between temperature, precipitation, maternal mortality, stillbirth, and neonatal mortality in the Democratic Republic of the Congo

Carrie J. Ngongo [a,*], Donal Bisanzio [a], Gabriella Corrigan [a], Karl B. Angendu [b,c], Alisha Smith-Arthur [a], Brian Hutchinson [a], Pierre Akilimali [b,d]

[a] Global Health Division, RTI International, Research Triangle Park, USA
[b] The Democratic Republic of Congo National Public Health Institute, Kinshasa, Democratic Republic of the Congo
[c] Inserm U1094, IRD UMR270, CHU Limoges, EpiMaCT—Epidemiology of Chronic Diseases in Tropical Zone, Institute of Epidemiology and Tropical Neurology, OmegaHealth, Univ. Limoges, Limoges, France
[d] Patrick Kayembe Research Center, Kinshasa School of Public Health, University of Kinshasa, Kinshasa, Democratic Republic of the Congo

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ABSTRACT

Background: Evidence connecting extreme heat to maternal and newborn health outcomes is needed at country level, especially in tropical areas. DHIS2 (District Health Information Software 2) collects aggregated population health data by health zone in the Democratic Republic of the Congo (DRC).

Methods: Drawing from DHIS2 records of 22·7 million DRC births 2018–2023, spatio-temporal modeling assessed associations between maternal mortality, stillbirth, and neonatal mortality and same-month, remotely sensed temperature, precipitation, anomalous high temperature (>95th percentile), and anomalous heavy precipitation (>95th percentile), controlling for month, year, remoteness, and health zone.

Findings: Temperatures > 34 °C and anomalous heavy precipitation were strongly associated with increases in same-month stillbirth and maternal mortality and less strongly associated with neonatal mortality. The stillbirth rate rose by 2·3/1,000 births for every degree increase above 34 °C (95% CI: 1·9; 2·5) or by 5·9/1,000 births in months > 95th percentile (32·9 °C; 95% CI: 5·1; 6·7). Maternal mortality rose by 27·3 deaths/100,000 live births for every degree increase above 34 °C (95% CI: 19·1; 35·7) or by 95·3 deaths/100,000 live births in months > 95th percentile (95% CI: 71·3; 119·4). Months with anomalous heavy precipitation were associated with an increase of 5·4 stillbirths/1,000 births (95% CI: 4·8; 6·2) and with 120 maternal deaths/100,000 live births (95% CI: 100·9; 139·5).

Interpretation: DHIS2 data offer a readily available opportunity to assess associations between climate and country-level population health outcomes. Further work is needed to hone and evaluate effective approaches that protect mothers and newborns in the face of projected warming and rainfall changes. Risk-based planning, geographic targeting, and stakeholder coordination will support appropriate, context-specific responses.

1. Introduction

Pregnant women, developing fetuses, and neonates are particularly vulnerable to heat stress and flooding.(Kuehn and McCormick, 2017) Maternal exposure to elevated environmental temperatures has been shown to increase the risk of preterm birth, low birth weight, and stillbirths.(Nyadanu et al., 2024; Weeda et al., 2024) One systematic review and *meta*-analysis reported that heat wave exposure increased the risk of preterm birth by an average of 60 percent, constituting the most significant impact of climate on child health.(Weeda et al., 2024) Relationships between heatwaves and preterm birth have been more widely investigated than the associations between heat and maternal mortality, stillbirth, and neonatal mortality.(McElroy et al., 2022) Epidemiological studies of heavy precipitation typically focus on infectious diseases rather than maternal and newborn health outcomes, but gestational flood exposure has been associated with an 8 percent increase in the odds of pregnancy loss.(He et al., 2024) While a growing body of research has analyzed the role of extreme heat in maternal and

* Corresponding author at: RTI International, 3040 E Cornwallis Road, PO Box 12194, Research Triangle Park, NC 27709, USA.
E-mail address: cngongo@gmail.com (C.J. Ngongo).

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newborn health outcomes, more evidence is needed at country level, especially in tropical and sub-tropical areas.(Chersich et al., 2020; Li et al., 2023; Weeda et al., 2024) No studies of environmental heat, precipitation, and maternal and newborn outcomes have previously been conducted in the Democratic Republic of the Congo (DRC).

The DRC is the largest country in equatorial Africa and has a population of over 105 million people. The DRC ranks low in global climate adaptation indices even as it experiences a surge of climate-related disasters including floods and droughts.(World Bank Group, 2023) Across varied topography and diverse regions, the overall nationwide mean temperature in DRC is projected to increase from historical means by 1-2·5 °C by 2050.(World Bank Group, 2023) Heavy rainfall indicators, such as the maximum one-day rainfall and the count of days when rainfall is ≥ 20 mm, are also projected to increase over the medium term (2035–2060).(Bangelesa et al., 2023) At the same time, increased evaporation is projected to increase drought frequency.(Karam et al., 2022) There is an urgent need to improve our understanding of the impacts of the changing climate on population health to inform adaptive strategies to save lives.

