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Population Conflicts and Tropical Cyclones:

Relationship with Birthweight and Stunting in Low and Middle-Income Countries

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by

Jiemin Yao

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ABSTRACT OF THE DISSERTATION

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Population conflicts and tropical cyclones represent significant public health threats, particularly in low and middle-income countries, disrupting societies and profoundly impacting child health outcomes. Birthweight and stunting are key measures for assessing impacts of environmental, nutritional, and social stressors during early development. Although existing research suggests that conflicts and cyclones adversely affect birthweight and childhood stunting, most studies focus on single countries or events. Large-scale studies across multiple countries and extended periods are scarce. This dissertation combines geo-referenced data from various independent sources to examine the impacts of conflicts and cyclones on birthweight and stunting across multiple countries over time. Causal inference methods were used to evaluate potential interventions to mitigate these adversities.

First, the impact of population conflicts on birthweight and stunting was investigated in Sub-Saharan African countries, using data from the 1990-2020 DHS and UCDP GED. Fixed effect regression models compared children in conflict-affected regions to those in unaffected areas, considering conflict intensity and duration. Results showed reduced birthweight and increased stunting odds for children exposed to conflicts, particularly girls in rural areas with less educated mothers and no healthcare autonomy.

Second, the impact of tropical cyclones on birthweight and stunting was examined in Southern and Southeastern Asia using data from the 2000-2018 DHS and EM-DAT. Similar regression models were used. In-utero exposure to cyclones in the Philippines reduced birthweight, especially for children in rural areas. In Bangladesh and India, cyclones increased stunting odds, with more pronounced effects in girls and rural children with less educated mothers. No interactions between cyclones and conflicts were found.

Lastly, hypothetical interventions were estimated using causal inference methods. Results indicated that preventing exposure to conflicts and cyclones could significantly increase birthweight and reduce stunting prevalence.

In summary, these studies provide evidence of the adverse impacts of population conflicts and tropical cyclones on child growth and development, highlighting the need for effective prevention and adaptation strategies in low and middle-income countries. Addressing these issues aligns with the SDGs and offers insights for global public health interventions to mitigate environmental and social disruptions for vulnerable children.

The dissertation of Jiemin Yao is approved.

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CHAPTER 1. BACKGROUND

1.1 Birthweight

Birthweight, the weight of a newborn at birth, is a fundamental indicator of neonatal health and future developmental potential. Low birthweight, defined as a birthweight below 2500g irrespective of gestational age, signals potential maternal malnutrition, ill-health, and inadequate healthcare during pregnancy [1]. The global public health community has focused extensively on reducing the prevalence of low birthweight due to its association with increased risk of infant mortality and long-term health complications. In response, the World Health Assembly (WHA) endorsed a Comprehensive Implementation Plan on Maternal, Infant and Young Child Nutrition in 2012, aiming to achieve a 30% reduction in the number of low birthweight livebirths by 2025. Low birthweight prevalence has also been included as one of the core indicators the Global Nutrition Monitoring Framework as well as in the WHO Global reference list of 100 core health indicators [2]. In addition, the prevalence of low birthweight is listed as indicator to monitor the progress of the Sustainable Development Goals (SDGs) [3].

Despite these efforts, the prevalence of low birthweight remains high. In 2020, an estimated 19.8 million newborns globally were of low birthweight, representing 14.7% of live births (Figure 1-1) [4, 5]. Of those who were born with low birthweight, over 19 million low birthweight births were in Asia, followed by over 8 million in Sub-Saharan African countries [4]. Although there has been a slight decrease in the estimated annual rate of from 2012 to 2020, with 0.3% worldwide, 0.85% in Southern Asia, and 0.59% in Sub-Saharan Africa, insufficient progress has occurred over the past two decades to meet the Global Nutrition Target of a 30% reduction in low birthweight prevalence by 2030 [4].

The health risks associated with low birthweight extend beyond the immediate postnatal period, affecting infants throughout their lives. Compared to infants who were born with normal weights, those with low birthweight are at higher risk of dying. Several studies suggest that more than 80% of neonatal deaths affect newborns with low birthweight, of which two thirds are preterm and one third are term small-for-gestational-age [6-9]. These children also face higher morbidity rates, stunted growth, and long-term health issues, including chronic conditions like cardiovascular disease in adulthood [10-13].

Several factors contribute to low birthweight, including maternal age, multiple pregnancies, obstetric complications, chronic maternal conditions, infections, and nutritional status [1]. Particularly, extreme maternal age, especially younger than 16 years old or older than 40 years old, was associated with increased risk of low birth weight of the child [14, 15]. According to a scoping review, children born from mothers with poor nutritional status were more likely to have lower birthweight compared to those born from mother with normal nutritional status, with an OR of 2.28 [16]. Environmental exposures, such as water contamination and sanitation, were also found to be associated with low birthweight [17]. Moreover, prenatal care plays a significant role in preventing low birthweight. Compared with women who have received optimal level of prenatal care, women who reported not receiving any prenatal care are 1.38 times more likely to give birth to a low birthweight infant [18].

1.2 Childhood Stunting

Stunting, characterized by inadequate linear growth in the early years, reflects a child's failure to achieve their growth potential due to suboptimal health, malnutrition, environmental factors particularly water contamination, and insufficient care [19, 20]. It is evaluated by comparing a child’s length (for children < 2 years old) or height (for children ≥ 2 years old) against age and sex-specific reference standards. A child is considered stunted if their measurement falls below 2 standard deviations (SDs) from the reference standards [21]. As a critical indicator reflecting a child’s growth and developmental status, stunting is a manifestation of malnutrition and a significant public health issue among children. Consequently, stunting is currently a major health priority globally. Reduction of child stunting is one of the six goals in the Global Nutrition Targets of 2025. In addition, a key indicator in the Sustainable

Development Goal (SDG) of Zero Hunger, which aiming to end all forms of malnutrition by 2030 and to achieve the internationally agreed targets on stunting and wasting in children under 5 years of age [22, 23].

According to the data from UNICEF, there were 148 million children under age of five suffering from stunting in 2022 around the world, accounting for 22.3% of all children under age of five [24]. Of all under five children affected by stunting, more than half of them lived in Asia, and 43% were from African countries (Figure 1-2) [24]. The proportions of stunted children among all under the age of five remained significantly high in Asia and Africa compared to children in other regions, with percentages of stunting of 21.3% and 30% for children lived in Asia and Africa, respectively [24]. Despite a global reduction in stunting prevalence from 26.3% in 2012 to 22.3% in 2022, the number of stunted children increased from 177.9 million in 2012 to 148.1 million in 2022 [24]. Notably, 33% of the countries demonstrated some but off-track progress to achieve the child malnutrition SDG, and 15% of the countries showed no or even worse progress towards the stunting reduction target [24]. Moreover, the number of stunted children in Africa demonstrated an increase trend from 61.3 million in 2012 to 63.1 million in 2022, suggesting an alarming alert to public health professionals [24].

