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Uttajug, Athicha

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Association between extreme rainfall and acute respiratory infection among children under-5 years in sub-Saharan Africa: an analysis of Demographic and Health Survey data, 2006–2020

Athicha Uttajug ,[1] Kayo Ueda,[1] Xerxes Seposo,[1] Joel Msafiri Francis [2]

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[1]Department of Hygiene, Graduate School of Medicine, Hokkaido University, Hokkaido, Japan
[2]Department of Family Medicine and Primary Care, School of Clinical Medicine, University of the Witwatersrand, Johannesburg, South Africa

Correspondence to
Dr Athicha Uttajug;
u.athicha@med.hokudai.ac.jp

ABSTRACT

Objective Despite an increase in the number of studies examining the association between extreme weather events and infectious diseases, evidence on respiratory infection remains scarce. This study examined the association between extreme rainfall and acute respiratory infection (ARI) in children aged <5 years in sub-Saharan Africa.

Setting Study data were taken from recent (2006–2020) Demographic and Health Survey data sets from 33 countries in sub-Saharan Africa.

Participants 280 157 children aged below 5 years were included.

Outcome measures The proportions of ARI according to individual, household and geographical characteristics were compared using the χ^2 test. The association between extreme rainfall (≥90th percentile) and ARI was examined using multivariate logistic regression for 10 of 33 countries with an adequate sample size of ARI and extreme rainfall events. The model was adjusted for temperature, comorbidity and sociodemographic factors as covariates. Stratification analyses by climate zone were also performed.

Results The prevalence of ARI in children aged <5 years ranged from 1.0% to 9.1% across sub-Saharan Africa. By country, no significant association was observed between extreme rainfall and ARI, except in Nigeria (OR: 2.14, 95% CI 1.06 to 4.31). Larger effect estimates were observed in the tropical zone (OR: 1.13, 95% CI 0.69 to 1.84) than in the arid zone (OR: 0.72, 95% CI 0.17 to 2.95), although the difference was not statistically significant.

Conclusion We found no association between extreme rainfall and ARI in sub-Saharan Africa. Effect estimates tended to be larger in the tropical zone where intense rainfall events regularly occur. Comprehensive studies to investigate subsequent extreme climate events, such as flooding, are warranted in the future.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This is the first study examined the association between extreme rainfall and childhood acute respiratory infection (ARI) in sub-Saharan Africa.
⇒ Our findings provided a representative overview of the association between extreme rainfall and childhood ARI in sub-Saharan Africa as we performed a multicountry analysis.
⇒ Our findings were obtained by adjusting a wide range of important confounders (eg, comorbidities, sociodemographic and environmental factors).
⇒ As we used a cross-sectional household survey data, there might be misclassification and under-reporting of childhood ARI due to self-reported method.

INTRODUCTION

Globally, preventable diseases such as lower respiratory infections are common causes of death among children under age 5.[1] The past two decades have seen a substantial reduction in under-5 mortality, with a decrease in the number of deaths from 9.92 to 5.30 million.[2] This decrease reflects efforts by several stakeholders to address child mortality issues in millennium development goals and sustainable development goals (SGDs).[3] However, a large proportion of deaths in young children due to acute respiratory infection (ARI) across low and middle-income countries suggests that there is still room for improvement in meeting the SGD child survival target by 2030, especially in sub-Saharan Africa.[2]

Climate change is expected to increase the temperature and subsequently alter rainfall patterns and other extreme weather events. Extreme rainfall intensity is also projected to increase across tropical and arid zones in the future.[4] The accelerated change in climate induces extreme weather events, which may have direct and indirect impacts on respiratory health outcomes.[5 6]

A link between extreme rainfall events and influenza was demonstrated in a previous study conducted in the USA.[7] Extreme weather events can increase the risk of ARI by altering climate conditions and promoting

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indoor-seeking behaviours.[8] Specifically, extreme rainfall increases pathogen stability via reduced ultraviolet radiation and increased humidity and promotes indoor crowding during rainfall events. Moreover, a study in the Netherlands reported that flooding that occurs subsequent to extreme rainfall events is associated with an increase in ARI.[9]