While maternal mortality in DRC fell 22 percent from 2000 to 2020, more than seven percent of global maternal deaths occur in DRC, for an estimated 547 maternal deaths/100,000 live births in 2020.("Trends in maternal mortality 2000 to 2020: estimates by WHO, UNICEF, UNFPA, World Bank Group and UNDESA/Population Division," 2023) Neonatal mortality rates have improved over the same time period—declining by nearly one-third—to roughly 100,000 neonatal deaths occurring each year.(UN Inter-agency Group for Child Mortality Estimation., 2022a) With an estimated 27 neonatal deaths/1,000 live births in 2021, however, the decline is not on pace to meet the United Nations Sustainable Development Goal to reduce neonatal mortality by 2030 to 12 or fewer deaths/1,000 live births.(UN Inter-agency Group for Child Mortality Estimation., 2022b) An estimated 28 stillbirths occur/1,000 births in DRC, for a 2021 estimated annual total of nearly 115,000 stillbirths. (UNICEF, 2023).

In view of the imperative to improve maternal and neonatal health outcomes and the projected changes in temperature and precipitation, this study aimed to examine the available data infrastructure and assess associations to better understand how climate factors may inhibit progress on population-level maternal and perinatal health. Building the evidence base with data from tropical regions can help to inform discussions regarding appropriate policy responses. We used population health data from DRC's platform for aggregated health information, DHIS2 (District Health Information Software 2, developed by the Health Information Systems Programme). Recognizing the lack of universally accepted definitions related to heat exposure, we focused on ongoing high temperatures, anomalous high temperatures, precipitation, and anomalous heavy precipitation.(Baharav et al., 2023) We hypothesized that anomalous high temperatures and heavy precipitation are drivers of maternal and perinatal mortality in the Congolese population.

2. Methods

This analysis used routinely collected national data on maternal mortality, stillbirth, and neonatal mortality aggregated monthly by health zone from 2018 to 2023. Remote sensing surveys provided monthly temperature and precipitation data at health zone level. We built non-linear statistical models to assess associations between temperature, precipitation, anomalous high temperature, and anomalous heavy precipitation and the outcomes of maternal mortality, stillbirth, and neonatal mortality.

The DRC collects routine, national health data using DHIS2. Health facilities collect and report on health events on their premises and in their catchment areas. Paper-based records are sent to health zone offices, where facility-level data is aggregated and entered in the electronic national health information system. The DRC National Public Health Institute provided health-zone level monthly DHIS2 data on maternal and newborn outcomes January 2018-December 2023. Indicators included counts of births, live births, stillbirths, neonatal deaths (0–28 days), and maternal deaths reported in health facilities using World Health Organization indicator definitions.(CHIS - Newborn Health, 2022; Indicators, 2021).

Data quality assessments were conducted using health zone and province-level data.(Amouzou et al., 2022) Districts exhibiting problematic reporting rates and inconsistencies were identified for additional scrutiny and, if necessary, rectifications. Facility reporting completeness, defined as the ratio of facilities that submitted data for a specific month to the total number of facilities anticipated to report, influenced the quantity of reported events and was evaluated at health zone level. Each province summarized the percentage of health zone-months with facility reporting rates below 90% and enumerated all health zone-months with facility reporting rates below 75%. In this instance, the median value for the calendar year was assigned to the month. For all remaining districts, we accounted for incomplete reporting by evaluating the reporting completeness of facilities and the anticipated service provision level from non-reporting facilities. For the latter, we employed an adjustment factor between 0 and 1, where 1 indicates a service level comparable to reporting facilities, and 0 assumes that non-reporting facilities rendered no services.(Maina et al., 2017) The determination of this adjustment factor was informed by an understanding of service provision and the distribution of facilities within each province. In the majority of provinces, the default adjustment factor of 0.25 was established following deliberations among the province team regarding the most suitable factor for each intervention. In instances of absent values, the median value for the calendar year was utilized, unless there was justification to consider it a true zero.

Extreme outliers were discovered using a modified Z-score, a standardized measure of observations that quantifies deviation from the median by dividing the difference from the median by the median absolute deviation. Monthly data exhibiting a score over 5 standard deviations from the annual median were classified as extreme outliers. (World Health Organization, 2017) Corrections were made by imputing a value derived from the median of the calendar year. Additional information about data completeness and cleaning is available in **Supplemental File 1**.

Monthly mean land surface temperature (LST) satellite images were obtained from NASA's Terra Moderate resolution Imaging Spectrometer (MODIS) as rasters with a resolution of 0.05 degrees. We downloaded monthly LST MODIS rasters from 2013 to 2023 to provide data for our study period (2018–2023) and establish a history of temperature fluctuations. Consistent daily data were not available due to cloud cover. We applied a zonal statistic procedure to calculate the mean monthly temperatures in Celsius degrees for each of the 519 health zone boundaries, averaging across all raster values lying in each health zone.

