

Effect of heat stress on the risk of pregnancy termination in 33 countries of sub-Saharan Africa

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Abstract

Rising temperatures in sub-Saharan Africa represent one of the most critical environmental challenges of the 21st century. Climate change is a critical determinant of health, with far-reaching impacts on vulnerable populations, especially pregnant women and their unborn children. Maternal and fetal health are particularly sensitive to climate-induced stressors, such as extreme heat and extreme weather events stress. The objective of this study is to investigate to what extent the relative risk for pregnancy termination has been changing with heat stress in 33 countries of sub-Saharan Africa and if access to cooling mechanisms allow counteracting the effects of heat stress. The analysis will also focus on potential impact of heterogeneity for the risk of pregnancy termination and the effect of confounding risk factors contributing to an increased risk for women. To address our objective, we used logistic regressions, combining climate and pregnancy termination data from two different sources: ERA5-Land post-processed data and the Demographic and Health Surveys Program. We assessed heat stress using the proportion of days with temperatures one, one-and-a-half, or two standard deviations above the average temperature for a given month. Our preliminary results suggest that heat stress increases the risk of pregnancy termination. Additionally, we found that the risk of pregnancy termination increases with the intensity of heat stress. The estimated risk is higher when the proportion of days with atypical temperatures corresponds to hotter days. Our findings confirm the relationship between heat stress and pregnancy termination, particularly in a context of accelerating climate change and environmental vulnerability.

1. Introduction

Rising temperatures in sub-Saharan Africa (SSA) represent one of the most critical environmental challenges of the 21st century. Climate models consistently project that the region will experience warming trends surpassing the global average, with increasing frequency and intensity of heatwaves that exacerbate vulnerabilities in food security, water resources, population health and health infrastructure (IPCC, 2022). Observational studies have confirmed that average temperatures in parts of SSA are rising by about 0.3°C per decade, intensifying existing socioeconomic and health challenges.

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Climate change is a critical determinant of health, with far-reaching impacts on vulnerable populations, especially pregnant women and their unborn children. Maternal and fetal health are particularly sensitive to climate-induced stressors, such as extreme heat and extreme weather events stress (Basu et al. 2010, 2017; Hough et al. 2023; McElroy et al. 2022; Samuels et al. 2022; Zhong et al. 2018). During pregnancy, heat stress, i.e., very high temperatures, can disrupt various physiological processes, including maternal thermoregulation, impairing placental function and fetal development, exacerbating maternal health conditions, and inducing systemic.

Emerging evidence from epidemiological studies highlights the direct and indirect effects that increased ambient temperatures have on pregnancy outcomes, particularly pregnancy termination, which includes both miscarriage and stillbirth. Some studies analyzing the effects of heat stress on maternal, fetal, and neonatal health have documented an increased risk of pregnancy termination and perinatal mortality (stillbirth and deaths within 24 hours after birth) among pregnant women exposed to extreme heat during the last week of pregnancy, ranging from 4% to 34% (Hanson et al., 2024; Lakhoo et al., 2024; Ngongo et al., 2025; Yang et al., 2022). Pregnancy termination risk was particularly high during the hottest months, highlighting the seasonal aspect of heat-related pregnancy risks in SSA. Recent estimates show that SSA accounts for about 42–45% of global stillbirths each year, and the rate of reduction in stillbirths remains slow (Gwacham-Anisiobi et al., 2024; UNICEF, 2023). Although temperatures are rising more rapidly in SSA and the prevalence of pregnancy termination, particularly stillbirths, is higher there, the relationship between heat stress and pregnancy termination remains understudied.

The objective of this study is to investigate to what extent the relative risk for pregnancy termination has been changing with heat stress in SSA and if access to cooling mechanisms allow counteracting the effects of heat stress. Access to cooling mechanisms is not generalized in SSA (less than half of the population) and it is correlated with socioeconomic status. The analysis will also focus on potential impact of heterogeneity for the risk of pregnancy termination and the effect of confounding risk factors contributing to an increased risk for women.

2. Data and methods

We analyzed the effect of heat stress on the risk of pregnancy termination in 33 countries in SSA. To do this, we combined climate and pregnancy termination data from two different sources, the ERA5-Land post-processed data (Muñoz Sabater 2021) and the Demographic and Health Surveys Program (The DHS program, 2025), respectively.

2.1. Climate data

ERA5-Land post-processed data represents the latest advancement in land surface reanalysis datasets, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) as part of the Copernicus Climate Change Service (C3S). This dataset provides a high-resolution, consistent view of the evolution of land variables globally, beginning in January 1950 and continuing to the present with updates available

generally up to five or six days behind real time. ERA5-Land has spatial resolution for a global land surface reanalysis, featuring a regular latitude-longitude grid at $0.1^\circ \times 0.1^\circ$, which corresponds to an effective native resolution of approximately 9 km. The dataset covers the entire globe and includes vertical information from the land surface, as well as selected parameters measured 2 meters (2m) above the surface.

The post-processed data products from ERA5-Land include daily statistics (mean, maximum, minimum) for a wide array of meteorological and land surface variables, such as temperature, soil moisture, wind, snow cover, and radiation. The 2m temperature data in ERA5-Land refers to the air temperature measured or modeled at 2 meters above the land surface. This parameter is commonly used in meteorology and climatology as it approximates the standard screen-level temperature, which is representative of what is typically experienced by humans and recorded at weather stations. In the ERA5-Land system, the 2m temperature is derived by interpolating between the surface level and the lowest atmospheric model level, considering the atmospheric conditions at each grid point.

2.2. Pregnancy termination data

The Demographic and Health Surveys (DHS) are large-scale, nationally representative household surveys conducted primarily in low- and middle-income countries since the 1980s. They are designed to collect data on a wide range of demographic, health, and social indicators. DHS data are useful for studying population health, fertility, family planning, nutrition, child and maternal health, and gender-related issues. DHS datasets are organized into several recode files, each corresponding to a specific level of analysis (e.g., household, woman, man, child, birth, or community). These files share a consistent structure across countries and survey rounds, which facilitates cross-national and temporal comparisons.