The prevalence of respiratory infections is influenced by climatic conditions.[10] Areas with tropical climates, where high rainfall intensity and frequency are observed, have been reported to have a high incidence of ARI due to overcrowding during rainfall events.[11] On the other hand, in dry areas such as temperate and arid zones, the occurrence of ARI is more likely to be pronounced due to dry–cold conditions, which are favourable conditions for virus survival.[12]

Children are particularly vulnerable to the risks of extreme rainfall events as they are more sensitive and are dependent on their family or caregivers. However, evidence that links extreme rainfall to ARI in children is limited, particularly in sub-Saharan African countries where the burden of ARI is high. Understanding the relationship between extreme weather events and infectious respiratory diseases in children in sub-Saharan Africa is important in preparing climate change adaptation strategies as well as developing early warning systems to reduce the risk of future extreme climate events. This study aimed to examine the association between extreme rainfall and childhood ARI in sub-Saharan Africa and explore effect modification by climate zone.

METHODS

Demographic and Health Survey and covariate data

We used individual-level data collected from Demographic and Health Survey (DHS) data sets of the most recent years (2006–2020) from 33 countries across sub-Saharan Africa.[13] The DHS, a cross-sectional nationally representative household survey, provides a wide range of data pertaining to family planning practices, maternal and child health and environmental health indicators.[14] Data used in this study regarding children included ARI occurrence, age, household wealth status, residential area (rural or urban), household members and smoke exposure risk (SER). The occurrence of ARI was defined when the children having any of the following symptoms within 2 weeks prior to the survey: coughs, short and rapid breaths, problems in the chest and a stuffy or runny nose. SER based on information on cooking fuel type and cooking area[15] was used as a proxy indicator of indoor air pollution exposure. Binary variables of malnutrition status (stunted, wasted or underweight)[16] and malaria (microscopy or rapid diagnostic testing) were generated and used as comorbidity measures of ARI. We also obtained a geographic coordinate (Global Positioning System) collected for each household cluster.

Environmental data

We retrieved daily gridded rainfall data from the Climate Hazards group InfraRed Precipitation with Stations (CHIRPS) from 2005 to 2020. Briefly, CHIRPS data are generated from satellite imagery and weather stations at 0.05° resolution from 1981 onward.[17] The validation of these data across Africa has been well documented.[17 18] We computed monthly cumulative rainfall by summing daily rainfall amounts over the last 30 days prior to the DHS. Monthly temperature data were obtained from the fifth generation of European Reanalysis for land applications.[19]

Previously, the threshold exceedance-based definition (top 10%, 5% or 1% of rainfall events) was primarily used for investigating the association between extreme rainfall events and infectious diseases, including enteric illnesses[20–23] and influenza.[7] In the present study, extreme rainfall events were categorised as a binary variable based on monthly rainfall distribution data during 2005–2020. We used the cut-point of 90th percentile of extreme events to investigate the risk of extreme rainfall events on ARI in children because we anticipated that these events would be severe enough to potentially trigger ARI in sub-Saharan Africa. The grid with 0 mm rainfall was excluded from the extreme rainfall classification.

We also explored the role of climate zone on the association of extreme rainfall with childhood ARI using the updated Köppen-Geiger climate data.[24] These data were overlaid with DHS and meteorological data by country boundaries. Climate zones were grouped into tropical, arid and temperate zones.

Statistical analysis

Initially, we compared the proportions of ARI cases according to different characteristics using the chi-squared test (χ^2 test). We subsequently used multivariate logistic regression models to investigate the association between extreme rainfall and childhood ARI. The models were adjusted for comorbidity and meteorological, seasonal and sociodemographic factors. With a large proportion of missing data for some of the covariates (eg, malnutrition, malaria, smoke risk exposure and household member) (table 1), we treated those variables as missing while retained all observations for the analysis. We did not perform the imputation for missing data due to the data are mostly missing at random (eg, the respondent did not answer to some parts of the survey), and further auxiliary variables related to those missing variables are not well provided. We controlled rainfall in the models to reflect the actual relationship between extreme rainfall and childhood ARI. The model with the best fit was chosen by testing the significance of deletion of terms from the maximum model and comparing the change in deviance with χ^2 statistic. The final model excluded malaria, residential area and household members, as there was no significant difference between the models with and without these variables. We performed country-specific