Stunting can result in negative health effects during childhood and even lifespan. Short-term health consequences of stunting include (1) increased morbidity and mortality; and (2) greater vulnerability to infectious diseases such as diarrheal diseases and pneumonia resulting from a weaker immune system [25]. Compared with well-nourished peers, children with stunted growth tend to have poor cognitive development, leading to failure to achieve their full developmental potential and educational goal [26]. Stunting also impacts health beyond childhood. It is suggested that stunting may increase the risk of communicable and non-communicable diseases in adulthood and decrease the productivity and economic capability among people who were stunted during their childhood [27]. According to a randomized study conducted in Guatemala, people without stunting growth had an increased wage of $0.62-0.67 per hour compared to those who were stunting during childhood [28].

As a key indicator of malnutrition, stunting shares most of the risk factors with malnutrition among children. Besides biological risk factors such as sex, age, and birthweight of the child, it is suggested that family factors such as socioeconomic status (SES) of the family, household size, as well as sanitation of the house are also potential risk factors of stunting [29-31]. Mother's education level, access to health care during pregnancy, and maternal age and BMI are also considered to be contributed to stunting of the child [30-33]. It is worth noticing that maternal stunting, which is defined as a women who is less than 145 centimeter, is associated with greater risk of having a stunted child, promoting the continuation of the cycle of negative effects of stunting [25]. Several studies also found association between stunting and area of residence, indicating children living in rural areas have higher risk of stunting compared to those in urban areas [34]. Region/community factors, like extreme temperature and rainfall, were associated with increased risk of childhood stunting [35].

1.3 Population Conflicts, Birthweight, and Childhood Stunting

Population conflicts is defined as any organized dispute that involves the use of weapons, violence, or force, across or within national boundaries, and whether involving state actors or nongovernment entities [36]. According to the Uppsala Conflict Data Program (UCDP), there are three types of conflicts: (1) state-based armed conflict: a contested incompatibility that concerns government and/or territory where the use of armed force between two parties, of which at least one is the government of a state, results in at least 25 battle-related deaths in one calendar year; (2) non-state conflict: the use of armed force between two organized armed groups, neither of which is the government of a state, which results in at least 25 battle-related deaths in a year; (3) one-sided violence: the deliberate use of armed force by the government of a state or by a formally organized group against civilians which results in at least 25 deaths in a year [37]. In 2022, UCDP reported 187 active conflict events worldwide, with 56 state-based armed conflicts, 83 non-state conflicts, and 48 one-sided violences [38]. Although the number of conflict events did not increase significantly compared to 2021, the number of conflict-related deaths in 2022 surged remarkably from

120,000 in 2021 to 237,000 in 2022 with a 97% increase [39]. It is suggested that the increase in conflict fatalities was mainly due to the interstate conflict events occurred in Ethiopia and Russia-Ukraine, contributing to 89% of all state-based related deaths [39]. Among all continents, Africa was the region with the highest number of state-based armed conflicts and contributed to the largest number of deaths in one-sided violences, resulting in over 100,000 conflict-related deaths in 2022 [39]. In addition, Africa dominated the increase trend in number of civilians killed by one-sided violence, with approximately 70% of both actors in the violence and violence-related fatalities [39].

The human cost of conflicts extends beyond fatalities. According to the Internal Displacement Monitoring Center (IDMC), there were 62.5 million people internally displaced due to conflict and violent events, and 28 million of them were living in Sub-Saharan Africa [40]. Although typically not combatants, children and women were disproportionately affected by conflicts. It is estimated that, in 2017, 265 million women and 368 million children were living closely to conflict events, and 16.2 million women and 35.7 million children were displaced by conflicts [41]. Children in conflict zones suffer negative consequences due to the violent and destructive nature of conflicts. Mortality is the most direct negative consequence of conflict events. A comparison of mortality trends in children under five years old in 13 conflict-affected Sub-Saharan African countries using the Demographic Health Survey (DHS) data during 1990–2016 showed that, during the active conflict phase, the median annual rate of reduction in child mortality was 1.1% slower in the affected countries in comparison with regional trends [42]. In addition, results from a recent study among infants across 35 African countries from 1995 to 2015 demonstrated that infants who were exposed to armed conflict in their first year of life had a 7.7% higher probability of dying before reaching age 1 year [43]. Beyond mortality, conflicts are also directly related to injuries and disabilities. According to the Global Burden of Disease study, in 2019, the DALYs were around 6 million due to conflicts and terror globally, contributing 0.25% of the total DALYs [44].

Beyond direct trauma, during conflicts, mothers and children are facing population displacement, increased exposure to communicable and non-communicable diseases, increased poverty, reduction in food production, unsafe water and inadequate sanitation facilities, insufficient water supply, and collapsed healthcare infrastructures, resulting in increased risk of poor nutritional status, particularly lower birthweight and stunting (Figure 1-3) [45]. On one hand, refugees and internally displaced persons, were shown to be at increased risks for diarrhea, cholera and infection from parasites such as soli-transmitted helminths due to inadequate water, sanitation and hygiene infrastructure [46]. On the other hand, access to essential services, including healthcare and education, is severely compromised during conflicts. During a conflict, military groups target schools and health centers simply to destabilize the country. In the 1980s, the Mozambican National Resistance destroyed almost 50% of the primary healthcare centers in Mozambique [47]. They also targeted primary schools that resulted in closure of 45% of the primary schools, leading to half a million children lost their access to education [47]. Similar situations occurred in Nicaragua, where 106 of the 450 healthcare units were inoperable as the contras stealing medicines or placing landmines under the clinic walls [48]. In addition, conflict events make travelling to the healthcare facilities more difficult, and fees for health services are likely to increase in response to conflicts. Evidence from a recent study conducted among 35 Sub-Saharan African countries demonstrated that armed conflict was associated with reduced coverage of health services, including facility-based delivery, timely childhood vaccination, and treatment of common childhood illnesses [49]. Another study demonstrated a significant decreased probability of receiving full set of recommended vaccines among children lived in conflict-affected areas [50].

Other mechanisms through which population conflicts affect birthweight and stunting include environmental contamination and food insecurity. Specifically, conflicts can impact water quality, sanitation, and hygiene in conflict-affected areas, which in turn link to a greater risk of infectious diseases thus malnutrition among children [51, 52]. According to a study conducted by Cooten et al., a clean water sources close to home are associated with lower prevalence of malnutrition, and children with safe drinking water had lower risk of underweight compared to children without safe drinking water, based on study results from Johri et al [51, 52].

