

Heat exposure and child stunting in Nigeria: a reversed and replicated interaction between healthcare access and thermal stress across two Demographic and Health Surveys

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Research Article

Keywords: heat exposure, child stunting, healthcare access, effect modification, multilevel modelling, Nigeria, Demographic and Health Surveys

Posted Date: October 23rd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11097318/v1>

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Additional Declarations: No competing interests reported.

Abstract

Background

Heat exposure and poor healthcare access each threaten child health in sub-Saharan Africa, and they frequently converge in the same places. Whether they interact, such that heat's effect on child health depends on healthcare accessibility, has rarely been tested.

Methods

Two independent rounds of the Nigeria Demographic and Health Survey were linked (2018, $n = 11,308$ children; 2023-24, $n = 9,410$) to ERA5-Land reanalysis temperature data. Heat was characterised as each cluster's 1991–2020 climatological normal of daytime maximum temperature; healthcare inaccessibility as the cluster-level proportion of women reporting distance as a major barrier to care. Using a three-level logistic mixed-effects model (children within clusters within states), we tested the heat-by-access interaction on child stunting, adjusting for wealth, maternal education, child age and sex, and residence. The analysis was pre-specified; robustness checks included an objective travel-time access measure, severe stunting, infant mortality, and models without the state level. Survey-weighted sensitivity analyses were conducted, and mortality was assessed as infant mortality in a separately constructed birth-history sample because under-five mortality was not adequately observable in this retrospective survey.

Results

Contrary to the pre-specified hypothesis, the heat-by-access interaction was reversed and significant (2018 OR 0.925, 95% CI 0.877–0.975, $p = 0.004$; 2023-24 OR 0.937, 95% CI 0.886–0.991): heat was more strongly associated with stunting where access was good than where it was poor. The pattern reproduced across rounds and held for severe stunting and for cluster-only models. It did not extend to an objective travel-time access measure (both rounds null) or to infant mortality (both rounds null).

Conclusions

Heat's association with stunting was weaker, not stronger, where healthcare access was poorer. This reversed interaction was observed consistently across both survey rounds but was measure-dependent. The pattern is consistent with a ceiling effect: where baseline stunting is already very high, additional heat stress produces little further measurable increase. The priority in such communities may be to reduce the chronic baseline burden rather than the marginal effect of heat.

1. Introduction

1.1 Heat and child health in sub-Saharan Africa

Sub-Saharan Africa faces rising temperatures and more frequent extreme heat, with limited capacity to adapt [1]. A growing body of evidence links heat exposure to adverse child health, including undernutrition and impaired growth, though findings across low- and middle-income settings remain heterogeneous and the underlying pathways are incompletely understood [2, 3]. Chronic undernutrition, expressed as stunting, is a particularly important outcome: it reflects cumulative deprivation over early childhood and is associated with lifelong consequences for health, cognition, and economic productivity [4]. How environmental stressors such as heat contribute to stunting, and whether their effect depends on the wider conditions in which children live, remains an open question.

1.2 Healthcare access and child health in Nigeria

Nigeria carries one of the world's heaviest burdens of child undernutrition and mortality, distributed highly unequally across the country [5, 18]. Access to healthcare is a central axis of this inequality: distance to facilities, poor transport infrastructure, and workforce shortages leave many children, particularly in rural and northern areas, with limited access to timely care [5, 6]. Healthcare access is widely understood to buffer children against health threats, enabling early treatment of illness and monitoring of growth. It is therefore plausible that the health consequences of environmental stressors such as heat depend on whether accessible care is available to mitigate them.

1.3 Convergent disadvantage and the question of interaction

Heat exposure, poverty, and poor healthcare access frequently co-occur in the same places, and this geographic convergence has been documented in Nigeria and comparable settings [7]. Yet co-occurrence at the population level does not establish that these disadvantages interact, that is, that the effect of one depends on the level of another. Whether heat's effect on child health is amplified where healthcare is hardest to reach has been theorised but rarely tested directly, and, to our knowledge, not at sub-national resolution across repeated national surveys. This distinction matters: if heat and poor access compound one another, the children facing both would represent a priority for combined intervention.

1.4 The present study

Two independent rounds of the Nigeria Demographic and Health Survey, linked to ERA5-Land reanalysis temperature data, were used to test whether the association between heat exposure and child stunting is modified by healthcare accessibility. We hypothesised, in advance, that heat would be more strongly associated with stunting in communities with poorer healthcare access, that is, that inaccessibility and heat would compound one another, because accessible care buffers the health consequences of heat stress while its absence allows heat-related illness to progress untreated. We pre-specified this interaction as the primary test, applied an identical analysis to both survey rounds to assess

reproducibility, and pre-specified a series of robustness checks. We report the results as specified, including the direction of the interaction, which proved to be the opposite of what we anticipated.