We downloaded 2013–2023 monthly precipitation raster images at a resolution of 2·5 degrees from the Global Precipitation Climatology Center (GPCC).(National Center for Atmospheric Research Staff (Eds), 2024) A zonal-statistic approach was applied to average the values of each image pixels contained in each health zone boundary.

Health zone remoteness was approximated by the mean time to reach a city with a population of > 50,000 people using the 2019 friction maps provided by the Malaria Atlas Project.(Malaria Atlas Project, 2022; Weiss et al., 2018).

Linear trends of health and weather indicators were estimated using generalized linear models (GLMs) in which the indicator was set as dependent variable and the independent variable was the month number (1–72). Generalized additive mixed models (GAMMs) investigated relationships using the formula:

$$INDICATOR = TEMP + RAIN + (TEMP*RAIN) + MONTH + YEAR \\ + DIST + HEALTH\ ZONE_{rnd}$$

where INDICATOR was maternal mortality, stillbirth, or neonatal mortality, RAIN was health zone monthly precipitation, TEMP was mean monthly temperature, (TEMP*RAIN) was the interaction between monthly precipitation and temperature, MONTH was the year's month (from January to December), YEAR was the year, DIST was the health zone's mean travel time to a city with > 50,000 people, and HEALTH $ZONE_{rnd}$ captured health zone differences as an unstructured random effect.(Wood, 2017) All numeric covariates were included as non-linear effects. Given the possible lag effect of temperature and precipitation on health indicators, we tested all possible monthly lags between 0 and 8 months. We used the Akaike information criteria (AIC) to select the best temporal lag describing the relationship between health indicators and weather indicators.

Separate GAMMs investigated the association between health outcomes, anomalous high temperatures, and anomalous heavy precipitation. The model formula was similar except that TEMP and RAIN were substituted by dichotomous variables indicating months with and without anomalous high temperature or precipitation. We assessed 8 potential time lags (0–8 months) and selected the model with the lowest AIC. We tested thresholds of 90th, 95th, and 99th percentiles for historical (11-year) mean temperature and precipitation. At the 90th percentile, modeling did not identify associations, perhaps because this threshold defined too much as "anomalous." The 99th percentile did not include enough data for the model to converge. This approach relied on the statistical distribution of monthly health, temperature, and precipitation data. We defined anomalous high temperature as months at or above the 95th percentile of the historical (11-year) mean temperature. Months at or above the 95th percentile of national-level historical precipitation were flagged as experiencing anomalous heavy precipitation.

The Getis-Ord G_i* local spatial clustering test was used to identify health zone hotspots of maternal mortality, stillbirths, neonatal mortality, anomalous heat, and anomalous precipitation.(Waller and Gotway, 2004) The significance of the computed G_i* was estimated by comparing observed values to the random value distribution (null hypothesis) by randomly reassigning values to the health zones. The statistical significance calculation was based on 10,000 Monte Carlo randomizations setting significant threshold to $p < 0{\cdot}05$, with spatial weights base on queen contiguity.(Waller and Gotway, 2004).

Geographical data were processed using GRASS and QGIS geographical information systems (GISs). Health data was cleaned and compiled in Stata. Statistical analyses were performed using R language through the RStudio platform, with code available at https://github.com/dadedodo/DRC-maternal-neonatal-and-climate/tree/main. RTI International (Research Triangle Institute International) funded this work.

3. Results

DHIS2 reported 22·7 million births between 2018 and 2023, with 253,178 stillbirths, 86,962 neonatal deaths, and 35,136 maternal deaths registered in facilities (Table 1). National maternal mortality, stillbirth, and neonatal mortality rates all declined 2018–2023, even as live births increased. Rates varied substantially across health zones (Fig. 1). Statistically significant hotspots for all three indicators were identified in the northeast (Bas-Uele, Haut-Uele, and Ituri Provinces) and west (Kinshasa and Kongo-Central provinces). An additional hot spot of stillbirths occurred in the southeast (Haut-Katanga, Haut-Lomami, and Lualaba Provinces).

The maternal mortality ratio and stillbirth rate varied by month of the year with an annual peak between August and November (**Supplemental Fig. 1**). The neonatal mortality rate did not demonstrate seasonality because variability in newborn death mirrored the volume of births, which peaked annually between April and June.

This analysis did not identify much change in mean temperature in DRC 2018–2023, with a national average for the period of 27·9 °C (interquartile range [IQR]: 26·1; 29·5 °C, min 16 °C, max 41·7 °C) (Table 1). The national 95th percentile of monthly temperature was

Table 1
Births, stillbirths, neonatal mortality, maternal mortality and temperature, precipitation in DRC, 2018–2023.