In this study, we use two DHS datasets, Individual Recode (IR) and Geographic (GE). The IR dataset contains information collected from women aged 15–49, with each record corresponding to one-woman respondent. The core variables include, among others, demographics (age, marital status, education, place of residence, wealth quintile), fertility history (number and timing of births, pregnancy duration for live births, pregnancy outcomes), and maternal health (antenatal care, delivery assistance, postnatal visits). In addition, IR datasets usually include reproductive calendar data. These data are stored as compact string variables that record month-by-month information for several years preceding the interview, typically the five years prior to the survey date. Calendar data records whether a woman was using contraception, pregnant, gave birth, or had a pregnancy termination each month. The GE dataset contains GPS coordinates (latitude and longitude) for each survey cluster (enumeration area). In order to ensure that respondent confidentiality is maintained, the DHS randomly displace the GPS latitude/longitude positions for all surveys. The displacement is randomly carried out so that urban clusters are displaced up to 2 kilometers (km) and rural clusters are displaced up to 5 km, with 1% of the rural clusters displaced up to 10 km. IR and GE datasets can be merged using the cluster number (variable v001 in the IR file and DHSCLUST in the

GE file). We used all available DHS that have both datasets, IR (and also contain calendar data) and GE.

2.3. Combining climate and pregnancy termination data

In the IR dataset, women are linked to clusters that have a GPS location available in the GE dataset. For illustrative purposes, Nigeria is used as an example (see Figure 1). As mentioned above, the GPS location of each cluster has been displaced to ensure confidentiality. First, we calculate the buffer for each cluster based on place of residence: a 2-km buffer in urban areas and a 5-km buffer in rural areas. The map at the top of Figure 2 shows the buffer calculation for Nigeria in 2018. Since we are interested in analyzing the effects of heat stress on pregnancy termination over time, we pooled all DHS surveys for the same country. This results in more clusters being available for each country, as shown by the map at the bottom of Figure 2.

Then, we use ERA5-Land data to map temperature differentials. As we have calculated the buffers, temperature data and buffers can be combined (see Figure 3). Since we have data on women located within each buffer, it is necessary to focus on the temperature data of the buffer. To do so, the average temperature of the buffer is calculated, as we do not know the exact coordinates of each woman included in the IR dataset. Therefore, it is assumed that all women within the same buffer are affected by the same average temperature (see Figure 4). When creating buffers, it is possible that a buffer may extend beyond the borders of its country. Although the design of cluster displacement in DHS ensures that the cluster is within the same country, a buffer that shares territory between two or more countries is not a problem, as the average temperature of the buffer is assigned regardless of country borders, given that ERA5-Land data is not restricted to a specific country but contains data for geographic coordinates.

In this study, we first analyze the effect of heat stress on pregnancy termination. We measure heat stress as the proportion of days above the monthly average temperature. For doing so, we calculated the average temperature and standard deviation (SD) for each day between 1950 and 1990 at each geographic coordinate (see the map at the top of Figure 4). We refer to this period as the reference temperature average period. This provides a reference temperature average for each day of the year. Then, for each geographic coordinate, we determined whether the temperature on each day from 1990 to 2024 was 1, 1.5, or 2 SDs above the reference average temperature for that same day. We then calculated the proportion of days in a month when the temperature is above the reference temperature average. Ideally, we would use the proportion of days in the week, but the calendar data records events on a monthly basis.

Since the calendar data identifies the month in which the pregnancy outcome occurred, whether pregnancy termination or live birth, the average proportion of days with temperatures above the reference temperature average for the buffer corresponding to the woman can be assigned to that month. We then estimated the effect of heat stress on pregnancy termination using a logit model. The outcome variable is pregnancy outcome, 1 for a pregnancy termination and 0 for a live birth. We conducted two sets of regressions. In the first set –unadjusted estimates– we regressed the outcome variable on each of the

heat stress measures, i.e., the proportion of days with temperatures 1, 1.5, or 2 SD above the average temperature in the reference period. In the second set –adjusted estimates– we added age group at the time of pregnancy outcome, educational level, place of residence, marital status, and contraceptive use at the time of conception as independent variables. Also, we include as controls survey year and country fixed effects.

In the full paper, we will also analyze whether there are specific differences in the case of stillbirths and whether heat stress mitigation mechanisms change the risk of pregnancy termination. Also, we will examine potential impact of heterogeneity for the risk of pregnancy termination and the effect of confounding risk factors contributing to an increased risk for women. We will provide regional estimates and, when possible, country estimates.

Figure 1. GPS location of clusters in DHS surveys: Nigeria 2018.