2. Methods

Individual-level data from two rounds of the Nigeria Demographic and Health Survey were linked to ERA5-Land reanalysis temperature data, and multilevel regression was used to test whether the association between heat exposure and child stunting depends on healthcare accessibility. A dated analysis plan was archived before the final confirmatory analyses were completed. We report the pre-specified primary interaction and robustness analyses, including results that ran contrary to our hypothesis.

2.1 Study design and pre-specification

This was a secondary analysis of two independent, nationally representative household surveys. The primary outcome, the primary exposure, the effect modifier, the confounders, the statistical model, and all sensitivity analyses were specified in a dated analysis plan that was archived before the final confirmatory analyses were completed; we report the pre-specified primary interaction and robustness analyses as specified, including results that contradicted the original directional hypothesis.

2.2 Data sources and study setting

The 2018 and 2023-24 Nigeria Demographic and Health Surveys (NDHS) were used, nationally representative household surveys conducted using a stratified two-stage cluster sampling design [8, 9]. The surveys collect data within geographically defined clusters, each corresponding to a census enumeration area. Anthropometric measurement, used to define stunting, was conducted on a subsample of children, yielding analytic samples of 11,308 (2018) and 9,410 (2023-24) children with a valid height-for-age measurement, complete covariate data, and linked cluster coordinates, spanning 1,371 and 1,343 clusters respectively within 37 states in both rounds.

To protect respondent confidentiality, the DHS Program randomly displaces each cluster's coordinates by up to 2 km in urban areas and up to 5 km in rural areas, with 1% of rural clusters displaced up to 10 km, constrained to remain within the same second-level administrative area [10]. Temperature data were obtained from ERA5-Land, a reanalysis product providing hourly 2-metre temperature on an approximately 0.1° (9 km) grid [11].

2.3 Outcome: child stunting

The primary outcome was stunting, defined as a height-for-age z-score more than two standard deviations below the World Health Organization growth-standard median, a widely used indicator of chronic undernutrition [12]. Height-for-age was measured directly by trained fieldworkers. Stunting prevalence was 36.2% (2018) and 36.6% (2023-24) in the analytic samples. As pre-specified secondary outcomes we examined severe stunting (a height-for-age z-score below -3) and infant mortality (death

before twelve months). Under-five mortality was pre-specified but could not be adequately observed in this retrospective birth-history sample (see Section 3.4), so infant mortality was used for the mortality robustness check.

2.4 Primary exposure: heat

Heat exposure was characterised at the cluster level as the long-run climatological normal of daytime maximum temperature. For each cluster we extracted, from ERA5-Land, the daily maximum temperature during daytime hours (10:00–16:00 UTC, approximately 11:00–17:00 local time) and averaged these across the full 1991–2020 period, the standard 30-year climatological reference period defined by the World Meteorological Organization [13]. This yielded a single mean daytime-maximum temperature per cluster, applied identically to both survey rounds.

A 30-year climatological normal was used rather than temperature during the survey period, for two reasons. First, stunting is a chronic outcome reflecting a child's cumulative exposure history, for which the long-run temperature regime of a location serves as an ecological indicator of the thermal environment in which children lived, rather than a measure of any individual child's complete exposure history. Second, an identical, survey-independent window removes any confounding by differing fieldwork seasons between the two rounds. Because DHS records only current residence, this place-based measure also avoids assumptions about individual migration histories.

2.5 Effect modifier: healthcare inaccessibility

The pre-specified effect modifier was healthcare inaccessibility, measured as a cluster-level perceived access barrier: the proportion of women in each cluster reporting that distance to a health facility was a major barrier to accessing medical care. This is an ecological, cluster-level measure describing the community rather than each individual child's access. As a pre-specified robustness check (Section 2.8) we additionally used an objective measure of access: modelled travel time to the nearest city, drawn from a global accessibility surface [14].

2.6 Confounders

All models adjusted for household wealth (measured by the DHS wealth index, in quintiles [17]), mother's education, the child's age in months, the child's sex, and urban or rural residence. These were selected a priori as established determinants of child stunting that also plausibly relate to heat exposure and healthcare access.

2.7 Statistical model

A three-level logistic mixed-effects model was fitted, in which children (level 1) were nested within survey clusters (level 2) nested within states (level 3), with random intercepts at the cluster and state levels. Multilevel models of this kind account for the fact that children in the same community, and communities in the same state, are more similar to one another than to those elsewhere; ignoring this structure would understate uncertainty. The model included heat, healthcare inaccessibility, their

interaction, and all confounders as fixed effects; heat and healthcare inaccessibility each entered as continuous, standardised cluster-level variables. Because temperature-health relationships are not necessarily linear, we tested for departure from linearity in the heat term by comparing the linear specification against a restricted cubic spline (natural spline, three degrees of freedom) using a likelihood-ratio test, in each survey round.