DHIS Data registered in facilities	2018	2019	2020	2021	2022	2023	Total
Total births	3,279,800	3,496,211	3,759,033	3,757,424	4,173,177	4,238,041	22,703,686
Total live births	3,248,352	3,465,818	3,726,446	3,754,491	4,167,735	4,234,639	22,597,481
Total stillbirths (per 1,000 births)	42,197 (12·9)	42,374 (12·1)	43,579 (11·6)	42,011 (11·2)	42,236 (10·1)	40,781 (9·6)	253,178 (11·2)
Neonatal deaths (per 1,000 live births)	13,522 (4·2)	13,093 (3·8)	14,613 (3·9)	14,915 (4·0)	15,880 (3·8)	14,939 (3·5)	86,962 (3·8)
Maternal deaths (per 100,000 live births)	5,889 (181·3)	5,919 (170·8)	5,827 (156·4)	5,849 (155·8)	6,046 (145·1)	5,606 (132·4)	35,136 (155·5)
Temperature and precipitation	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Total**
Mean temperature (°C) [IQR]	27·9 (26·1; 29·5)	27·9 (26·2; 29·4)	27·7 (26·0; 29·2)	28·2 (26·4; 29·9)	27·7 (26·0; 29·3)	27·9 (26·0; 29·6)	27·9 (26·1; 29·5)
Months when temperature > 95th percentile of historical mean temperature (32·9°C), % of 12 months x 519 health zones	331 (5·3%)	251 (4·0%)	251 (4·0%)	319 (5·1%)	228 (3·7%)	330 (5·3%)	
Number of health zones experiencing temperatures > 95th percentile of historical mean temperature, % of 519 health zones	121 (23·3%)	91 (17·5%)	101 (19·5%)	117 (22·5%)	96 (18·5%)	111 (21·4%)	
Precipitation (mm) [IQR]	1,431 (1,349; 1,698)	1,556 (1,373; 1,727)	1,512 (1,281; 1,739)	1,409 (1,186; 1,697)	1,463 (1,296; 1,709)	1,418 (1,250; 1,674)	1,465 (1,429; 1537)
Months when precipitation > 95th percentile of historical precipitation (233·5 mm), % of 12 months x 519 health zones	543 (8·7%)	380 (6·1%)	518 (8·3%)	279 (4·5%)	374 (6·0%)	371 (6·0%)	
Number of health zones experiencing anomalous heavy precipitation, % of 519 health zones	269 (51·8%)	253 (48·7%)	219 (42·2%)	187 (36·0%)	194 (37·4%)	222 (42·8%)	