Moreover, conflicts may damage public infrastructure and interrupt local trade, resulting in reduction of economic activity which may lead to food insecurity [77-79]. Another pathway for food insecurity, which is the disruption of agricultural inputs, such as seeds and fertilizers, may lead to decrease household food availability more directly. According to the Food and Agriculture Organization, the per-capita agricultural production decreases by 1.5% annually during conflict period [80]. As a result, the growth of children is compromised when the amount and types of food available to children are reduced [81].

1.4 Tropical Cyclones, Birthweight, and Childhood Stunting

Climate change, as defined by the Intergovernmental Panel on Climate Change (IPCC), involves significant alterations in climate properties, persisting for decades or longer, including changes in weather variability, climate conditions, and the frequency and intensity of extreme weather events like heatwaves, heavy rainfall, droughts, and tropical cyclones [53, 54]. Recent decades have witnessed events related to climate change globally, including rising temperature, rainfall, and sea level [55-57]. Changes in climate-related factors have resulted in increased frequency and intensity of extreme weather events and natural disasters. According to the Climate Science Special Report from the U.S. Global Change Research Program, the number of extreme climate events were increasing, including extreme rainfall and storms, floods, and wildfires [58]. Moreover, the number of natural disasters are projected to increase in both frequency and intensity, resulting in significant public health challenge globally [59].

Tropical cyclones, comprising hurricanes and tropical storms, rank among the most destructive weather events, with recent seasons producing stronger and longer-lasting cyclones [60, 61]. The anticipated intensification of future cyclones under a warming climate highlights their continued public health relevance [81-83], especially for its negative impacts on nutritional status of affected populations. In the immediate aftermath of a tropical cyclone, household food consumption is often severely disrupted by a variety of factors (Figure 1-4), such as broken food supply chains, increased risk of infectious diseases, lack of safe water and adequate sanitation facilities, insufficient water supplies, and damaged healthcare facilities [62]. These disruptions contribute to deteriorating nutritional conditions for both mothers and children, ultimately leading to lower birthweight and an increased risk of childhood stunting.

Tropical cyclones and their associated storm surges often lead to the destruction or damage of crops, fruits, vegetables, and the spoilage of stored food. In addition, food prices typically surge after natural disasters [63]. As prices escalate, affected families, especially lower-income households, often reduce their consumption of nutritious foods like vegetables, fruits, and meat, resorting instead to cheaper, less nutritious alternatives and decreasing the quantity and frequency of meals. This reduction in quality and quantity of diet inevitably aggravates malnutrition [63, 64].

Tropical cyclones also severely compromise the quality and accessibility of drinking water and disrupt sanitation services. Sources of drinking water, such as ponds and rivers, can become contaminated with saline during cyclones or polluted with hazardous materials during floods, including debris, sewage, and chemicals [65-68], posing significant health risk on infectious disease and compromised growth among children.

The destruction of health infrastructure is another mechanism from cyclones to poor nutritional status among children. Hospitals and clinics are often damaged or destroyed during tropical cyclones, making it difficult to provide necessary medical care. The absence of healthcare workers and a lack of medical supplies further hinder effective treatment, increasing the likelihood of communicable diseases and other health issues. This inadequate healthcare response not only prolongs suffering but also contributes to poor nutritional status due to prolonged illnesses and conditions that inhibit proper food absorption and utilization [66].

CHAPTER 2. RESEARCH OBJECTIVES

2.1 Rationale and Objectives

2.1.1 Research Gap in Studies on Population Conflicts, Birthweight, and Childhood Stunting

According to a systematic review of nine studies, exposure to conflict was significantly associated with increased risk of low birthweight in all studies [69]. However, all included studies focused on single conflicts within one country (e.g., Iraq, Kuwait, Libya, Croatia, Bosnia and Herzegovina, Palestinian territories and Israel), limiting their broader applicability to other countries or regions. Another study, analyzing data from 53 countries, demonstrated an increase of low birthweight by 3.2% among children who were exposed to conflict events during the first trimester [70]. Despite its broad inclusion of countries, this study raised some concerns about exposure assessment and fixed effect modeling. Particularly, this study assigned children's conflict exposure based on the district they resided in, but further included district fixed effect in the regression model, resulting in potential control for exposure itself.

Research on the impact of conflicts on childhood stunting has consistently revealed that children in conflict zones are more likely to experience stunted growth. Studies conducted during the Ethiopia-Eritrea war in 1991–2000 found children who resided in conflict-affected areas experienced higher levels of stunting compared to children living outside the conflict-affected areas in those countries [71, 72]. Similar results were also observed in a study in Burundi [73]. However, these studies were limited by their focus on individual countries and smaller sample sizes. Multi-country analyses have been performed in recent years [43, 50]. A study combined all national surveys in Sub-Saharan Africa during 1995–2005 showed a 2.9% higher probability of stunting in children exposed to conflict in their first year of life compared to children unexposed [43]. However, this study's approach to defining conflict exposure—using a fixed 50km radius—may have led to misclassification in conflict exposure, potentially biasing the effect estimates. Furthermore, the study provided limited information on the heterogenous effect of conflicts across maternal factors, place of residence, and child's sex. Lastly, given that the vulnerable growth trajectory extends over childhood, and the height of the child was generally measured years after childbirth , only considering the conflict exposure during the first year of life does not capture the relevant exposure period and might result in misclassification of the exposure. While the study conducted by Goli et al. considered an extended lifetime exposure period and observed lower Height-for-Age Z-scores in children exposed to conflict events [50], their method did not utilize GPS locations to link conflict data. This lack of precise exposure assessment approach may have introduced exposure misclassification, thus biased their results. In our study, we addressed these gaps by leveraging DHS data from Sub-Saharan Africa during 1990-2020 to examine the relationships between conflict and childhood nutritional outcomes, including birthweight and stunting, as further described below.

2.1.2 Research Gap in Studies on Tropical Cyclones, Birthweight, and Childhood Stunting

According to WHO estimates, it is projected that the number of additional deaths among children under the age of five due to climate-related undernutrition will be 77,000 to 131,000 in 2030, and another study projected that the number of moderate and severe stunting in children under the age of five will be 570,000 to more than 1 million in 2030 [88, 93]. Moreover, several studies reported lower birthweight among infants who had perinatal exposure to tropical cyclones compared to those without cyclone exposure [74-77]. Despite the recognized impact of cyclones on child nutritional status, systematic reviews focusing on their association with childhood malnutrition are lacking. Therefore, we conducted a systematic review aiming to fill this gap by searching existing literatures in PubMed, Embase, PubAg, and Web of Science with terms related to "children", "cyclones", and "malnutrition". The search yielded 3,451 references, from which 13 studies were ultimately included after title and abstract screening. These studies are primarily cross-sectional and spanning six countries (e.g., India, Bangladesh, the Philippines, Honduras, Jamica, and Dominican Republic) [62, 78-89]. Among the analyzed studies, Barrios et al. (2000) [79] and Ahsanuzzaman et al. (2020) [78] identified significant adverse effects of cyclones on child nutrition, with increased stunting prevalence and decreased Height-for-Age Z (HAZ) scores among cyclone-affected children. However, Paul et al. (2012) found no significant differences in stunting percentage between children in cyclone-impacted villages and those in unaffected areas [62]. Additionally, Nowak-Szczepanska (2021) observed significant reductions in Body Mass Index (BMI) and Mid-Upper Arm Circumference (MUAC), further indicators of malnutrition [84]. These findings collectively highlight the negative consequences of cyclones on child development and health, manifesting in increased likelihood of stunting, wasting, and undernutrition. Nevertheless, these studies often concentrated on a single cyclone's impacts, mainly assessing outcomes one to two years post-event.