The coefficient of primary interest was the heat-by-access interaction, which tests whether the association between heat and stunting differs according to healthcare accessibility. Effects are reported as odds ratios with 95% confidence intervals; an interaction odds ratio below one indicates that heat's association with stunting is weaker where access is poorer. For the predicted-probability plots (Fig. 1), we illustrate this interaction by contrasting model predictions at the 10th and 90th percentiles of the access distribution, denoted good and poor access; the model itself treats access as continuous throughout. Models were fitted separately for each survey round, allowing the finding to be assessed for consistency across two independent samples, and were estimated using the lme4 package in R [15].

Survey design and weighting. The NDHS uses a stratified two-stage cluster sampling design [8]. The cluster and state components of our model account for correlation among observations within these geographic groups; they do not by themselves reproduce the stratified selection probabilities of the survey design. Because our mixed-effects implementation did not fully incorporate the DHS complex survey design, we conducted a separate survey-weighted sensitivity analysis using the DHS individual sampling weight (v005 divided by 1,000,000, the standard DHS scaling) to assess whether the main interaction was sensitive to unequal selection probabilities. The reversed heat-by-access interaction was preserved in both rounds under weighting (2018 weighted OR 0.909, 95% CI 0.858–0.964, $p = 0.001$; 2023-24 weighted OR 0.927, 95% CI 0.867–0.992, $p = 0.028$), consistent in direction and significance with the primary estimates. Applying non-integer sampling weights within a mixed-effects model is not fully principled and produced a non-integer-successes warning in lme4; we therefore report this as a sensitivity analysis rather than a definitive survey-weighted estimate, and note that a design-based alternative would strengthen future work. Temperature showed no significant departure from linearity in either round (likelihood-ratio test $p = 0.18$ in 2018 and $p = 0.62$ in 2023-24), supporting the linear specification of the heat term.

2.8 Pre-specified robustness checks

Several robustness analyses were pre-specified: substituting the objective travel-time measure for self-reported access; using severe stunting and infant mortality as alternative outcomes; and fitting the model with cluster random effects only, omitting the state level. Each robustness analysis was applied identically to both survey rounds and is reported regardless of direction or statistical significance.

2.9 Ethics and data availability

This study analysed de-identified, publicly available secondary data and required no additional ethical approval; the DHS surveys obtained informed consent from all participants and were approved by the relevant review boards. The survey data are available from the DHS Program (<https://dhsprogram.com>)

and ERA5-Land from the Copernicus Climate Data Store. The pre-specified analysis plan and associated study materials are publicly archived on the Open Science Framework (OSF): <https://osf.io/n84qr>; as stated in the registration, this is an archival registration of the pre-specified plan rather than a pre-data-access registration. Analysis code is available from the corresponding author on reasonable request.

3. Results

3.1 Sample characteristics

The analytic samples comprised 11,308 children in 2018 and 9,410 in 2023-24, each with a valid height-for-age measurement, complete covariate data, and linked cluster coordinates; these spanned 1,371 clusters in 2018 and 1,343 in 2023-24, nested within 37 states in both rounds (Table 1). Stunting prevalence was closely similar across the two rounds (36.2% and 36.6%), as were cluster-level heat exposure (means of 31.9°C and 32.1°C) and the proportion of women reporting distance as a barrier to care (29.1% and 28.8%). In both rounds, rural children were substantially more likely to be stunted than urban children (42.8% versus 25.9% in 2018; 44.1% versus 26.4% in 2023-24), and rural clusters were both hotter and markedly less accessible. The near-identical distributions across two independent surveys provide a strong basis for assessing replication.

Table 1
Sample characteristics by survey round and residence. Heat = cluster-level mean daytime-maximum temperature (1991–2020 climatological normal). Access barrier = proportion of women reporting distance to a facility as a major problem.

Children (n)	2018 All	Urban	Rural	2023-24 All	Urban	Rural
	11,308	4,399	6,909	9,410	4,007	5,403
Stunting (%)	36.2	25.9	42.8	36.6	26.4	44.1
Mean heat (°C)	31.9	31.4	32.3	32.1	31.5	32.5
Access barrier (%)	29.1	18.1	36.1	28.8	19.6	35.7

3.2 Heat, healthcare access, and their interaction

Higher heat was independently associated with greater odds of stunting in both rounds (odds ratio per standard-deviation increase, evaluated at mean access: 1.12, 95% CI 1.03–1.22 in 2018; 1.11, 95% CI 1.00-1.23 in 2023-24). The independent association of poorer access was significant in 2018 (OR 1.07, 95% CI 1.01–1.14) but not in 2023-24 (OR 1.00, 95% CI 0.93–1.07), indicating that access alone was not a consistent predictor across rounds.