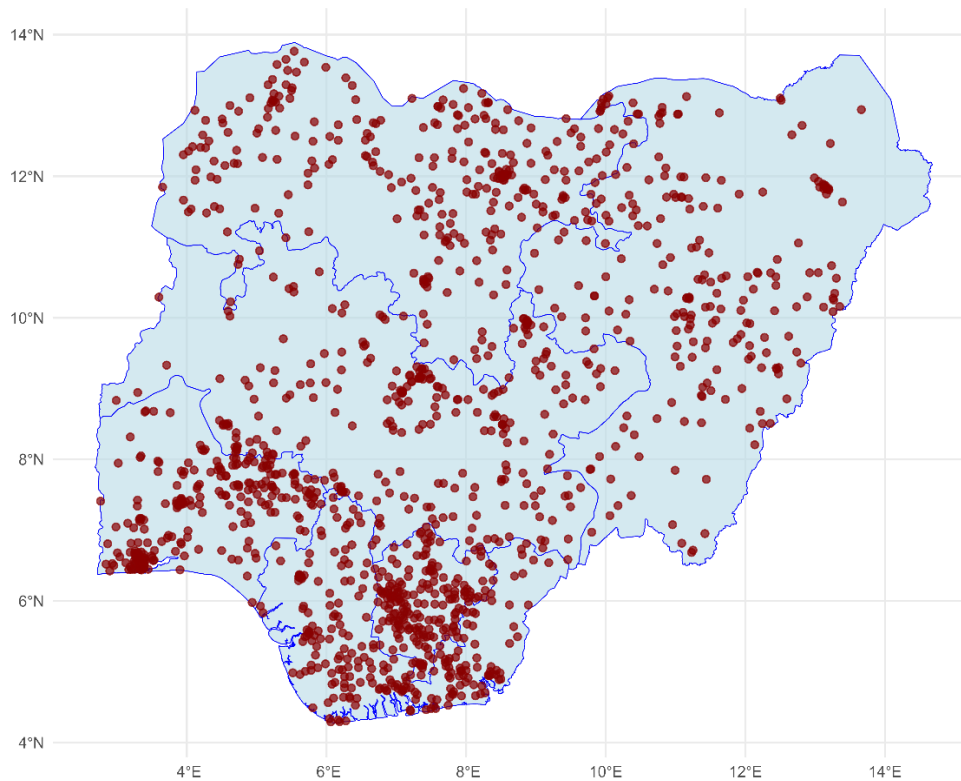
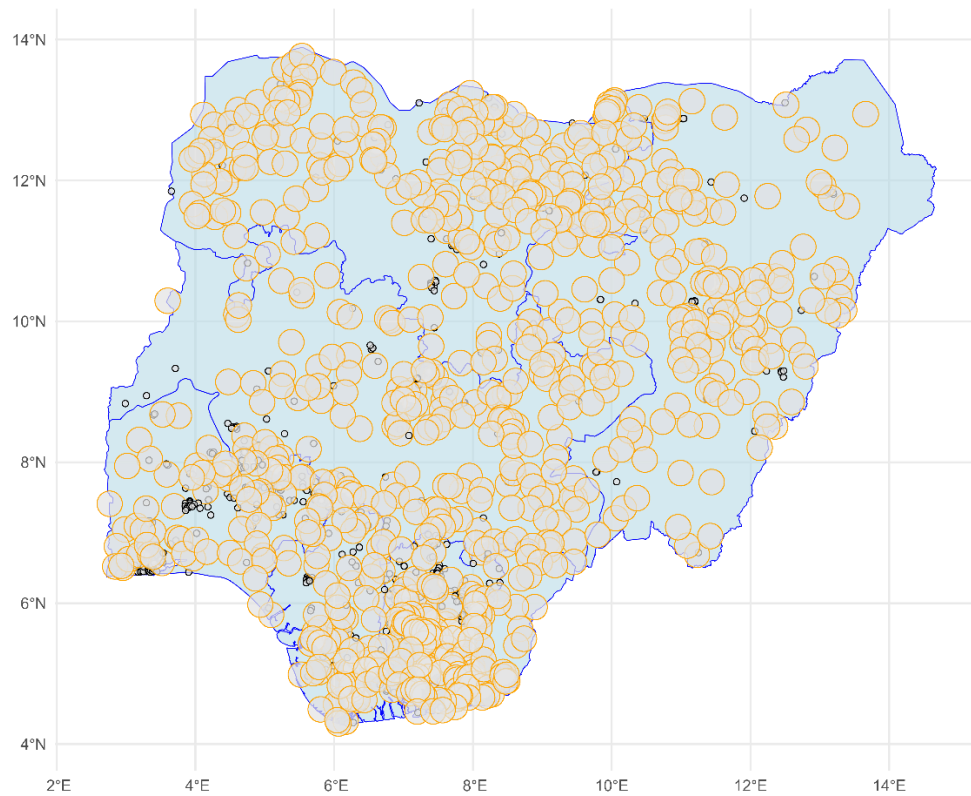
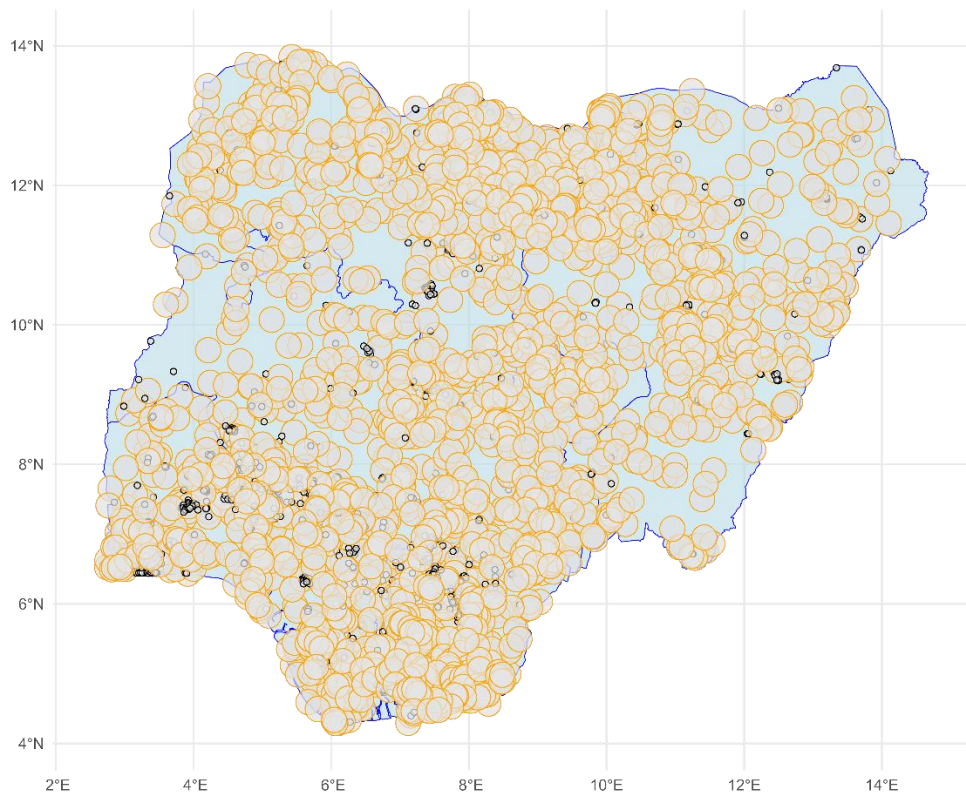


Figure 2. Buffer calculation: 2Km in urban areas and 5Km in rural areas. Upper map refers to 2018 DHS and bottom map to pooled DHS.