Based on our literature review, studies exploring the association of tropical cyclones on birthweight and stunting are scarce, with existing research often limited to single events within restricted areas. Furthermore, findings from these studies show inconsistency regarding both birthweight and stunting outcomes. Though some studies on childhood stunting were conducted in Asian countries (e.g., Bangladesh, India), most of the studies on birthweight were based in the United States. This geographical skew leaves a striking knowledge gap regarding cyclone impacts in other cyclone-prone countries where populations are likely disproportionally affected. To address this gap, our study seeks to examine the association between tropical cyclones and birthweight and stunting in children from Southern and Southeastern Asia, underscoring the potential public health implications of these climatic events, as further detailed below.

2.1.3 Overall Objectives

Current research on associations between population conflicts, tropical cyclones, and birthweight and childhood stunting, respectively, is limited, and related research with a global focus is even more rare. Therefore, the overall goal of this dissertation is to examine population conflicts and tropical cyclones, respectively, as risk factors for birthweight reductions and childhood stunting in low and middle-income countries utilizing DHS data. Further potential effect measure modification by maternal factors and place of residence will be assessed. Finally, hypothetical interventions will be constructed based on real world scenarios addressing conflicts and cyclones in relation to birthweight and childhood stunting among children in low and middle-income countries. The hypothesized pathways from population conflicts to birthweight and childhood stunting are shown in Figure 2-1 and Figure 2-2.

2.2 Specific Aims and Hypotheses

Aim 1: To examine population conflicts in relation to birthweight and childhood stunting; specifically, to estimate the impact of population conflicts on birthweight and stunting as measures of nutritional status among children under the age of five in Sub-Saharan African countries. Additionally, to examine potential effect measure modification on the associations between conflicts and the nutritional outcomes by maternal factors, child sex and place of residence.

- **Hypothesis 1**: Children exposed to population conflicts during pregnancy (here operationalized as the period of 1 year before birth) have lower birthweight compared to children unexposed to conflict events during the same period in Sub-Saharan Africa. In addition, the effects are more pronounced for more severe and longer duration conflicts.
- **Hypothesis 2**: The impact of population conflicts on birthweight varies by maternal factors, child sex and place of residence.
- **Hypothesis 3:** The risk of stunting for children living in conflict-affected regions during their childhood (0-4 years) is greater compared to those who lived in areas without conflicts in Sub-Saharan Africa. In addition, the effects are more pronounced for more severe and longer duration conflicts.
- **Hypothesis 4**: The impacts of population conflicts on the risk of stunting is modified by child’s sex, mother’s education level, place of residence, and mother’s autonomy on healthcare decision-making.

Aim 2: To examine the impacts of tropical cyclone in relation to birthweight and childhood stunting; specifically, to estimate the impact of tropical cyclones on birthweight and stunting as measures of nutritional status among children under the age of five in Southern and Southeastern Asian countries. Additionally, to examine potential statistical effect measure modification on the associations between cyclones and the nutritional outcomes by maternal factors, child sex and place of residence. The hypothesized pathways from tropical cyclones to birthweight and childhood stunting are shown in Figure 2-3 and Figure 2-4.

- **Hypothesis 1**: Children exposed to tropical cyclones during pregnancy (here operationalized as the period of 1 year before birth) have lower birthweight compared to children unexposed to tropical cyclones during the same period in Southern and Southeastern Asia.
- **Hypothesis 2**: The impacts of tropical cyclones on birthweight varies by maternal factors, child sex and place of residence.
- **Hypothesis 3:** The risk of stunting for children living in cyclone-affected regions during their childhood (0-4 years) is greater than those who lived in areas without cyclones in Southern and Southeastern Asia.
- **Hypothesis 4**: The impacts of tropical cyclones on the risk of stunting is modified by child's sex, mother's education level, and place of residence.
- **Hypothesis 5:** There is interaction between tropical cyclones and population conflicts in affecting the estimated risk of childhood stunting among children in Southern and Southeastern Asia.

Aim 3: To conduct hypothetical interventions addressing population conflicts and tropical cyclones in relation to birthweight and childhood stunting among children in low and middle-income countries in Sub-Saharan Africa and Southern and Southeastern Asia.

- **Hypothesis 1:** The mean birthweight increases in relation to the hypothetical interventions that reduce the level of exposure to population conflicts among children in Sub-Saharan African countries.
- **Hypothesis 2**: The mean prevalence of stunting decreases in relation to the hypothetical interventions that reduce the level of exposure to population conflicts among children in Sub-Saharan African countries.
- **Hypothesis 3**: The mean birthweight increases in relation to the hypothetical interventions that reduce the level of exposure to tropical cyclones among children in Southern and Southeastern Asian countries.
- **Hypothesis 4**: The mean prevalence of stunting decreases in relation to the hypothetical interventions that reduce the level of exposure to tropical cyclones among children in Southern and Southeastern Asian countries.

CHAPTER 3. POPULATION CONFLICTS IN RELATION TO BIRTHWEIGHT AND CHILDHOOD STUNTING

3.1 Introduction

Worldwide, nearly 368 million children live in close proximity to conflict zones, with 35.7 million displaced due to ongoing conflicts [41]. Such humanitarian crises severely disrupts child health, leading to increased risks of low birthweight and stunting—conditions exacerbated by the destruction of healthcare infrastructure, pervasive food insecurity, and poor living conditions, including inadequate water and sanitation [45]. These factors collectively undermine the nutritional status of children from birth to childhood, critically impairing their growth and development in conflict-affected regions.

Prior research consistently shows that conflict exposure increases the risk of low birthweight and childhood stunting [69, 71-73]. However, these studies, often limited to specific conflicts within a single country, lack generalizability across diverse settings. Multi-country analyses have been conducted in recent years [43, 50, 70], while they covered broader geographical regions with extensive study periods, these studies have a number of methodological limitation including potential bias due to exposure misclassification and incorrect model specification, as noted above.