The coefficient of primary interest, the heat-by-access interaction, was statistically significant and below one: OR 0.925 (95% CI 0.877–0.975; $p = 0.004$) in 2018. The pre-specified null hypothesis of no interaction is therefore rejected. Because the interaction odds ratio is below one, the association between heat and stunting was weaker, not stronger, in clusters with poorer access, the opposite

direction to our pre-specified alternative hypothesis: a significant interaction in the reverse direction still constitutes rejection of the null of no interaction. Figure 1 illustrates this pattern: in clusters with good access, predicted stunting rose steeply with temperature, whereas in clusters with poor access it was already high at lower temperatures and changed little as temperature increased. Because the modifier was coded as inaccessibility, lower values indicate better perceived access and higher values indicate poorer perceived access.

To illustrate the interaction concretely, the model translated these odds ratios into predicted probabilities of stunting. In 2018, in good-access clusters the predicted probability of stunting rose from 38.2% (95% CI 32.4–44.3) in cooler areas to 50.3% (44.1–56.5) in hotter areas, a steep gradient with temperature. In poor-access clusters, by contrast, predicted stunting was already high in cooler areas (48.4%, 42.1–54.8) and essentially unchanged in hotter areas (47.9%, 41.6–54.3), a flat gradient. The 2023-24 round showed the same pattern (good access: 32.4% rising to 43.1%; poor access: 36.8% to 37.4%). Thus the interaction reflects a pronounced temperature gradient in stunting where access is good, and little or no gradient where access is poor.

3.3 Reproduction across survey rounds

The identical model, applied to the independent 2023-24 survey, reproduced the finding closely: the heat-by-access interaction was again significant and in the same direction, OR 0.937 (95% CI 0.886–0.991; $p = 0.023$). The two interaction estimates were statistically compatible, with substantially overlapping confidence intervals, indicating consistency rather than merely independent significance. Notably, while the independent main effect of access differed between rounds, the interaction was stable across both, suggesting that the operative pattern lies in how heat and access combine rather than in access alone. Figure 1 shows the same crossing pattern in both rounds.

3.4 Robustness analyses

The reversed interaction was robust across several pre-specified checks, all applied identically to both rounds and reported regardless of direction (Fig. 2). Using severe stunting as the outcome produced interactions of the same direction and significance (2018: OR 0.912, 95% CI 0.853–0.975; 2023-24: OR 0.903, 95% CI 0.841–0.970). Omitting the state level and retaining only cluster random effects likewise preserved the interaction, if anything more strongly (2018: OR 0.874, 95% CI 0.828–0.922; 2023-24: OR 0.891, 95% CI 0.843–0.943), likely because state-level random effects absorb part of the between-state variation in heat and access, which is instead attributed to the cluster-level predictors when that level is removed.

Two pre-specified checks did not reproduce the interaction. When self-reported access was replaced with an objective measure of travel time to the nearest city, the interaction was null in both rounds (2018: OR 0.987, 95% CI 0.947–1.028, $p = 0.53$; 2023-24: OR 0.981, 95% CI 0.942–1.022, $p = 0.37$). Mortality was also examined as an alternative outcome. Under-five mortality could not be adequately assessed in this retrospective birth-history sample, because most children were too young at interview to have completed

five years of observation, leaving too few events for a stable estimate; we therefore assessed infant mortality (death before twelve months), which is fully observable for children born at least twelve months before the survey. In a properly powered infant-mortality sample (2018: 27,198 children, 1,803 deaths; 2023-24: 22,167 children, 1,259 deaths), the heat-by-access interaction was null in both rounds, with confidence intervals narrowly bracketing one (2018: OR 1.00, 95% CI 0.94–1.06, $p = 0.97$; 2023-24: OR 1.04, 95% CI 0.97–1.11, $p = 0.28$). Thus the reversed interaction was specific to stunting measured against self-reported access, and did not extend to an objective access measure or to infant mortality.

4. Discussion

4.1 Principal findings

Using two independent rounds of the Nigeria DHS linked to ERA5-Land reanalysis temperature data, we tested whether the association between heat exposure and child stunting depends on healthcare accessibility. Contrary to our pre-specified hypothesis, the interaction was reversed: heat was more strongly associated with stunting in clusters with good access than in those with poor access. This pattern was consistent across three stunting specifications and reproduced closely across two surveys conducted six years apart. It did not, however, extend to an objective measure of access or to child mortality. The finding is therefore best characterised as a reversed, reproduced, but measure-dependent interaction.