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Table 1 Prevalence of ARI in children under age 5 according to individual, household and geographical characteristics and extreme rainfall

Variable	Number of children	Prevalence of ARI (count, (%))	P value of χ^2 test	Missing (%)
Total	280 157			
Age			<0.01	0.4
<6 months	27 017	1068 (3.8)		
6–11 months	27 334	1608 (5.6)		
12–23 months	52 303	2850 (5.1)		
24–35 months	51 103	2357 (4.3)		
36–47 months	51 933	1960 (3.5)		
48–59 months	50 411	1640 (3.0)		
Malnutrition			0.08	62.8
Without symptoms	63 438	3137 (4.9)		
With symptoms	40 308	1895 (4.7)		
Malaria			<0.01	75.7
Without symptoms	27 518	1232 (4.4)		
With symptoms	39 976	1570 (3.9)		
Wealth quintiles			<0.01	0
Lowest	64 626	3348 (5.2)		
Second	55 573	2542 (4.6)		
Middle	51 504	2202 (4.3)		
Fourth	47 224	1872 (4.0)		
Highest	42 105	1546 (3.7)		
Household members			<0.01	17.2
1–3 persons	28 186	1320 (4.7)		
4–6 persons	116 949	5206 (4.5)		
7–9 persons	70 957	3110 (4.2)		
Smoke exposure risk (SER)			<0.01	35.8
Very Low	209	9 (4.3)		
Low	5108	165 (3.2)		
Medium	64 355	2381 (3.7)		
High	97 713	4775 (4.9)		

ARI, acute respiratory infection.

regression analysis using the same model presented in Equation 1.

$$Y_{i,k} \sim binomial$$

$$Y_{i,k} = \beta_0 + \beta_1 extreme_k + \beta_2 rain_k + \beta_3 temp_k + \beta_4 month_{i,k} + \beta_5 VARS_{i,k} + \mu_k + \varepsilon_{i,k} \quad \text{(equation 1)}$$

where $Y_{i,k}$ is the binary variable for ARI for child i in cluster k; $extreme_k$ is the binary variable for extreme rainfall in cluster k; $rain_k$ is the cumulative monthly rainfall in cluster k; $temp_k$ is the mean monthly temperature in cluster k; $month_{i,k}$ is the categorical variable of survey month for child i in cluster k; $VARS_{i,k}$ corresponds to individual and household-level variables such as child age, household wealth status, comorbidity (malnutrition) and SER for child i in cluster k; μ_k is the DHS cluster random effect term, which accounts for the nesting of children within DHS clusters; and $\varepsilon_{i,k}$ is the error term.

The role of climate zone on the association of extreme rainfall with childhood ARI was further investigated using the same analyses described above. We then pooled climate zone-specific effect estimates using random-effects meta-analysis. Heterogeneity was assessed using I^2 statistics, and the significance of heterogeneity was tested by Cochran's Q statistic. A sensitivity analysis was conducted to examine the robustness of the results by using the cut-points of 95th and 99th percentiles to identify extreme rainfall events in the analyses.

All statistical analyses were performed using the R package *lme4* and *meta* (V.4.1.1, The R Foundation for