Here, we aimed to address these gaps by leveraging DHS data from Sub-Saharan Africa during 1990-2020 to examine the relationships between conflict and childhood nutritional outcomes, including birthweight and stunting, considering overall and country-specific impacts. In addition, we aimed to assess whether the impacts of conflict on birthweight and childhood stunting were heterogenous by child’s sex, mother’s education, and place of residence. Lastly, we examined whether the associations of conflict on birthweight and stunting vary by conflict severity measured as number of conflict-related deaths, conflict duration, and type of conflict.

3.2 Methods

3.2.1 Study Population

The study population for this study was children aged 0-5 years old in the 20 Sub-Saharan African countries from the 1990-2020 Demographic Health Survey (DHS). Funded by the U.S. Agency for International Development (USAID), the DHS is a series of nationally representative cross-sectional surveys in over 90 developing countries since 1984 [90]. The sampling strategy of DHS is based on a two-stage method. Initially, clusters representing villages or communities are selected with the probability proportional to the size of the cluster [90]. Subsequently, within each sampled cluster, approximately 20-30 households are randomly selected for detailed interviews [90]. The interviews are conducted by trained staffs using standardized methods to collect various information on household socioeconomic status, nutrition, healthcare access, behavior, and geo-referenced location of the cluster [90].

Children were eligible for inclusion in our study if they met the following criteria: (1) they were under five years old; (2) they were alive at the time of the survey; (3) their anthropometric measurements are valid; (3) geo-referenced information on children's residential locations was available and valid; (4) conflict information of the child's residential area was available. Exclusion criteria for our study were: (1) children died before the survey; (2) information on anthropometric measurements, residential location, conflict exposure, or other covariates are missing. To enhance the robustness of our findings, we further excluded countries where less than 5% of children experienced conflict exposure, resulting in a final sample of 146,229 births in 17 countries and 225,605 children in 20 countries for birthweight and stunting analyses, respectively.

3.2.2 Outcome Ascertainment of Birthweight and Stunting

We used all available data from 1990-2020 DHS surveys in Sub-Saharan African countries as the data sources on child's birthweight and stunting status in our analyses. Children's birthweight was obtained from birth records or from mothers' recall. Anthropometric measurements, including length or height for children, were collected by DHS-trained interviewers during the survey [90].

To assess stunting status, DHS calculates Height-for-Age Z-scores (HAZ) based on the World Health Organization (WHO) growth standards [91]. In our study, we defined children being stunted as their HAZ falls below -2 SDs from the WHO reference population median. Thus, in our analysis, children with an HAZ less than -2 SDs were classified as stunted (assigned a value of 1), while those above this threshold were considered not stunted (assigned a value of 0).

3.2.3 Exposure Assessment of Population Conflicts

3.2.3.1 Population conflicts definition and data collection process

Data on conflict events were obtained from the UCDP Georeferenced Events Dataset (UCDP GED) [92, 93]. All conflict events that occurred from January 1, 1989, to December 31, 2020, were included in our analyses. According to the UCDP GED, a conflict event is defined as any instance where armed force was used by an organized entity against another such entity or civilians [94]. Information of each conflict event is collected using a rigorous process, in which potential events are identified from local and global news-sources, Non-Governmental organizations (NGOs), and Inter-Governmental organizations (IGOs) reports, field reports, governmental publications, and research articles or books [94]. Details of conflict events, including the timing of conflicts, type of conflicts, GPS coordinates of conflict centroids, and the number of deaths due to each conflict event, are then collected according to the sources [92, 93]. To ensure the quality of the data, the conflict events are at least triple-checked by the coders, project managers, and automatic tests [93, 94].

GPS coordinates of the conflict events are determined by employing various sources such as global gazetteers (e.g. the United States National Geospatial-Intelligence Agency's [NGA] GEOnet Names Server [GNS]), local maps, as well as historical maps [94]. UCDP codes conflict locations at the areal level that is the most precise known (e.g., city of Harar in Ethiopia), with villages or town are the most granular location.

However, streets, neighborhoods, and parts of towns are not coded, even when such information is available in the reporting. These locations are then recoded to a single pair of coordinates, placed at the centroid of the most precise known location. The dataset included a precision indicator of what level of precision is available for the conflict location – (1) a village or district, (2) near a specific location, (3) a higher-level administrative division, or (4) the whole country [93, 94]. These provided GPS coordinates therefore limited information on the true location and extent of areas affected by corresponding conflicts, resulting in potential measurement error. Therefore, we mapped each event's point coordinates to their corresponding administrative level 1 region (typically a province) using the Global Administrative Areas Database (GADM) [95], and defined the corresponding regions as conflict-affected areas.

3.2.3.2 Exposure period definition

We used different exposure period windows for birthweight and stunting analyses. For analyses on birthweight, the exposure period was one-year preceding birth. For stunting analyses, we expanded it to one year before birth until the date of DHS survey (0-5 years).

3.2.3.3 Population conflicts-related variables definition

Our analytical framework transformed the UCDP GED data into a binary variable indicating whether children in the DHS dataset were exposed to conflict events during a pre-defined exposure period specified above. This was achieved by linking geospatial data from children's residences, as recorded in the DHS surveys, to the conflict event locations from the UCDP GED. DHS interviewers recorded the central coordinates of each survey cluster, which were then subject to random displacement (up to 2 km in urban clusters, 5 km in 99% of the rural clusters, and 10 km in 1% of the rural clusters) for confidentiality reasons [96, 97]. To account for these random displacement and potential measurement errors, we created a 5 km radius buffer around each DHS cluster as a basis for linking conflict events to children's exposure, following DHS guidelines [97].

Children were coded as exposed if there was any conflict event occurred in their corresponding 5-km buffered DHS clusters during the pre-defined exposure period. Besides binary conflict exposure, we also incorporated categorical variables such as conflict intensity and conflict duration to examine the prolonged effects of conflict exposure. The conflict intensity variable was defined based on the quintiles of the total conflict-related fatalities (birthweight: no conflict, 0-3 deaths, 4-13 deaths, 14-59 deaths, 60-1,000 deaths, >1000 deaths; childhood stunting: no conflict, 0-7 deaths, 8-25 deaths, 26-110 deaths, 111-1,000 deaths, >1000 deaths). Conflict duration, on the other hand, was the length between the end date of the latest conflict and the start date of the earliest conflict occurred during the child's exposure period, and we categorized them into relevant groups accordingly (birthweight: no conflict, ≤1 month, 1-6 months, 6-12 months; childhood stunting: ≤1 year, 1-2 years, 2-3 years, ≥3 years). In addition, continuous variables for conflict intensity (per IQR increase) and duration (per additional year) were also created.