4.2 A ceiling-effect interpretation

One plausible explanation for the reversed interaction is a ceiling effect, although it is one of several candidate explanations and is not directly tested by our data. In clusters with poor access, stunting prevalence is already very high, driven by the accumulation of poverty, food insecurity, repeated untreated illness, and distance from care [5]. Where baseline stunting is already near its practical maximum, additional heat stress has limited room to raise it further, so the measured association between heat and stunting is small. In better-served clusters, where baseline stunting is lower, heat has more scope to produce a detectable increase. On this reading, the steep heat-stunting gradient in good-access areas and the flat gradient in poor-access areas (Fig. 1) would reflect differences in baseline burden rather than a protective effect of poor access. Equal weight is given below to an alternative account based on the divergence between perceived and objective access, and the ceiling effect is not regarded as established.

This interpretation carries an important caution: it does not imply that heat is harmless where access is poor. Rather, it implies that such communities are already so burdened that the incremental effect of heat is difficult to detect against an elevated baseline. The absence of a strong statistical interaction in these settings is a feature of measurement near a ceiling, not evidence of resilience.

4.3 Perceived versus objective access

An alternative, and complementary, explanation is suggested by the divergence between the self-reported and objective access measures. The interaction was present with self-reported access, whether respondents considered distance to a facility a major barrier, but absent when access was measured objectively as modelled travel time to the nearest city. These two measures capture genuinely different things. Access is itself a multi-dimensional construct, encompassing not only geographic proximity but also availability, affordability, accommodation, and acceptability [16]. Objective travel time reflects geometric distance and transport infrastructure, whereas perceived access incorporates experience: road quality, seasonal passability, cost, facility opening hours, and prior encounters with the health system. A woman on a paved road may have short travel time yet perceive access as adequate, while another at a similar distance on a track that floods seasonally may experience access as a genuine barrier, and be correct to do so. That the interaction appears with perceived but not objective access suggests the effect may operate through experienced rather than purely geometric access, though we cannot exclude that the self-reported measure captures unmeasured dimensions of disadvantage correlated with both heat and stunting. The objective measure used here, modelled travel time to the nearest city, approximates but does not directly measure facility access; a community may be distant from a city yet close to a primary health centre. The null result with objective access may therefore partly reflect this mismatch rather than a genuine absence of a geometric access effect.

4.4 Comparison with existing literature

Our results sit alongside a growing body of work linking heat exposure to child undernutrition and adverse growth in low-income settings [2, 3], but they complicate any simple expectation that environmental and health-system disadvantages compound. Much prior work has documented that heat, poverty, and poor access co-occur geographically in northern Nigeria and comparable settings [7]; our finding indicates that co-occurrence at the population level need not translate into a multiplicative effect on measured outcomes. The specificity of the interaction, present for stunting and self-reported access but absent for mortality and objective access, underscores that how vulnerability is measured materially shapes what interactions are detected, a caution relevant to the wider literature on convergent climate-health vulnerability.

A further consideration concerns the nature of the temperature exposure itself. The outdoor climatological temperature used here is shaped not only by regional climate but also by urbanisation and the built environment: urban areas tend to experience elevated temperatures through the urban heat island effect, driven by dense construction, reduced vegetation, and human activity, while green space and tree cover conversely moderate local temperature through shading and evapotranspiration, and housing quality and local land use further modify the heat that individuals actually experience. Our measure therefore approximates the ambient thermal environment rather than the precise heat exposure of any individual child. This built-environment dimension, though not directly measured in the present study, is likely to shape both the level and the local variation of temperature exposure, and represents an important avenue for interdisciplinary work linking urban planning, the built environment, and child health.

4.5 Limitations

Several limitations bear on interpretation. First, the analysis is ecological in its exposures and cross-sectional in design: heat and access are characterised at the cluster level, so we cannot attribute effects to individual children, nor establish causal relationships. Second, the ceiling-effect interpretation, while consistent with the data, is not directly tested; distinguishing it from alternative explanations would require designs that track outcomes below the stunting threshold. Third, our primary access measure is self-reported and therefore subject to perception, though this may also be a strength if experienced access is more relevant to care-seeking than geometric distance. Fourth, the analytic sample was restricted to children with valid anthropometric measurements, a subset of the full survey; if measurement completion was lower in the most remote or disadvantaged clusters, the sample may under-represent precisely those settings, a possible source of selection bias. Fifth, cluster coordinates are displaced for confidentiality, introducing minor spatial error. Sixth, the exposure is a long-term climatological measure of the daytime temperature regime and does not capture acute extreme-heat events; whether the interaction persists when heat is characterised by an extreme-heat metric, such as the annual frequency of days exceeding the 95th percentile of local temperature, is a valuable extension that we were unable to complete within the timeframe of this submission and that we identify as a priority for future work. Finally, and most importantly for interpretation, the interaction ran opposite to our pre-specified hypothesis. We report it as it emerged: the hypothesis was specified before analysis, and the reversed finding is presented without modification. That the result contradicts our prior expectation is, we believe, a marker of the analysis's integrity rather than a weakness. Relatedly, the access measure is a cluster-level proportion of surveyed women reporting distance as a major barrier to care; as an ecological, community-level indicator it describes the cluster rather than each individual child's access, and the exact denominator of women contributing to each cluster estimate should be read with this ecological framing in mind.