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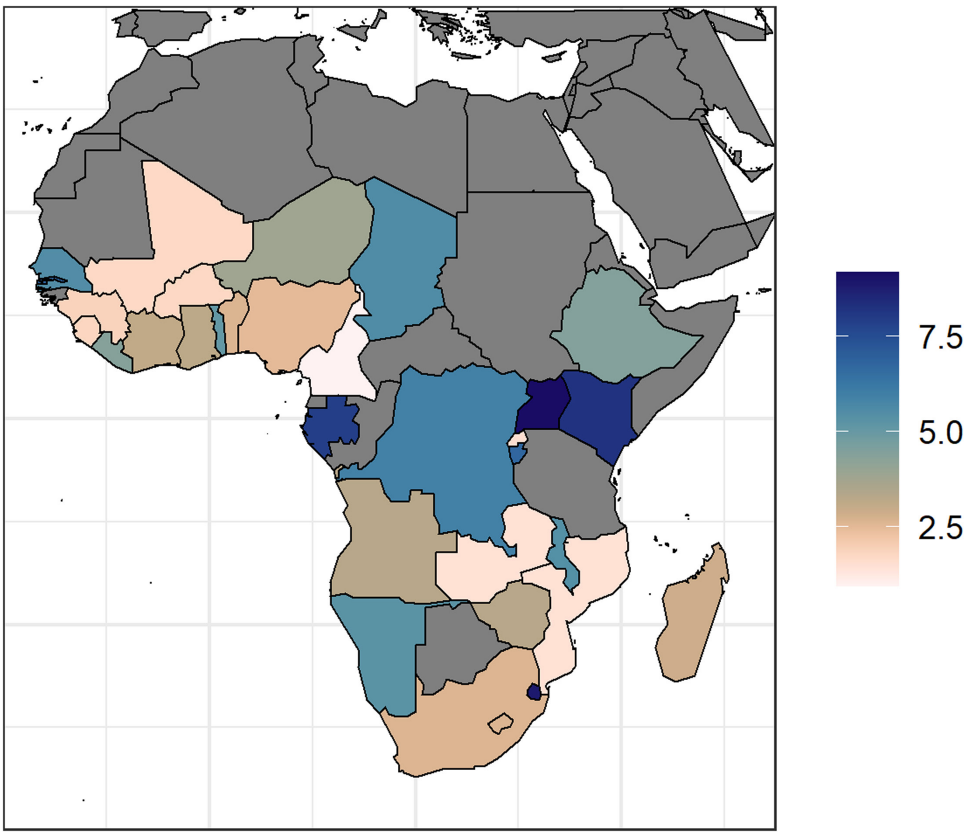


Figure 1 Prevalence of ARI (%) in children under age 5 in sub-Saharan Africa according to the latest DHS datasets. ARI, acute respiratory infection; DHS, Demographic and Health Survey.

Statistical Computing, Vienna, Austria).[25–27] The results are presented as adjusted ORs with 95% CIs.

Patient and public involvement

No patients were involved in selecting the research question, conducting the study or interpretation the results.

RESULTS

Totally, 280 157 children aged <5 years from the recent DHS (2006–2020) in 33 countries across sub-Saharan Africa were examined (online supplemental table S1). Among these children, the prevalence of ARI ranged from 1.0 to 9.1% across sub-Saharan Africa (figure 1). Table 1 shows the prevalence of ARI categorised according to sociodemographic characteristics, climate zones and extreme rainfall events.

The average monthly rainfall during the study period ranged from 0 to 638.5 mm across sub-Saharan Africa (online supplemental table S2). The median monthly rainfall varied by climate zone: 133.8 mm in the tropical zone, 121.8 mm in the temperate zone and 5.4 mm in the arid zone (table 2). The monthly rainfall during the survey period was 0 mm in several countries (online supplemental table S2). Most countries with an average monthly rainfall of >100 mm were in the tropical zone (ie, Burkina Faso, Cameroon, Nigeria and Togo) (online supplemental table S2). Cut points of extreme rainfall throughout sub-Saharan Africa are presented in figure 2: 273.3 mm in the tropical zone, 207.5 mm in the temperate zone and 58.9 mm in the arid zone (table 2). The average monthly temperature varied slightly by climate zone and was 25.4°C in the arid zone, 22.7°C in the tropical zone and 20.2°C in the temperate zone (table 2).

Logistic regression analyses were performed for 10 of 33 countries with adequate sample size of ARI and extreme rainfall events. Figure 3 shows effect estimates of ARI and extreme rainfall for each country. In general, we observed a null association between extreme rainfall and childhood ARI in all countries except for Nigeria (OR: 2.14 (95% CI 1.06 to 4.31)). Figure 4 shows the stratification results of country-specific and pooled effect estimates for tropical and arid zones. A non-significant positive association between extreme rainfall and childhood ARI was observed for most countries in the tropical zone (eg, Nigeria and Uganda).