3.2.4 Statistical Analysis

3.2.4.1 Primary analyses

To explore the impact of conflict on birthweight and stunting, respectively, we compared the birthweight and stunting odds among children exposed to conflict with children unexposed to conflict within the same country over time. Specifically, we deployed fixed effect linear regression model (1) for birthweight and logistic regression model (2) for childhood stunting constructed by Wagner et al. to account for country fixed effect and year fixed effects [43], which are shown in equation below:

$$Y_{itc} = \beta_1 X_{tc} + \mu_l + \varphi_c + \gamma_t + \beta_2 C_{itc} + \varepsilon_{itc} \qquad (1)$$

$$\Pr(Y_{itc}) = \beta_1 X_{tc} + \mu_l + \varphi_c + \gamma_t + \beta_2 C_{itc} + \varepsilon_{itc} \qquad (2)$$

Where Y_{itc} denotes the (1) birthweight or (2) stunting status for child i in year t of country c, with X_{tc} representing the exposure indicator of whether the child was exposed to conflict during the exposure window. To account for country variations and temporal trend, the model incorporates country (φ_c) and year (γ_t) fixed effects. In addition, a series of pre-defined confounders (C_{imtc}), including child's sex (boy or girl), birth order (continuous), mother's age at birth (continuous), mother's education (low: equal or less than primary, high: equal or greater than secondary), place of residence (urban or rural), cluster average temperature (continuous), rainfall (continuous), and nightlight luminosity (continuous, a proxy of poverty and population density), were adjusted for in all regression models [43, 49, 98]. For birthweight, we additionally added whether a child was part of multiple births (yes/no) as a covariate, while child's age (continuous) was included for analyses in childhood stunting. The regression coefficient of X_{tc}, β_1, represented the change in birth weight or logit odds of stunting comparing children exposed to conflict with children unexposed to conflict. To further address the two-steps sampling strategy in DHS, we used robust standard errors clustered at the DHS cluster level [43].

We further estimated the effects of conflict types, intensity, and duration on both outcomes using the same regression model. Categorical variables indicating conflict duration and related fatalities were incorporated, along with binary indicators for distinct conflict types, to examine their differential impacts.

3.2.4.2 Stratified analyses

To assess the effect of heterogeneity by various factors, we performed stratified analyses by child's sex, mother's education, place of residence, and mother's autonomy on healthcare choice. Heterogeneity across groups was evaluated by Wald test assessing whether the interaction term between the exposure and the factor was statistically significantly different from zero ($p_{heterogeneity}<0.05$). Country-specific analyses on the association of conflict exposure on birthweight and childhood stunting were also performed for children in each country.

3.2.4.2 Sensitivity analyses

It is likely that older children are more likely to experience conflicts during their childhood, and child age is associated with stunting. To explore whether the length of exposure window period (from one year before birth to DHS assessment) affected the association between population conflicts and childhood stunting, we repeated the primary analyses restricting children who were five years old.

All statistical tests were two-sided. We interpreted statistical significance at $p<0.05$. We performed all analyses using R version 4.1.2 (The R Foundation for Statistical Computing) [99].

3.3 Results

3.3.1 Population Conflicts and Birthweight

The final dataset comprised 146,229 births from 17 Sub-Saharan African countries born between 1990-2020, with a total of 21,806 conflict events and 782,556 conflict fatalities associated (Figure 3-1). A summary of demographic characteristics is presented in Table 3-1 and Table 3-2. Specifically, 50.8% of the included births were boys, and 44.1% of them lived in urban areas. The mother's mean age at childbirth was 27.3 years, and 41.6% of them had a higher education level (completed ⩾ secondary schooling). In the observed dataset, 28.8% of the children had in-utero population conflicts exposure.

Our findings suggested a statistically significant decrement in birthweight for infants exposed to conflicts in-utero. Specifically, in Sub-Saharan African countries, any conflict in the child's province one year prior to birth was associated with a 27.3g reduction in birthweight (95% CI -38.7, -15.8) in Sub-Saharan African countries, before adjusting for confounders (Table 3-3). The association remained in the fully adjusted model, indicating a 22.3g reduction (95% CI -33.4, -11.1). The negative estimated impact was the strongest for state-based conflicts, relating to a 36.8g decrease (95% CI -52.7, -21.0) in birthweight (Table 3-3 and Figure 3-2). Other conflict types showed similar impacts on birthweight, with -24.2g (95% CI -43.5. -4.9) and -23.7g (95% CI -36.8, -10.5) for nonstate-based and one-sided conflicts, respectively.

Notably, birthweight reductions were more substantial with increased conflict intensity and duration (Table 3-3 and Figure 3-2). Among our study population, the reduction of birthweight among children was greater with higher conflict intensity. Compared with no conflict, the birthweight reduction was -14.0g (95% CI -28.6, 0.5) for conflicts with 0-3 deaths, -16.7g for (95% CI -36.0, 2.7) conflicts with

4-13 deaths, -13.3g (95% CI -32.1, 5.4) for conflicts with 14-59 deaths, -30.6g (95% CI -52.3, -8.9) for conflicts with 60-1,000 deaths, and -82.2g (95% CI -116.7, -47.8) for conflicts with more than 1,000 deaths. Although the effects for conflicts with less than 60 deaths were not statistically significant, test for trend suggested statistically significant increase trend across conflict intensity groups (p-trend < 0.001). Furthermore, when treating conflict intensity as a continuous variable, our analyses indicated a statistically significant decrease of 2.0g (95% CI -3.2, -0.7) of birthweight per IQR (70 deaths) increase in conflict-related deaths. Similar trends were observed in relation to the impact of conflict duration on birthweight reduction, with -11.6g (95% CI -24.8, 1.6) for conflicts lasting less than 1 month, -24.5g (95% CI -43.3, -5.7) for conflicts lasting 1-6 months, and -33.3g (95% CI -50.6, -15.9) for conflicts lasting 6-12 months (p-trend <0.001). Each additional month of conflict exposure is related to a 3.2g (95% CI -4.9, -1.5) decrease in birthweight.

Results from stratified analyses (Table 3-4 and Figure 3-3) indicated that boys and girls were equally affected by conflict events ($p_{heterogeneity}$=0.0977), while greater reduction of 29.48g (95% CI -43.23, -15.73) in birthweight was observed among girls compared to boys (change in birthweight: -15.26g, 95% CI -29.38, -1.13). Similar effect estimates were also detected among children living in rural areas (change in birthweight: -28.03g, 95% CI -43.43, -12.62) and urban areas (change in birthweight: -15.65g, 95% CI -30.59, -0.70, $p_{heterogeneity}$=0.2426). Interestingly, maternal healthcare autonomy appeared to mitigate the negative impacts of conflicts on birthweight. Infants whose mother could make decision on their healthcare exhibited a 9.49g (95% CI -23.09, 4.11) decrease of birthweight, compared to a statistically significant birthweight reduction of 39.66g (95% CI -57.68, -21.63) among those who were born to mothers without healthcare autonomy. Lastly, infants of mothers with higher education attainment had less reduction in their birthweight (change in birthweight: -2.77g, 95% CI -18.21, 12.66), compared to infants whose mothers were in lower education level (change in birthweight: -36.52g, 95% CI -50.56, -22.48).