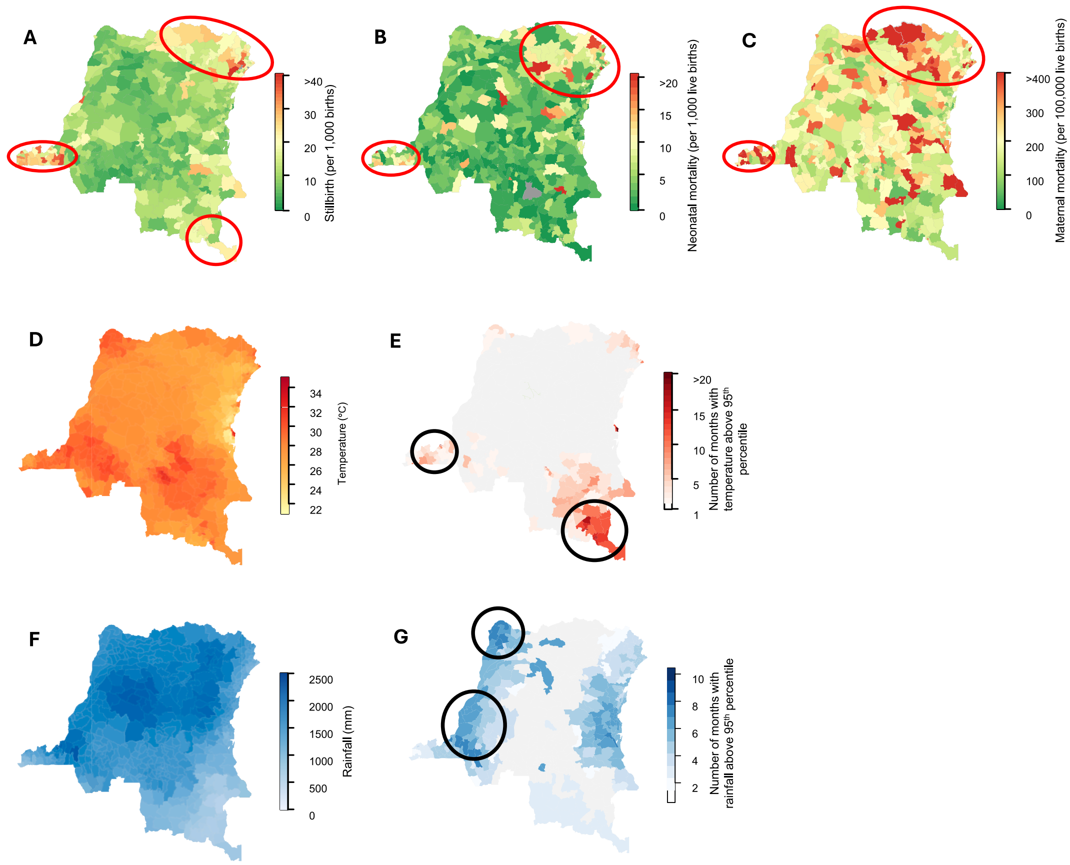

Fig. 1. Geographic variation in mean monthly stillbirth (A), neonatal mortality (B), maternal mortality (C), temperature (D), precipitation (F), anomalous high temperature (E), and anomalous high precipitation (G). Anomalous months had a temperature or precipitation > 95th percentile of historical norm) in DRC, 2018–23. The circles indicate statistically significant hotspots (G^*_I, p < 0,05).

32·9 °C. Hotspots for anomalously hot months included Kinshasa and the southeast (including parts of Haut-Katanga, Haut-Lomami, and Lualaba provinces, Fig. 1). National temperature peaked annually between June and July, the driest months, although this masks geographic variability between areas north and south of the equator (**Supplemental Fig. 2**).

National average precipitation varied over the period with an average of 1,465 mm/year (IQR: 1,429; 1,537 mm, min 1,409 mm, max 1,556 mm) (Table 1). The national 95th percentile for precipitation was 233·5 mm/month. Precipitation peaked twice in the year, between March and April and between October and December (**Supplemental Fig. 2**), with numerous identified hot spots for extreme precipitation (p < 0·05, Fig. 1).

Generalized additive mixed models identified statistical associations between temperature, precipitation, maternal mortality, stillbirth, and neonatal mortality, with linear relationships apparent above 34 °C (Table 2, Fig. 2). Model selection identified that the best description of the association between indicators did not include a time lag or interaction between temperature and rainfall. Among considered indicators, stillbirths demonstrated the strongest association with temperature and precipitation, with the modeled rate rising by 2·3 stillbirths/1,000 births for every degree increase above 34 °C (95% CI: 1·9; 2·5) or by 5·9 stillbirths/1,000 births in months exceeding the 95th percentile of historical mean temperature (95% CI: 5·1; 6·7). Maternal mortality rose by 27·3 deaths/100,000 live births for every degree increase above 34 °C (95% CI: 19·1; 35·7) or by 95·3 deaths/100,000 live births in months exceeding the 95th percentile of historical mean temperature (95% CI: 71·3; 119·4). Temperature associations with neonatal mortality were statistically significant but smaller in size. While our models did identify increases in stillbirth, maternal mortality, and neonatal mortality for every 10 mm increase in precipitation above 300 mm, associations were far stronger in months when precipitation exceeded the 95th percentile

Table 2
Association between high temperature, anomalous high temperature, precipitation, and anomalous heavy precipitation on stillbirth, neonatal mortality, and maternal mortality from generalized additive models adjusted for year, month, health zone remoteness, and health zone random effects.

	Stillbirth (total per 1,000 births)	Neonatal mortality (per 1,000 live births)	Maternal mortality (per 100,000 live births)
Rate increase for every degree above 34 °C (95% CI)	2·3 (1·9; 2·5)	0·6 (0·4; 0·8)	27·3 (19·1; 35·7)
Rate increase when heat exceeds 95th percentile of historical mean temperature (32·9 °C) (95% CI)	5·9 (5·1; 6·7)	1·5 (1·1; 2·1)	95·3 (71·3; 119·4)
Rate increase for every 10 mm above 300 mm (95% CI)	0·5 (0·48; 0·63)	0·2 (0·1; 0·3)	10·2 (8·5; 15·4)
Rate increase when precipitation exceeds 95th percentile of historical precipitation (233·5 mm) (95% CI)	5·4 (4·8; 6·2)	1·9 (1·4; 2·3)	120·2 (100·9; 139·5)