Table 2 Descriptive summary of monthly temperature, cumulative monthly rainfall and cut point of extreme rainfall by climate zone (mean or median (SD))

Climate zone	Temperature (°C)	Median rainfall (mm)	Cut point of extreme rainfall (mm)
Arid	25.4 (2.4)	5.4 (41.3)	58.9 (59.7)
Temperate	20.2 (2.1)	121.8 (70.4)	207.5 (20.0)
Tropical	22.7 (6.4)	133.8 (130.0)	273.3 (60.8)

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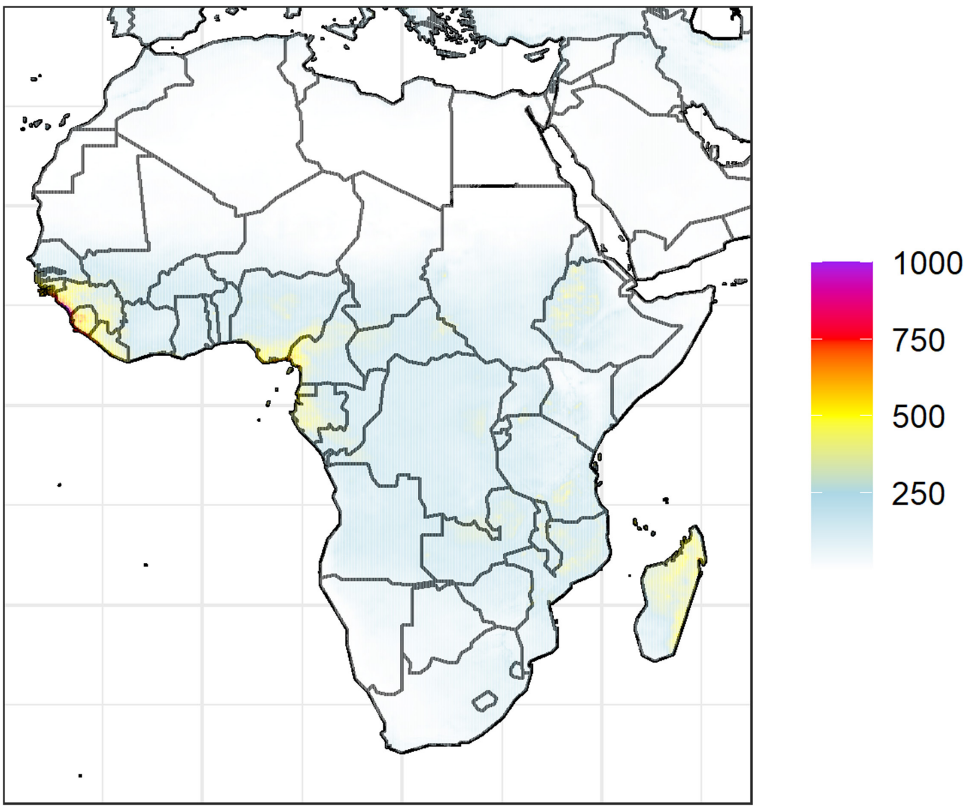


Figure 2 Cut points of extreme rainfall (millimetre (mm)). Data were computed using the 90th percentile of cumulative monthly rainfall from 2005 to 2020.

However, there was no difference in pooled effect estimates between the tropical zone (OR: 1.13 (95% CI 0.69 to 1.84)) and arid zone (OR: 0.72 (95% CI 0.17 to 2.95)). The results of sensitivity analysis revealed no difference in effect estimates between extreme rainfall and childhood ARI after using different cut-points of extreme rainfall (95th and 99th percentiles) (online supplemental figure S1).

DISCUSSION

The present study found no significant association between extreme rainfall and childhood ARI in all sub-Saharan African countries except for Nigeria. In the stratification analysis by climate zone, the pooled results revealed that children living in the tropical zone are more likely to have a higher risk of ARI due to extreme rainfall compared with children living in the arid zone.

A previous study reported a potential mechanism underlying the association between extreme rainfall and respiratory infections.[8] Extreme rainfall can