Place of residence Rural Urban



Place of residence Rural Urban

Figure 3. Combining temperature data and buffers in Nigeria in 2018.

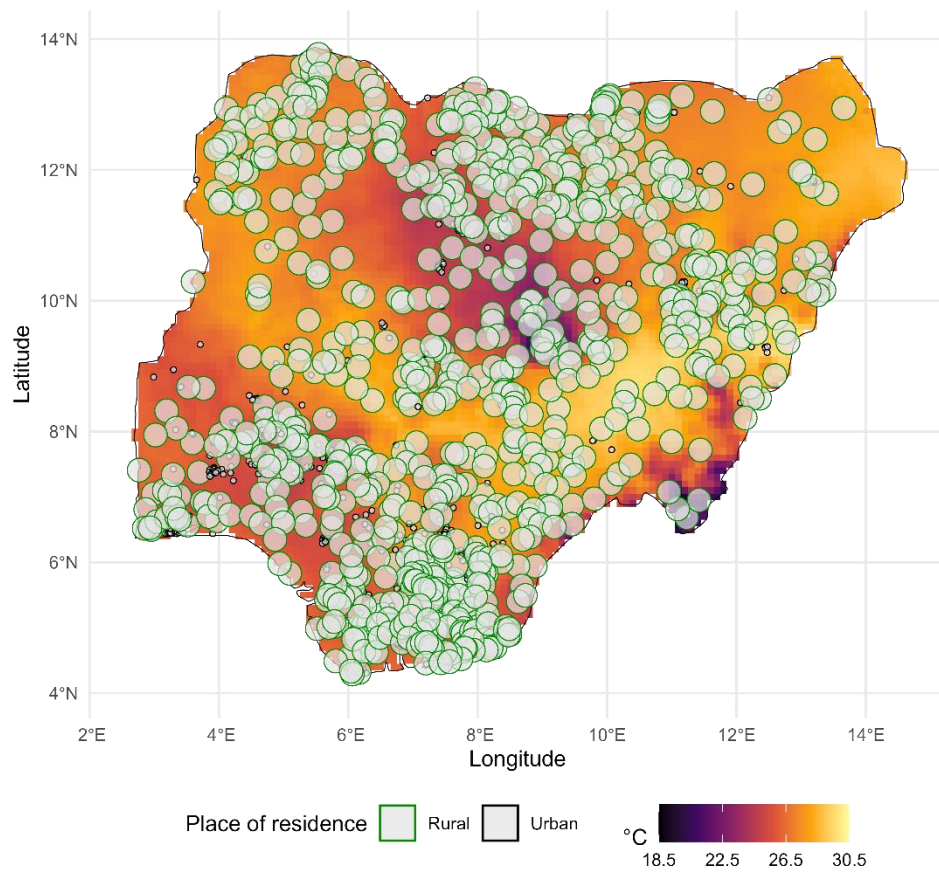
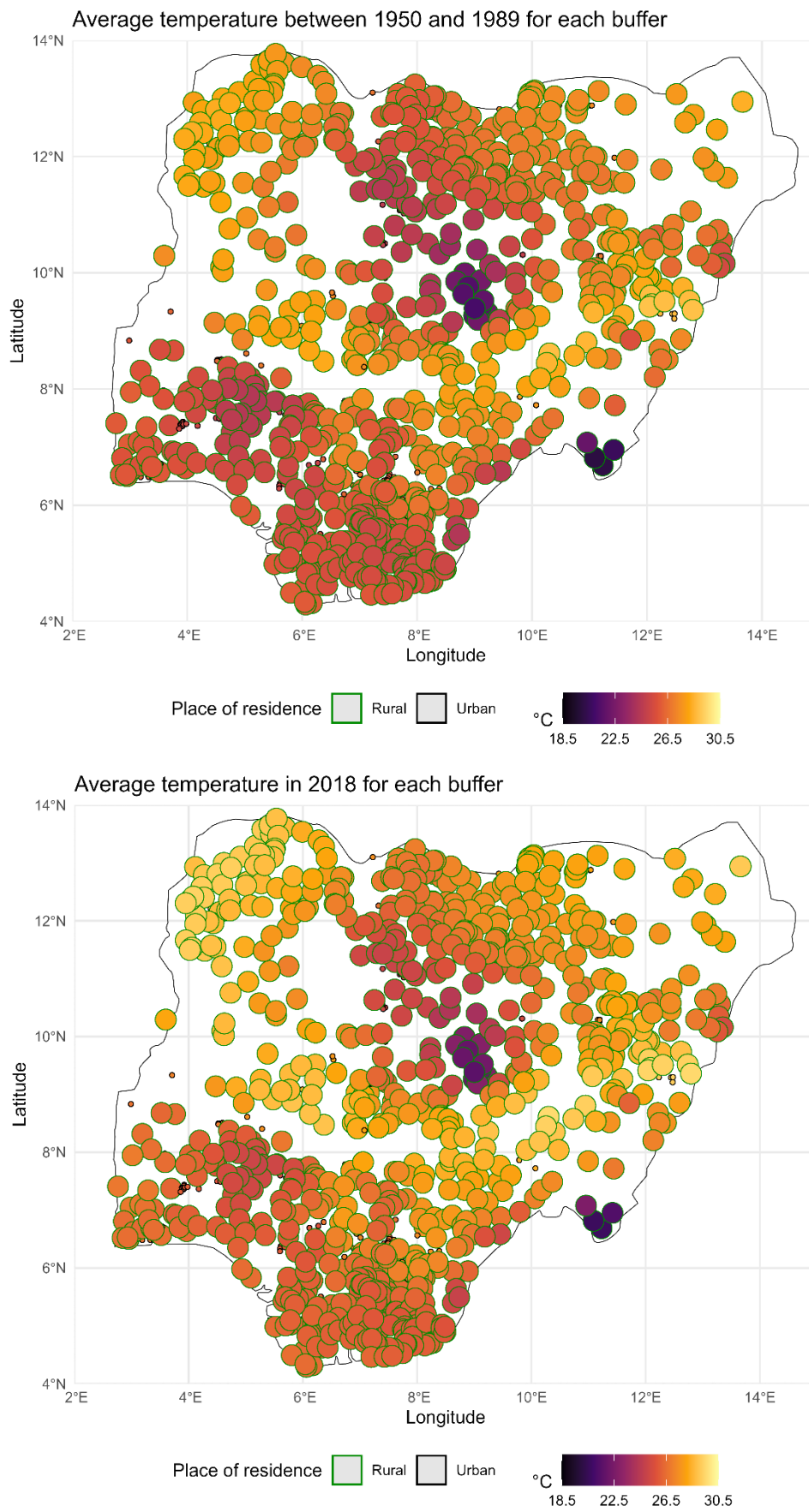