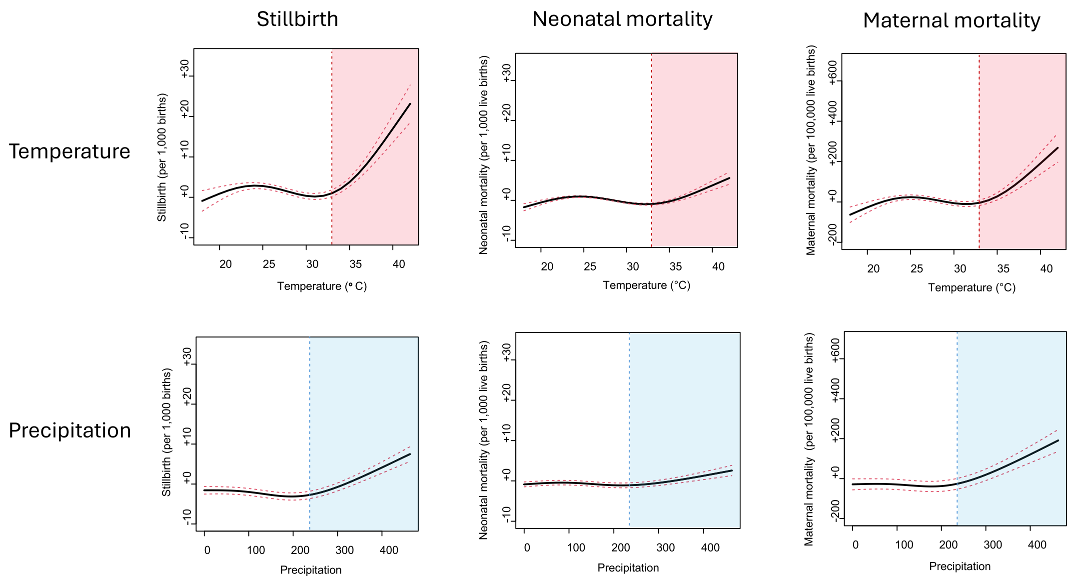

Fig. 2. Association between temperature, precipitation, stillbirths, neonatal mortality, and maternal mortality. The figures show non-linear association resulting from generalized additive mixed models. The red dotted lines represent 95% confidence intervals. Shaded boxes delineate values at or above the 95th percentile of historic norms.

of historical norms. The effect of anomalous heavy precipitation had a similar effect as anomalous high temperature on stillbirth and neonatal mortality. Months with anomalous heavy precipitation were associated with an increase of 120·2 maternal deaths/100,000 live births (95% CI: 100·9; 139·5), an effect even stronger than that observed with anomalous high heat. The deviance explained by all models was above 60%, indicating high explanatory power.

4. Discussion

Temperatures over 34 °C and anomalous heavy precipitation were strongly associated with increases in same-month stillbirth and maternal mortality in this spatio-temporal analysis of national DHIS2 data in the DRC. Although precipitation at typical levels did not have a strong effect on maternal and newborn outcomes, monthly precipitation > 95th percentile had a stronger association with maternal mortality than anomalous high heat, correlating with an increase of 120·2 maternal deaths/100,000 live births (95% CI 100·9; 139·5). Our finding that temperature and precipitation associations were stronger with stillbirth and maternal mortality than with neonatal mortality suggest that heat exposure as a direct environmental factor appears to be less consequential after mother and child have survived birth. The 1-2·5 °C projected increase in DRC average temperature by 2050 would increase the months with mean temperature above 34 °C, translating to likely increases in heat-associated stillbirths and maternal deaths if adaptation and health system response do not meet the challenge.(European Commission, United Nations Environment Programme, 2024; World Bank Group, 2023).

This work adds to a growing evidence base describing the effects of extreme weather on maternal and newborn outcomes. The heat danger threshold for pregnant women has not been well defined. A study from Benin, Malawi, Tanzania, and Uganda reported that pregnant women exposed to high temperatures in the week before childbirth had a 34 percent higher risk of perinatal death, a risk that doubled during the six hottest months of the year and was especially visible in intrapartum stillbirths.(Hanson et al., 2024) Another multi-country analysis reported that the odds of stillbirth were 1·9 times higher for pregnant women exposed to 30 °C temperatures compared to those exposed to 20 °C temperatures in the week preceding birth.(McElroy et al., 2022) An analysis from fifteen African countries modeled that a 10% increase in the proportion of days with maximum temperatures between 100 and 104 °F (37.8–40 °C) would correspond to an increase in the probability of a spontaneous abortion or stillbirth in the second or third trimester of 1·4 percentage points, while a 10% increase in the proportion of days with maximum temperatures over 105 °F (40.5 °C) would correspond to a probability increase of 1·9 percentage points.(Davenport et al., 2020) Pregnancy loss after flood exposure is heightened for women dependent on surface water and with lower income or education levels.(He et al., 2024).

Environmental impacts such as heatwaves and floods on maternal and newborn health may be direct, relating to the physiology of pregnancy, or indirect, reflecting the accessibility of timely care or changes in social conditions. Fetal and placental metabolism, increased body mass, reduced systemic vascular resistance, and physical strain all affect thermoregulation in pregnancy.(Chersich et al., 2020) Hyperthermia can cause oxidative stress, reduce blood flow to the uterus, and trigger central neuroendocrine and inflammatory systems, especially during late pregnancy.(Nyadanu et al., 2024) In mothers, heat exposure has been linked to gestational hypertension and diabetes, placental abruption, cardiovascular disease events, and severe maternal morbidity.(Jiao et al., 2023; Shankar et al., 2023) Previous literature suggests that extreme heat may trigger stillbirth through the decrease in the ratio of body surface area to body mass, dehydration, and birth defects.(McElroy et al., 2022).