5. Conclusion

Across two independent rounds of the Nigeria Demographic and Health Survey, heat exposure was more strongly associated with child stunting where healthcare was accessible than where it was not, a reversed interaction, opposite to what we hypothesised, that reproduced across surveys six years apart but did not extend to an objective access measure or to child mortality. The most plausible reading is a ceiling effect: in the poorest-served communities, stunting is already so prevalent that additional heat stress produces little further measurable increase. This reframes the policy implication. The priority in these communities is not primarily to shield children from the marginal effect of heat, but to reduce the chronic baseline burden, poverty, undernutrition, and barriers to care, that leaves stunting near its ceiling in the first place. Because the interaction was specific to perceived access and to stunting, future work should place objective and experienced access measures side by side in the same study. Designs that track outcomes below the stunting threshold, such as weight velocity, illness frequency, and recovery time, would help distinguish a ceiling effect from alternative explanations and clarify how heat and

access jointly shape child health in high-burden settings. In practical terms, while expanding healthcare access remains a broadly important goal for child health in underserved areas, our findings caution against expecting access improvements alone to reduce heat-related stunting risk, since the burden in the least-served communities appears already saturated. The more pressing priority is a comprehensive reduction of the underlying determinants of stunting, of which healthcare access is one component among several.

Declarations

Ethics approval and consent to participate: This study analysed de-identified, publicly available secondary survey data and required no additional ethical approval. The Nigeria Demographic and Health Surveys obtained informed consent from all participants and were approved by the relevant institutional review boards.

Consent for publication: Not applicable.

Availability of data and materials: DHS data are available from the DHS Program (<https://dhsprogram.com>); ERA5-Land from the Copernicus Climate Data Store; travel-time data from the Malaria Atlas Project. The pre-specified analysis plan and associated study materials are archived on the Open Science Framework (OSF): <https://osf.io/n84qr>. Analysis code is available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

Funding: This research did not receive any funding.

Clinical trial number: not applicable.

Authors' contributions: H.B. conceived the study, conducted the analysis, and wrote the manuscript. S.T.B. and H.S. contributed to data interpretation and manuscript revision. A.A.Y. contributed to methodological review and revision. All authors reviewed and approved the final manuscript.

Acknowledgements: Not applicable.

References

1. Kilungo A, Chukwuonye GS, Okpanachi V, Mohamed H. Assessing sub-Saharan Africa's readiness to address the impact of climate change and health: a scoping review. PLoS ONE. 2025;20(11):e0315482.
2. Lakhani S, Ambreen S, Padhani ZA, Fahim Y, Qamar S, Meherali S, et al. Impact of ambient heat exposure on pregnancy outcomes in low- and middle-income countries: a systematic review. Womens Health (Lond). 2024;20:17455057241291271.

3. Lakhoo DP, Brink N, Radebe L, Craig MH, Pham MD, Haghighi MM, et al. A systematic review and meta-analysis of heat exposure impacts on maternal, fetal and neonatal health. *Nat Med*. 2025;31(2):684–94.
4. Victora CG, Adair L, Fall C, Hallal PC, Martorell R, Richter L, et al. Maternal and child undernutrition: consequences for adult health and human capital. *Lancet*. 2008;371(9609):340–57.
5. Okoli C, Hajizadeh M, Rahman MM, Khanam R. Geographical and socioeconomic inequalities in the utilization of maternal healthcare services in Nigeria: 2003–2017. *BMC Health Serv Res*. 2020;20(1):849.
6. Adeyanju O, Tubeuf S, Ensor T. Socio-economic inequalities in access to maternal and child healthcare in Nigeria: changes over time and decomposition analysis. *Health Policy Plan*. 2017;32(8):1111–8.
7. Yourkavitch J, Burgert-Brucker C, Assaf S, Delgado S. Using geographical analysis to identify child health inequality in sub-Saharan Africa. *PLoS ONE*. 2018;13(8):e0201870.
8. National Population Commission (NPC). [Nigeria], ICF. Nigeria Demographic and Health Survey 2018. Nigeria, and Rockville, Maryland: NPC and ICF; Abuja; 2019.
9. Federal Ministry of Health and Social Welfare (FMoHSW). National Population Commission (NPC) [Nigeria], ICF. Nigeria Demographic and Health Survey 2024. Abuja, Nigeria, and Rockville. Maryland: FMoHSW, NPC, and ICF; 2025.
10. Burgert CR, Colston J, Roy T, Zachary B. Geographic displacement procedure and georeferenced data release policy for the Demographic and Health Surveys. DHS Spatial Analysis Reports No. 7. Calverton. Maryland: ICF International; 2013.
11. Muñoz-Sabater J, Dutra E, Agustí-Panareda A, Albergel C, Arduini G, Balsamo G, et al. ERA5-Land: a state-of-the-art global reanalysis dataset for land applications. *Earth Syst Sci Data*. 2021;13(9):4349–83.
12. World Health Organization. WHO child growth standards: the WHO Multicentre Growth Reference Study (MGRS). Geneva: World Health Organization; 2009.
13. World Meteorological Organization. WMO guidelines on the calculation of climate normals. WMO-No. 1203. Geneva: World Meteorological Organization; 2017.
14. Weiss DJ, Nelson A, Gibson HS, Temperley W, Peedell S, Lieber A, et al. A global map of travel time to cities to assess inequalities in accessibility in 2015. *Nature*. 2018;553(7688):333–6.
15. Bates D, Mächler M, Bolker B, Walker S. Fitting linear mixed-effects models using lme4. *J Stat Softw*. 2015;67(1):1–48.
16. Penchansky R, Thomas JW. The concept of access: definition and relationship to consumer satisfaction. *Med Care*. 1981;19(2):127–40.
17. Rutstein SO, Johnson K. The DHS Wealth Index. DHS Comparative Reports No. 6. Calverton. Maryland, USA: ORC Macro; 2004.