Figure 4. Average temperature and buffers in Nigeria.



3. Preliminary results

Temperature in Africa has increased constantly since the 1950s. The average temperature in 1950 was 22.8 Celsius degrees (°C) and in 2024, 24.8 °C. Thus, a 2°C increase has been observed over the last 70 years in Africa. Figure 5 shows average temperature in Africa in 1950 and 2024. The colors on the 2024 map are lighter than those on the 1950 map, showing that the African continent has warmed in recent decades. Figure 6 presents the change in average temperature between 1950 and 2024 in Nigeria. As in Africa, temperatures in Nigeria have risen, although the increase is well below the regional average, at 0.8°C, from an average of 26.5°C in 1950 to 27.3°C in 2024.

Figure 7 illustrates the trend in the average daily temperature in Nigeria from 1950 to 2024. The trend in average daily temperature (black line) remained stable from the 1950s to the 1970s. However, it begins to steadily increase in the 1980s, accelerating in the 2000s. The daily variations in average temperature (gray line) show that maximum temperatures have increased in recent decades, as have minimum temperatures. Nigeria, like the rest of the region, is not only becoming warmer but also less cool.

As a result of increasing temperatures, the proportion of days with average temperatures above the reference temperature average in a month has also increased in recent decades in Nigeria (see Figure 8). Before the 1980s, in a few months it was observed that the proportion of days above average was greater than 25% and, if so, these were days with temperatures 1 SD (green dots) above average. Since the 1980s, however, the proportion of days above average has increased significantly. During the 1980s and 1990s, days with temperatures 1.5 SD (orange dots) above average became more frequent, as did months with more than 50% of days with unusually high temperatures. But it is from the 2000s onwards that there has been an increase in the number of months with a proportion of days 2 SD above average (red dots), and in some cases, more than half of the days in a given month have been above average. Almost every month has a proportion of days with temperatures 1 SD above average of more than 50%, and 25% of days have temperatures 1.5 SD above average.

It is clear that Nigeria, and the region, is warming up, and this is having an effect on population dynamics. Figure 9 displays unadjusted and adjusted estimates of the effect of heat stress on pregnancy termination from Logit regressions in Nigeria. Unadjusted estimates (blue dots and lines) show that heat stress increases the risk of pregnancy termination in Nigeria. The higher the proportion of days with temperatures above the average, the higher the odds of pregnancy termination. In fact, the results show that heat intensity increases the risk of pregnancy termination. The model estimates when measuring heat stress from 1 SD show a 1.13-fold increase in the odds of pregnancy termination (95% CI: 1.00–1.28), while the increase in the odds when heat stress is measured from 1.5 SD is 1.19 (95% CI: 1.02–1.39) and is 1.42 (95% CI: 1.12–1.79) when measured from 2 SD. Given that the risk of pregnancy termination in the pooled DHS in Nigeria is 0.07, one additional day with temperatures 2 SD above average increases the probability of pregnancy termination by approximately 0.09 percentage points, and by 0.03 percentage points if the temperature is 1 SD above average. Adjusted estimates (red dots and lines) show also that more days with temperatures above the average increase

the odds of pregnancy termination, although coefficients are smaller. However, in this case all confidence intervals include 1.

Figure 5. Average temperature in Africa in 1950 and 2024.