Heavy precipitation likely compromises access to safe labor and delivery services, particularly where infrastructure is insufficient. Additional indirect consequences of heavy precipitation may include water scarcity, disrupted food supplies, infectious disease susceptibility, and prenatal maternal stress.(Dancause et al., 2011; He et al., 2024; Suhr and Steinert, 2022) Rainfall frequently tempers heat, increases humidity, and is associated with increases in vector-borne diseases. Malaria in pregnancy is associated with maternal mortality, stillbirth, and neonatal mortality.(Schantz-Dunn and Nour, 2009) During heatwaves people may be less likely to use insecticide-treated bed nets with complaints of poor ventilation, thereby increasing their exposure to malaria-transmitting mosquitoes.

Many maternal deaths in DRC reflect weaknesses in routine quality of care during labor and delivery. Expectant mothers often experience delays in accessing care, although roughly 80 percent of births ultimately occur in health facilities.(Ramazani et al., 2022) Associations

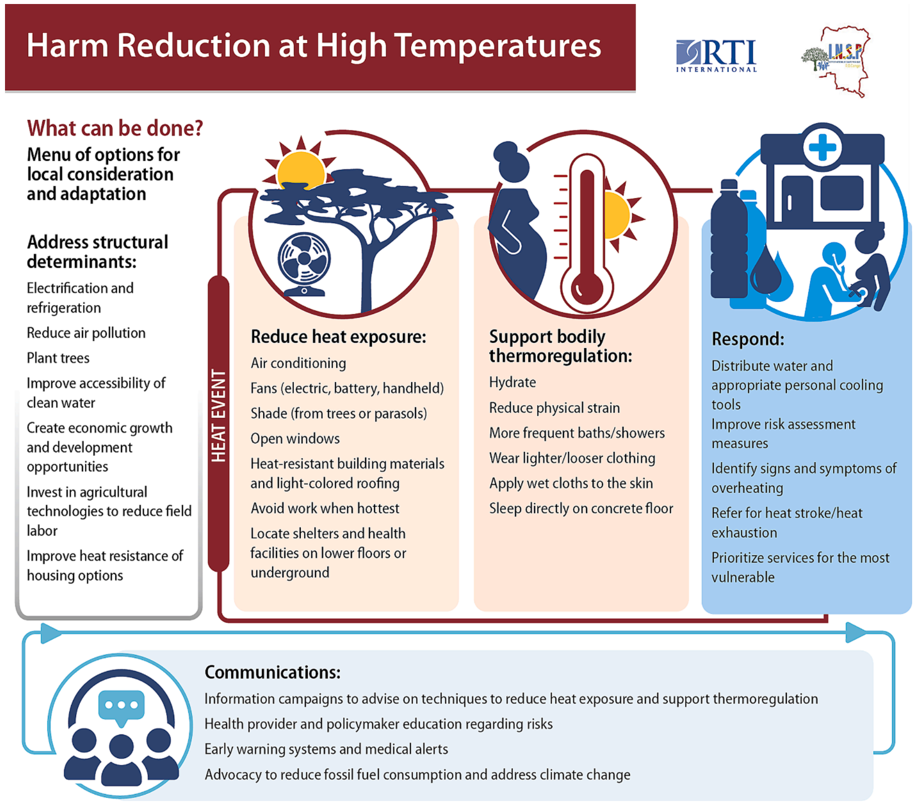

Fig. 3. Options to reduce harm at high temperatures.

between precipitation and maternal and perinatal mortality may reflect changes in socioeconomic activities and family dynamics. Rainy season coincides with fieldwork in DRC, and women may be more likely to carry heavy loads while at the same time receiving less assistance from occupied family members.

Heat- and precipitation-related risks likely vary across subgroups, although this was not possible to distinguish with aggregated data. Pregnant women who are poor, rural, and/or less educated have been reported to be at particular risk of stillbirth following after heatwaves. (McElroy et al., 2022) Women living with chronic conditions or infections may have reduced physiological ability to respond to high temperatures.(Chersich et al., 2020) Some women may be more exposed to the weather through agricultural and other outdoor work. Social vulnerability and poverty may push women to work beyond their heat tolerance limits.(Chersich et al., 2020) Some women may be less able to reduce their exposure because of insecurity, violence, and/or internal displacement.

While there is little consensus regarding the most critical periods for fetal heat sensitivity in late pregnancy, most published associations fall within the "same month" period of our modeling.(Kuehn and McCormick, 2017; McElroy et al., 2022) Our use of aggregated monthly data did not enable precision, but model selection indicated that same-month weather explained identified correlations better than weather occurring in months before the health event.

DHIS2 is a widely employed data solution, offering governments and their allies a readily available opportunity to understand population health trends. Routine DHIS2 data are limited by design, however. DHIS2 provides public facility-recorded data aggregated by month and health zone. We were not able to analyze individual characteristics that may influence risk, such as time spent inside and outside the home, physical activity, hydration, and comorbidities. We did not have data available regarding potential confounders such as socio-economic status or social determinants at health zone or lower levels. DHIS2-reported rates of maternal mortality, stillbirth, and neonatal mortality differ from estimates from the World Health Organization and World Bank, suggesting a challenge of generalized underreporting from DHIS2 not fully capturing events occurring outside of facilities and implying possible underestimation.