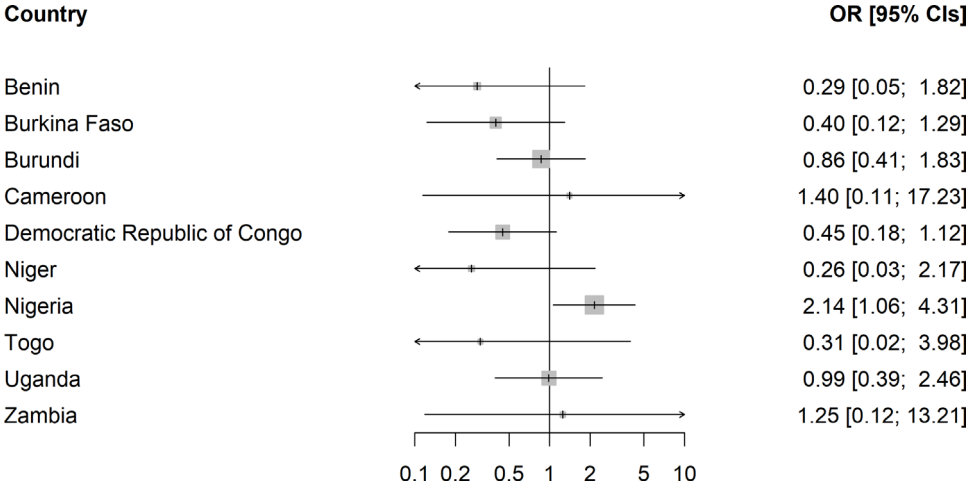


Figure 3 Effect estimates (ORs with 95% CIs) of ARI and extreme rainfall (≥90th percentile) by country. Results are presented in log scale. ARI, acute respiratory infection.

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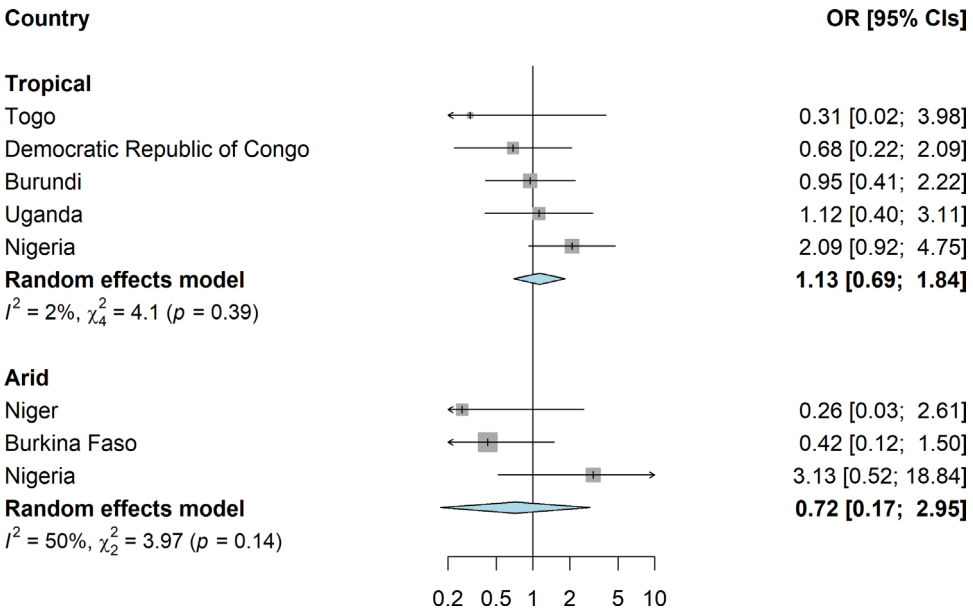


Figure 4 Effect estimates (ORs and pooled ORs with 95% CIs) of extreme rainfall (≥90th percentile) and ARI by country and climate zone. ARI, acute respiratory infection.

influence respiratory infections through changes in environmental conditions (ie, enhancing pathogen stability and persistence by increasing humidity and reducing solar radiation) and human behaviours (ie, prompting increased indoor-seeking behaviour and household crowding). While a positive association between extreme rainfall and respiratory infections (influenza) has been reported,[7] in the present study, we observed a null association between extreme rainfall and ARI in most countries across sub-Saharan Africa. This discrepancy is possibly due to differences in health outcomes, since the outcome used in the present study was more severe as well as differences in area characteristics.