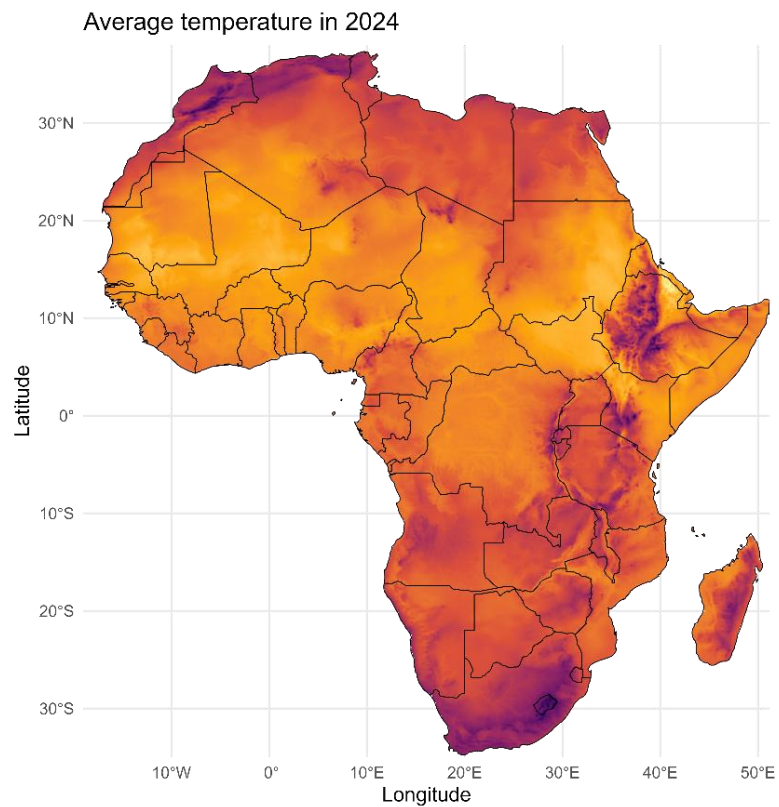
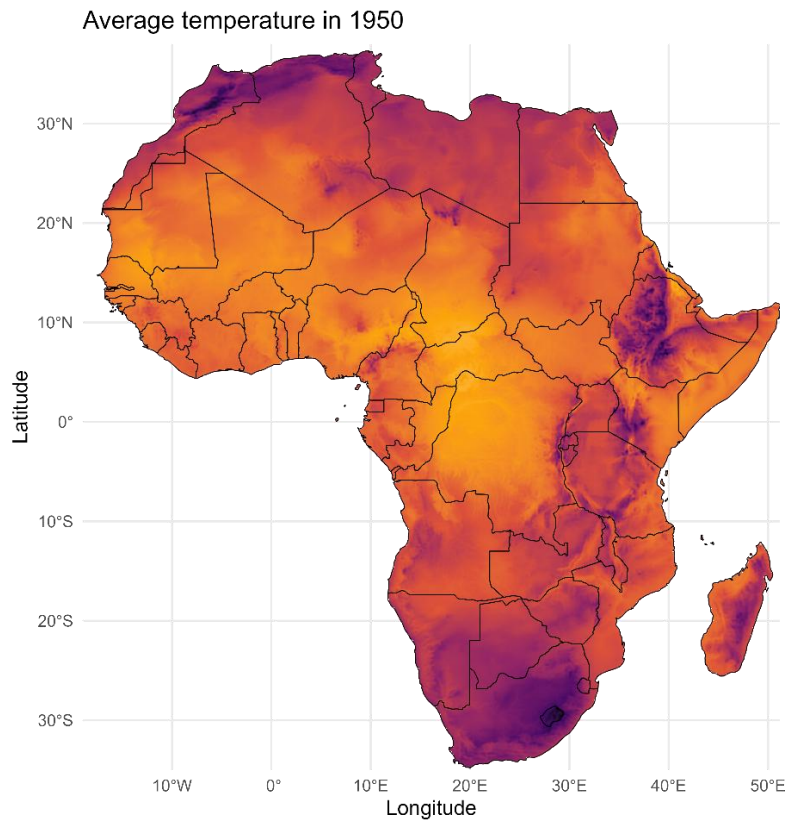


Figure 6. Average temperature in Nigeria in 1950 and 2024.