Figures

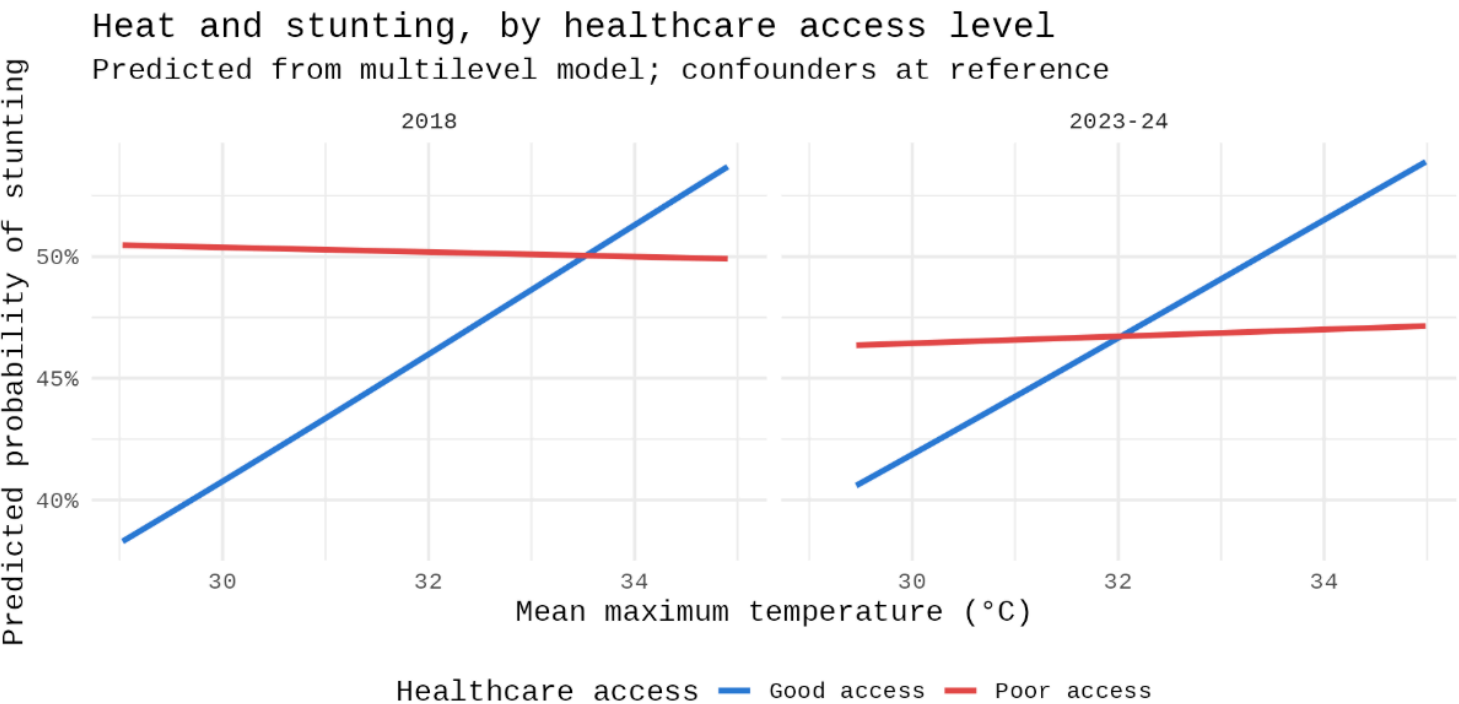


Figure 1

Predicted probability of child stunting by cluster mean daytime-maximum temperature, at good access (10th percentile) and poor access (90th percentile), for each survey round. Predictions are from the multilevel model with confounders held at reference values; the shape of the relationship, not the absolute levels, is the object of interpretation. Because the underlying variable is healthcare inaccessibility, 'good access' corresponds to the 10th percentile (lower inaccessibility) and 'poor access' to the 90th percentile (higher inaccessibility).