While our approach to checking and cleaning DRC DHIS2 data mirrored past efforts, the data remain subject to concerns about completeness and accuracy.(Amouzou et al., 2021) Our dataset was substantial, reflecting outcomes from over 22·7 million births. The timeliness, completeness, and accuracy of DHIS reporting is improving over time, but imputation was necessary for missing and outlier data. Some maternal deaths may have occurred before labor or in the 42 days following birth, timing that isn't captured by DHIS2 and could have affected our lag analysis. We do not have a record of when in the month each event occurred, and events occurring at the end of a month would have experienced more of that month's recorded weather than events at the start of a month. Gestation length was not recorded. We relied on remote-sensing international sources for temperature and precipitation, which were available monthly but not consistently daily due to cloud cover. The use of monthly rather than daily temperature and precipitation data meant that we could not determine thresholds at which health risks are lowest using the minimum mortality temperature method. Temperature alone does not fully represent the ambient thermal environment.(Nyadanu et al., 2024) We did not have access to weather stations or wet-bulb globe temperature data, which captures temperature in direct sunshine, humidity, wind speed, sun angle, and cloud cover. Lastly, our analysis cannot capture causation or the nuance underlying possible associations, such as the possible contributions of heat stress, inaccessible health services, vector exposure, and other factors.

Further research is needed to evaluate the direct and indirect health consequences of heavy precipitation and heatwaves, including how best to enable the maintenance and accessibility of essential health services. Qualitative research approaches could be helpful to identify underlying pathways and to determine appropriate approaches to mitigate risks. In addition, work is needed to identify and assess interventions that reduce risks for pregnant women experiencing extreme temperatures and anomalous heavy precipitation. Context-specific measures must be articulated and tested to mitigate the impacts of exposure to anomalous high heat and heavy precipitation. Very few evaluations of heatwave harm reduction interventions have documented effects on maternal and newborn health outcomes in low- and middle-income countries. Changes to the built environment have been demonstrated to be effective: One facility without air conditioning reduced neonatal intensive care admissions by moving its maternity ward to the ground floor during a heatwave.(Kakkad et al., 2014) Other adjustments to the built environment have been proposed but not yet evaluated in relation to maternal health outcomes, such as tree planting, increasing home ventilation, and upgrading access to water. More research is needed to identify the contribution of individual factors to maternal risks during heatwaves, such as hydration and outdoor physical labor during the final weeks of pregnancy. Existing programs that focus on maternal and newborn health should explore opportunities to protect women from heat effects and commit to evaluating programs to hone effective approaches. Health and environmental data should be routinely analyzed to inform health system planning for resilience. Additional evidence will complement practical and cultural considerations as communities and policymakers determine their focus.

We join with others who call for pregnant women to be identified as a vulnerable group in heatwave response plans.(Kuehn and McCormick, 2017) Fig. 3 summarizes a wide range of actions that could potentially reduce harm at high temperatures. Primary interventions focus on reducing heat exposure and supporting bodily thermoregulation on hot days. The possibilities for home-based planning and adaptation depend on the wider environment, and an adequate response to the threat requires societal commitment to address the structural determinants that worsen vulnerability. Advocacy and communications efforts are needed to raise awareness about heat risks. Early warning systems can advise people to recognize risks and take protective actions.(Baharav et al., 2023) Within the health system, clinical protocols and training content could be developed to help health providers to manage risks and offer preventative guidance to expectant mothers. Local community design processes may help reach populations most at risk of poor health outcomes from heat and precipitation anomalies, including manual outdoor laborers who have much higher odds of experiencing adverse outcomes. Within DRC, we recommend targeting interventions to the geographic hotspots identified to frequently experience anomalous heat.

Expectant mothers and their babies are vulnerable to high temperatures and heavy precipitation. Early warning systems, provider and patient education, and reliable access to health care and thermal comfort may improve maternal and newborn outcomes.(Baharav et al., 2023) Limitations in national data systems and connectivity between climate and health data limit effective planning to mitigate the impact of anomalous heat and precipitation, yet improved awareness could enable appropriate coordination and risk-based planning. DHIS2 data offer a routinely collected, freely available option to assess associations between climate and population health outcomes, informing stakeholders seeking to reduce the harms of heat exposure and to equip communities to contend with risks.

CRediT authorship contribution statement

Carrie J. Ngongo: Writing – original draft, Visualization, Project administration, Funding acquisition, Conceptualization. **Donal Bisanzio:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Gabriella Corrigan:** Writing – review & editing, Investigation. **Karl B. Angendu:** Writing – review & editing, Data curation. **Alisha Smith-Arthur:** Writing – review & editing, Funding acquisition, Conceptualization. **Brian Hutchinson:** Writing – review & editing, Investigation, Formal analysis. **Pierre Akilimali:** Writing – review & editing, Visualization, Data curation.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2025.109564.

Data availability

Data will be made available on request.

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