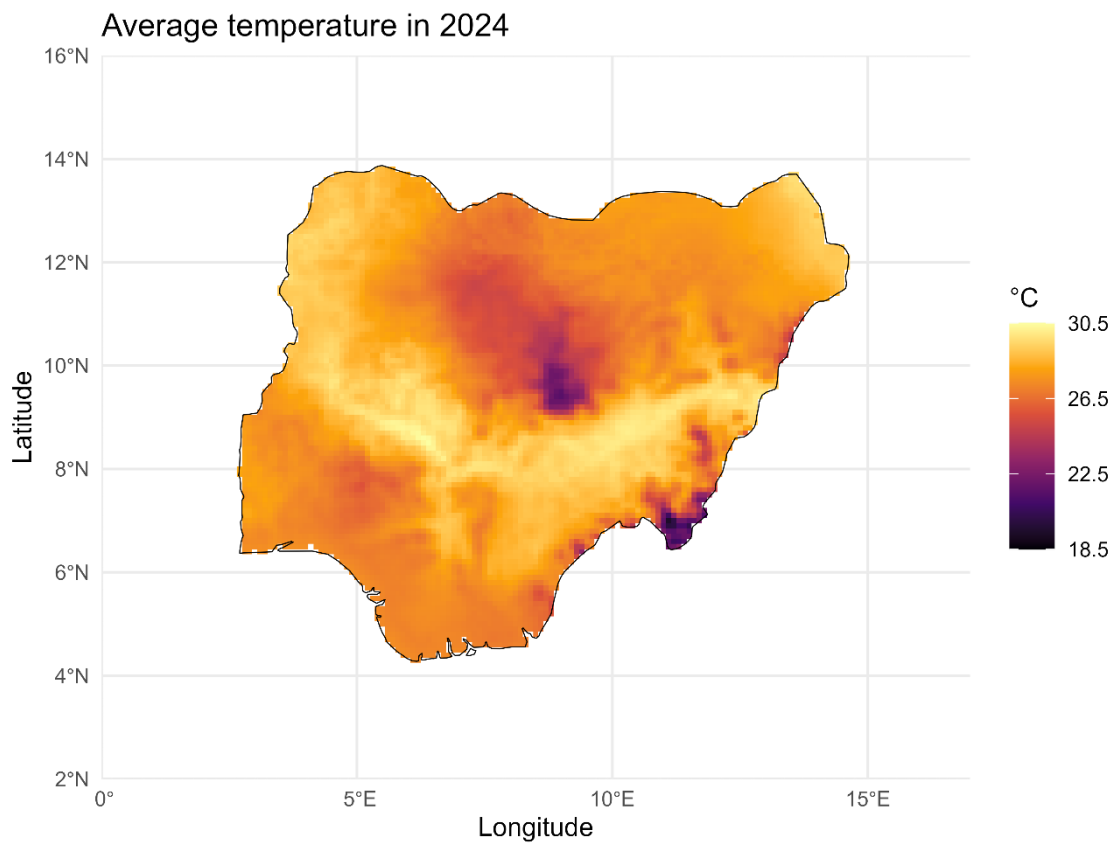
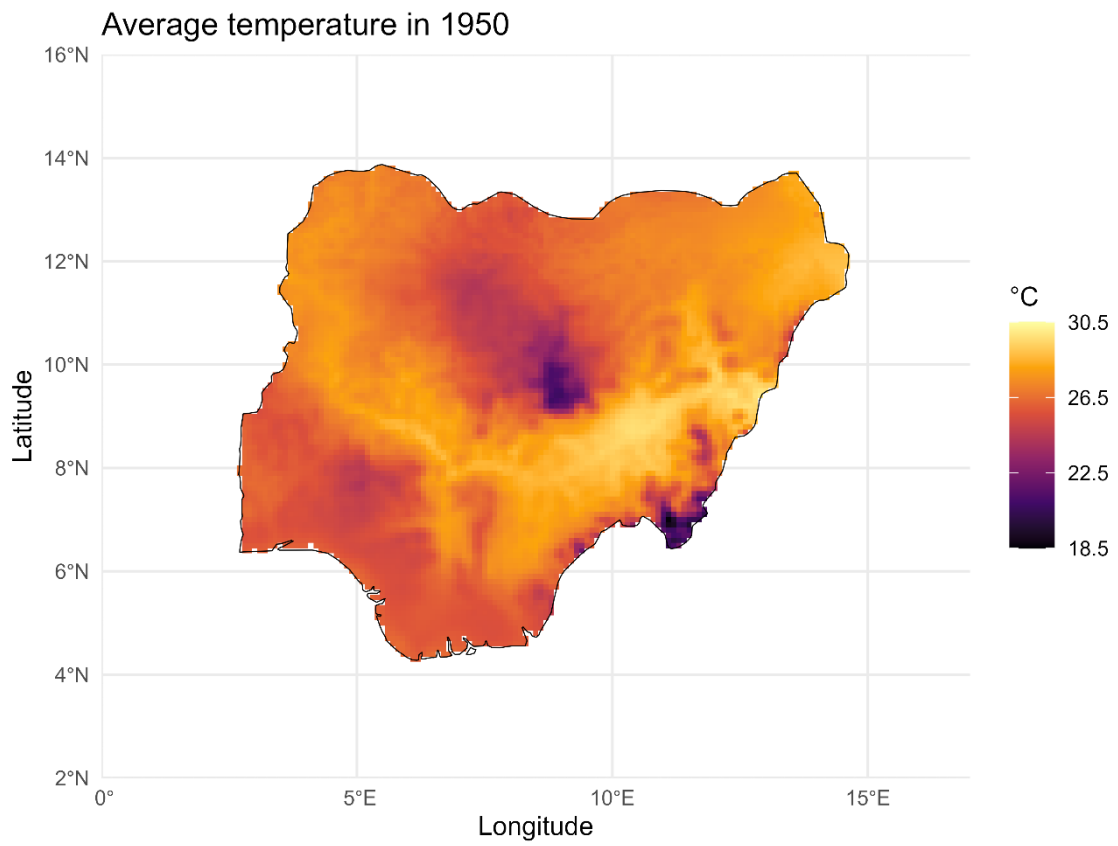


Figure 7. Trend in average temperature in Nigeria from 1950 to 2024.

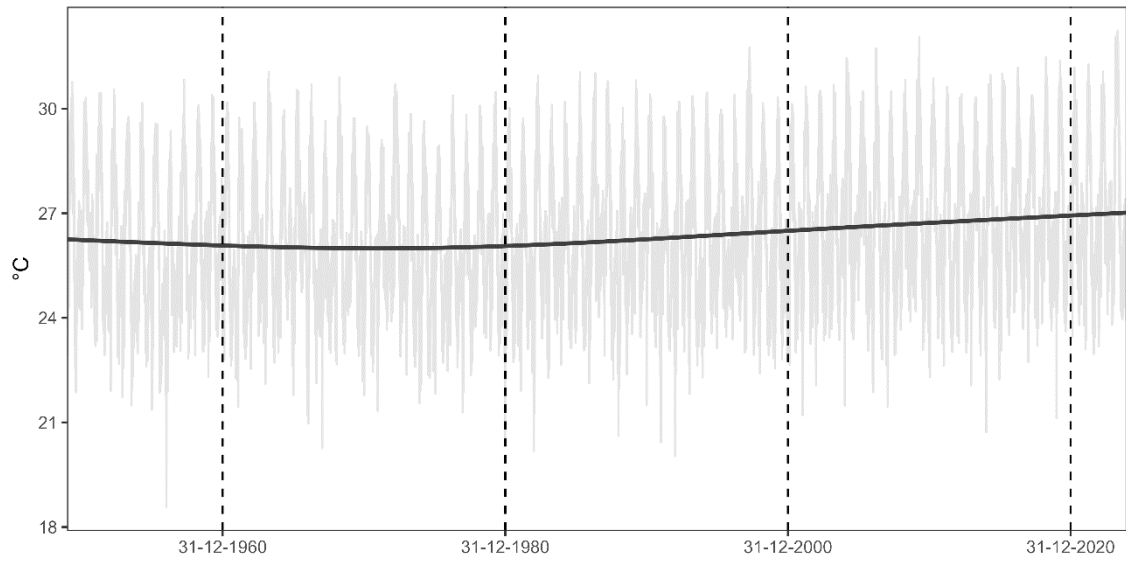


Figure 8. Proportion of days in a month when the temperature is above the reference temperature average in Nigeria.