Heat × access interaction across outcomes and s
Dashed line = no interaction (OR 1). Left of it = reverse

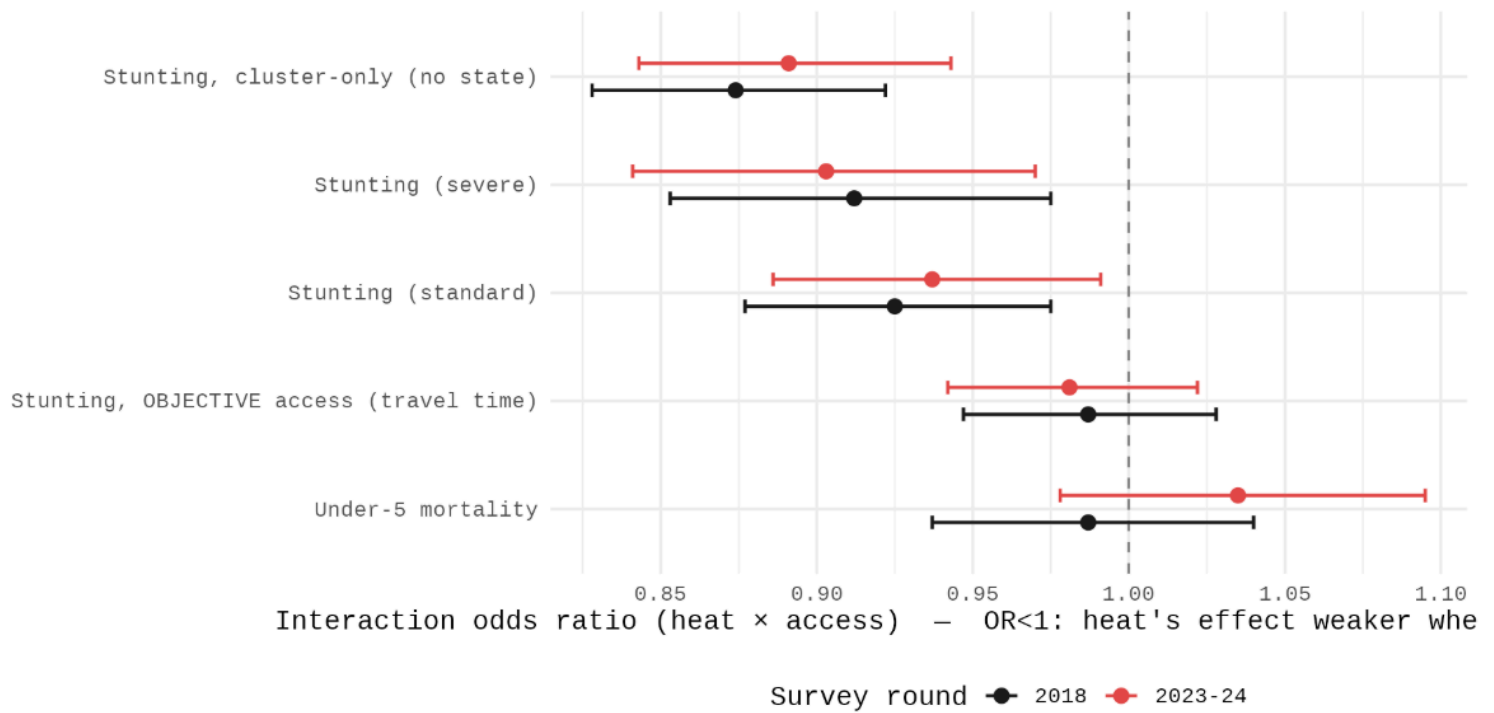


Figure 2

Heat-by-access interaction odds ratios across outcomes and specifications, for both survey rounds. Points are odds ratios; horizontal lines are 95% confidence intervals; the dashed line marks no interaction (OR = 1). Estimates left of the line indicate a reversed interaction (heat's effect weaker where access is poorer). Stunting specifications lie left of the line in both rounds; the objective-access and mortality checks span the line.