Country-specific associations showed variations by country in both directions (Table 3-5 and Figure 3-4). Particularly, we found statistically significant decrease of birthweight among infants who lived in conflict-affected areas in Angola, Cameroon, and Congo Democratic Republic. All these estimates were greater than the pooled estimate, and the strongest negative estimated effect was observed for infants in Angola (change in birthweight: -161.95g, 95% CI -273.47, -50.44).

3.3.2 Population Conflicts and Childhood Stunting

A total of 225,605 children from 20 Sub-Saharan African countries' DHS in 1990-2020 were included in the final dataset for childhood stunting, with 22,241 conflict events and 795,269 conflict fatalities linked to these children (Figure 3-1). Demographic characteristics of our study population were presented in Table 3-6 and Table 3-7. In general, the mean age of included children was 2.4 years, with 50.2% of them were boys, and 27.8% of them living in urban areas. Mothers of these children had a mean age at childbirth of 27.2 years, and 24.8% had completed ⩾ secondary education. Among these children, 48.1% were exposed to conflicts during their childhood.

When treating conflict exposure as a binary variable (yes/no), we observed a markedly increased odds of stunting among children who were exposed to any conflicts during their lifetime compared to those who were unexposed in the same country (Table 3-8 and Figure 3-5). Conflict events resulted in 1.13 times greater odds (95% CI 1.09, 1.17) of being stunted among children with lifetime conflict exposure compared to those without. The negative effects were similar across different types of conflicts (Table 3-8 and Figure 3-5).

Examining the associations between conflict intensity and stunting, results suggested that the negative impacts of conflict events increased in relation to high-intensity conflicts (Table 3-8 and Figure 3-5). Compared with children who were not exposed to conflict events, those who experienced conflicts with 8-25 deaths (OR = 1.26, 95% CI 1.19, 1.32) and 111-1,000 deaths (OR = 1.22, 95% CI 1.20, 1.30) had the greatest odds of being stunted. When investigating the association between conflict duration and stunting (Table 3-8 and Figure 3-5), we estimated 2% greater odds of stunting among children with every one-year additional conflict exposure. The strongest negative estimated effect was found for conflict events lasting for 2-3 years, where odds of stunting among exposed children was 1.33 times (95% CI 1.26, 1.41) greater compared to those with no conflict exposure.

The stratified analyses (Table 3-9 and Figure 3-6) suggested that girls were more vulnerable than boys for being stunted when exposed to conflict events ($p_{heterogeneity}$=0.0144). The odds of stunting was 1.14 times greater (95% CI 1.10, 1.19) among girls who were exposed to conflicts during childhood compared to those unexposed, whereas the estimated effect was 1.09 for boys (95% CI 1.05, 1.14). Notably, the heterogenous effects were observed among children with different maternal education levels ($p_{heterogeneity}$<0.001), while no statistically significant heterogeneity was observed across mothers with different levels of autonomy in healthcare decision making. In addition, statistically significantly greater adverse effect of conflicts ($p_{heterogeneity}$<0.001) was estimated among children living in rural areas, with an odds ratio of 1.15 (95% CI 1.10, 1.19) compared to those in urban regions (OR = 1.13, 95% CI 1.05, 1.22).

Country-specific analyses on conflict exposure in relation to stunting indicated that children exposed to conflict events in Burundi, Congo Democratic Republic, Ghana, Kenya, Mali, and Zimbabwe were at greater odds of being stunted compared to their unexposed peers (Table 3-10 and Figure 3-7). Specifically, conflict events in those countries led to notable increased odds in stunting of 1.20 (95% CI 1.03, 1.40), 1.27 (95% CI 1.05, 1.52), 1.44 (95% CI 1.08, 1.92), 1.13 (95% CI 1.03, 1.23), 1.20 (95% CI 1.02, 1.41), 1.40 (95% CI 1.22, 1.60) for Burundi, Congo Democratic Republic, Ghana, Kenya, Mali, and Zimbabwe, respectively. These estimates were higher than the negative estimated effect observed in the analysis among children with all countries combined.

Sensitivity analyses restricting children with age of five demonstrated similar results as in all children (Table 3-11).

3.4 Discussion

Utilizing geo-referenced data and fixed effect regression models, this study indicates that population conflicts relate to reduced birthweight and increased odds of stunting among children in Sub-

Saharan Africa. The negative effects were greater with higher intensity and longer duration of conflicts. Additionally, children of women lacking autonomy in healthcare decision-making were particularly vulnerable in having lower birthweights, and the detrimental impact of conflicts on childhood stunting was notably severe for girls.

Pooling data from 20 countries with diverse conflict characteristics, our findings demonstrated that children in conflict-affected areas faced substantial growth disadvantages already during prenatal development as manifest at birth, potentially persisting into childhood, increasing the likelihood of stunting. This aligns with prior research demonstrating the negative impact of population conflicts on child health outcomes, both in single-country studies and recent multi-country analyses. One recent study included eligible DHS countries from 1990 to 2020 found a significant decrease of birthweight by 2.8% among children exposed to conflicts during their first trimester [70], and studies found an increased probability of stunting associated with conflict exposure either in the first year of life [43] or throughout the entire childhood [50]. Our findings contribute to the existing literature by assessing effect heterogeneity across different demographic groups, including child’s sex, mother’s education level, mother’s autonomy on healthcare, and place of residence. These results align with previous studies, where mothers with higher education attainment and autonomy for healthcare are linked to decreased risk of childhood stunting [98]. This connection may be explained by the fact that mothers with autonomy on healthcare decisions are more likely to seek better prenatal and postnatal care even during conflict times, therefore alleviating the negative impacts of population conflicts on children’s growth. It is worth noting that, though no statistically significant heterogeneity was observed, the negative effects of conflicts on birthweight were generally more pronounced among children in urban areas. This may be explained by the fact that conflict-related violence in Africa has shifted from rural to urban areas during our study period [100].

With regard to conflict exposure assessment, it is important to note that the size of the area to which conflict is assigned in the UCDP dataset is determined by the precision of reporting, not its actual extent or scope. Similarly, the provided GPS coordinate locations depend on the precision level of reporting, as they are placed at the centroid of the most precise known areal location/polygon. Therefore, directly using these centroid point locations without regard for the precision and subsequent polygon size giving rise to their location could lead to substantial exposure misclassification. For all conflicts on the African region in the UCDP file, 53% were known at the precision level of towns/villages, 22% were known within a 25 km radius, 12% could be linked to a second-level administrative unit (e.g., district), and 9% to a first-order administrative unit (e.g., municipality). The remaining conflicts could only be associated with a linear feature (e.g., river or border) or fuzzy polygon, the entire country, or sea/air coordinates. Therefore, roughly 96% of conflicts are known at the first-order administrative level, or more exact.