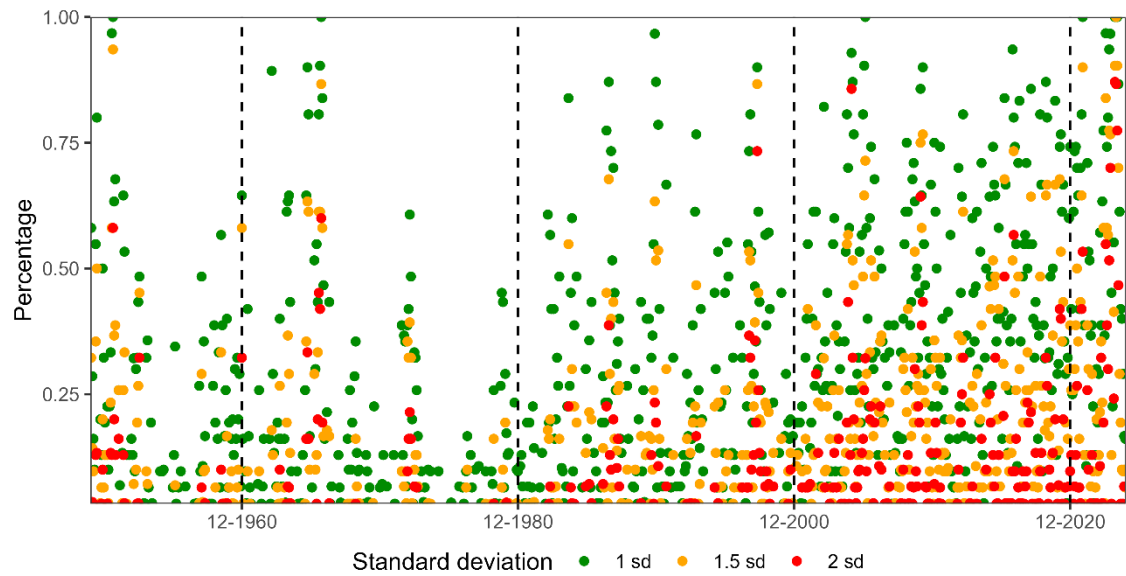
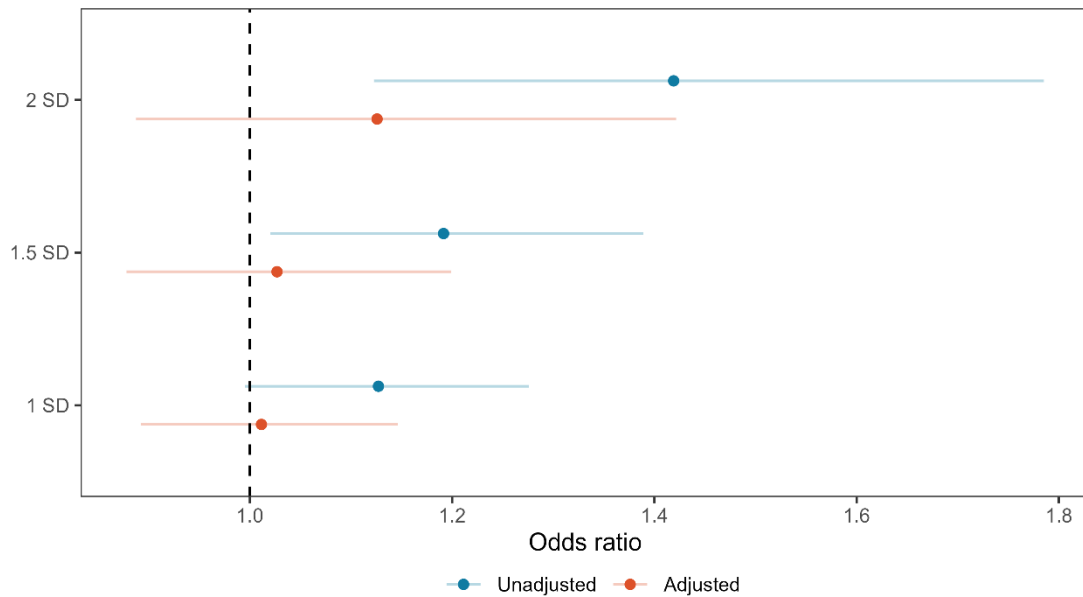


Figure 9. Unadjusted and adjusted estimates of the effect of heat stress on pregnancy termination from Logit regressions in Nigeria. 95% confidence level.



4. Preliminary conclusions

The findings of this study confirm the growing evidence that heat stress is a significant risk factor for pregnancy termination, particularly in the context of accelerating climate change and environmental vulnerability. Previous research has demonstrated that elevated temperatures can disrupt key physiological processes, including uterine blood flow and endocrine regulation, thereby compromising fetal viability (Basu et al. 2010, 2017; Hough et al. 2023; Kuehn and McCormick, 2017; McElroy et al. 2022; Samuels et al. 2022; Zhong et al. 2018). Moreover, exposure to heatwaves has been associated with increased risks of preterm birth, miscarriage, and stillbirth, especially in low- and middle-income regions (Chersich et al., 2020). These findings suggest that heat stress operates as an environmental determinant of maternal–fetal health, with its impact likely to intensify as global warming progresses. Consequently, incorporating heat exposure into public health and reproductive planning frameworks is an urgent priority to mitigate preventable adverse outcomes.

In the case of Nigeria, the country used for illustrative purposes, we observe an increased risk of pregnancy termination due to heat stress, as measured by the proportion of days above average in a month. However, the effects of heat stress on the risk of pregnancy termination from adjusted estimates are rather modest. This may be because the increase in temperatures has also been lower than in other countries in the region. However, the evidence from our preliminary explorations gives us confidence that the effects will be significant when the analysis of all countries of the region is completed.

The accumulated evidence underscores the need for preventive and adaptive strategies to safeguard reproductive health under rising temperature scenarios. Implementing early heat warning systems, improving health infrastructure, and strengthening epidemiological surveillance are crucial measures to reduce exposure and mitigate the

effects of heat stress on pregnant women. Furthermore, an intersectoral approach that links biomedical research with environmental sustainability, climate justice policies and population research is essential, as the most vulnerable populations—particularly in tropical and resource-limited settings—bear a dual burden of biological and social risk. The relationship between heat stress and pregnancy termination represents an emerging global health challenge that demands coordinated scientific and policy responses.

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