Notably, a significant positive association between extreme rainfall and childhood ARI was observed in Nigeria. The results of sensitivity analysis using different cut-points also revealed similar effect estimates to the principal model. A possible reason for this is that flooding after extreme rainfall events might have promoted indoor-seeking behaviour in this area. Major flooding due to extreme rainfall reported across Nigeria in August 2018 resulted in large-scale population displacement.[28] Indeed, the period of this event overlapped with the period from which DHS data in Nigeria were obtained. Flooding can increase respiratory fungal or polymicrobial infections by increasing inhalational exposure to these microorganisms under wet and humid conditions.[5] In some cases, increased transmission of ARI can occur from overcrowding in shelters after disasters.[29]

We hypothesised that the association between extreme rainfall and childhood ARI may differ by climate zone. Although no difference was observed in the range of effect estimates between the tropical and arid zones, point estimates among children living in the tropical zone were larger. According to previous studies, environmental factors may affect the prevalence of respiratory infections via cold–dry or humid–rainy conditions.[10] In the tropical zone, the prevalence of ARI generally increases during rainy periods.[11 30] The higher the intensity and frequency of rainfall, the longer the time spent indoors, and, hence, the risk of ARI may increase.

The strength of this study is that we performed multi-country analyses, which provide a representative overview of the association between extreme rainfall and childhood ARI across sub-Saharan Africa. A previous study focused on several risk factors that could affect the incidence of ARI, such as climate, socioeconomic and air pollution factors.[31] Importantly, immune status is another crucial factor contributing the risk of ARI in children. The incidence of ARI has also been reported for the children who have other comorbid conditions such as malnutrition, malaria and HIV infection.[32] Specifically, previous studies also documented the co-occurrence of childhood ARI, stunting and diarrhoea in sub-Saharan Africa.[33 34] In the present study, the results were adjusted for several potential individual and household-level risk factors for ARI.

The present study also has several limitations worth noting. First, due to the cross-sectional nature of the data used, the temporal relationship between extreme rainfall and childhood ARI could not be determined, and, thus, causality could not be established. Second, potential misclassification and under-reporting of ARI due to self-reporting by household members rather than diagnosis by medical doctors might have led to an underestimation of the association between extreme rainfall and childhood ARI. A future study should explore the risk of ARI due to extreme rainfall using specific health outcome data, such as hospitalisation or mortality from ARI. Third, we omitted some covariates from the model (eg, malnutritional status, malaria, smoke risk exposure and household members) due to high proportion of missing data, mostly missing at random. Forth, it has been found that child

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HIV infection is the underlying cause of increasing risk of ARI.[35] However, our model did not include HIV as comorbidity because the data are partially available in some countries and separately collected from the standard DHS data set. Finally, the surveys were mostly conducted for some periods of the year, and it is, thus, unlikely that all extreme rainfall events were captured for some countries. We were also unable to quantify the subsequent effect of extreme rainfall events (eg, flooding) in the analyses due to unavailability of data.

With ongoing climate change, extreme rainfall events are expected to increase, which will consequently increase flooding in both wet and dry regions.[4] An increase in these events poses a threat to public health, especially due to infectious illnesses. Understanding the relationship between extreme rainfall and infectious diseases may aid in the preparation for future events, such as developing early-warning systems, in sub-Saharan Africa.

CONCLUSION

The results of this study showed a null association between extreme rainfall and ARI in children aged <5 years in most countries across sub-Saharan Africa. However, effect estimates were larger in the tropical zone. Childhood ARI is a critical health burden in sub-Saharan Africa and is too important to ignore. The drivers of childhood ARI related to extreme climate events should be explored further (eg, spatial distribution and temporal patterns) to better predict their health impacts and guide future disaster preparedness as well as public health policymaking.

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Contributors AU, KU and XS conceptualised the study. AU performed the analyses and drafted the initial version of the manuscript. KU, XS and JMF supported data analysis, interpretation of the study results and revised the manuscript. All authors gave their approval for it to be published. AU is the guarantor responsible for the overall contents of this paper.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study was exempt from review by the ethics committee as publicly available dataset was used and no identifying participant information was obtained. The authorisation for using the data in the current analysis was granted from the DHS program: DHS, ICF International, Rockville, Maryland, USA office upon presenting the research protocol and research objectives.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. All data used in this study are made available by the DHS programme on https://www.dhsprogram.com/.

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ORCID iDs
Athicha Uttajug http://orcid.org/0000-0002-0101-2535
Joel Msafiri Francis http://orcid.org/0000-0003-1902-2683

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