Therefore, the choice of using point-level versus areal-level data to represent conflict exposure involves several considerations. First, whether the exposure data is a valid representation of reporting precision. As previously mentioned, conflict locations are coded at best, at the town- or village-level in the UCDP dataset. Using the point-level coordinates therefore does not incorporate the true locational uncertainty associated with this data. While previous researchers assigned a buffer (e.g., 50 km) around these point locations to assign conflict exposure status [43, 49, 101], this method fails to address the random displacement of the point location to the centroid of areal units of possibly vastly different sizes. Second, whether the exposure data is a valid representation of actual conflict extent. Using point-level coordinates with or without a buffer can be argued to not be the most realistic representation of the actual spatial extent and context of the conflict. Using areal locations, and especially those informed by administrative boundaries, which are closely related to political, legal, and sociocultural factors, may better represent the spatial extent and context of armed conflicts. In fact, guidance on handling areal units in spatial analysis asserts that the closer the areal unit used for analysis represents the actual exposure (or outcome) being assessed, the more valid results will be [102]. However, areal locations may also not accurately represent the exact location and extent of conflict, especially if the chosen administrative units are too small or large.

However, on the other hand, aggregating to larger areal units for analysis can introduce bias, especially if there is significant variation in exposure within the areal units. The modifiable areal unit problem (MAUP) is related to biases arising from aggregation, as well as arbitrary and modifiable sizes, shapes, and arrangements of areal units, which may affect the validity of analyses [102]. Analyzing data at the areal level is therefore more complex, especially when dealing with irregularly shaped areas of different sizes.

Our study had further limitations. First, while we attempted to identify the impacts of conflict events on birthweight and childhood stunting by using a fixed-effect design, and we controlled for multiple fixed effects and confounders at the individual, household, and cluster levels, residual confounding by potential unmeasured confounders within countries could still be present. Second, our analyses could be affected by selection bias due to missing data. We noticed a substantial amount of missingness on children's birthweight (more than 50% missing). Comparing infants with and without birthweight data available (Table 3-12), we noticed that this missingness was more likely occurring in conflict-affected areas, where collecting data is challenging and not a key priority [103]. However, this potential selection bias would result in underestimation of conflict exposure, likely pronounced for more severe exposure resulting in downward bias (Table 3-12), indicating the negative effects of conflicts were underestimated by our study results. Third, our study might suffer from survival bias where children died before anthropometric measurements were taken or pregnancies resulting in miscarriages because of conflict events. This bias, though, was expected to result in underestimation of the conflict effect. Fourth, spatial imprecision in UCDP GED and random displacement of DHS cluster locations might introduce measurement error in assessing conflict exposure. To minimize it, we converted the point coordinates of conflict events into their corresponding administrative level-1 (ADM1) polygons, since 96% of the conflict events were recorded at levels more geo-granular than ADM1. In terms of DHS cluster locations, to guard against measurement error, we created a 5km buffer around each cluster, as recommended by DHS [97]. Fifth, the cross-sectional design of the DHS limited our ability to explore the underlying mechanisms linking population conflicts to children's nutritional status comprehensively. Finally, effect estimates varied across countries, which may be partially explained by differences in macroeconomic status, health system, and the existence of national and local programs, as well as differences in data ascertainment.

In conclusion, our research provides empirical evidence of the adverse impacts of population conflicts on birthweight and stunting, especially for girls and children of less educated mothers without healthcare decision-making autonomy. These findings underscore the urgent need for policymakers to prioritize the health of children in conflict-affected regions, focusing on reducing conflicts and mitigating the impacts on birthweight and stunting, especially for those who are the most vulnerable. Future studies with precise conflict-affect exposure estimation possibly based in more valid area definition and longitudinal study design are needed to comprehensively understand the impacts and potentially the underlying mechanisms from population conflicts for birthweight and childhood stunting. We believe that our study provides evidence and important insights for the global health community to develop strategies to protect and promote the health of vulnerable children, thereby advancing towards the Sustainable Development Goal of Zero Hunger.

CHAPTER 4. TROPICAL CYCLONES IN RELATION TO BIRTHWEIGHT AND CHILDHOOD STUNTING

4.1 Introduction

Climate change poses a substantial threat to public health, particularly through the increased frequency and intensity of extreme weather events such as tropical cyclones, which disproportionately affect people in low and middle-income countries. Countries in Southern and Southeastern Asia are highly vulnerable to climate perturbations, and the potential health impacts of tropical cyclones on child nutrition are of significant concern. In the immediate aftermath of a tropical cyclone, household food consumption is often severely disrupted through broken food supply chains, increased risk of infectious diseases, lack of safe water and adequate sanitation facilities, insufficient water supplies, and damaged healthcare facilities [60] (Figure 1-5), leading to compromised nutritional conditions for both mothers and children, which ultimately leading to lower birthweight and an increased risk of childhood stunting. However, studies exploring the association of tropical cyclones on birthweight and stunting are scarce, with existing research often limited to single events within restricted areas [62, 78-89]. Furthermore, findings from these studies show inconsistency regarding both birthweight and stunting outcomes [62, 78, 79, 84]. Though some studies on childhood stunting were conducted in Asian countries (e.g., Bangladesh, India), most of the studies on birthweight were based in the United States. This geographical skew leaves a significant knowledge gap regarding cyclone impacts in other cyclone-prone countries.

This study aims to examine associations of tropical cyclones with birthweight and stunting, respectively, utilizing DHS data from three countries in Southern and Southeastern Asia, namely Bangladesh, India, and the Philippines, during 2000-2018. We further examined whether the impacts of cyclones on birthweight and childhood stunting were heterogenous by maternal factors, child's sex, and place of residence. Finally, we conducted an analysis assessing the potential interactions between tropical cyclones and population conflicts on child health outcomes.

4.2 Methods

4.2.1 Study Population

Children aged 0-5 years old in Bangladesh, India, and the Philippines from the 2004-2018 Demographic Health Survey (DHS) were included in this study. Funded by the U.S. Agency for International Development (USAID), the DHS is a series of nationally representative cross-sectional surveys in over 90 developing countries since 1984 [90]. The sampling strategy of DHS is based on a two-stage method. Initially, clusters representing villages or communities are selected with the probability proportional to the size of the cluster [90]. Subsequently, within each sampled cluster, approximately 20-30 households are randomly selected for detailed interviews [90]. The interviews are conducted by trained staffs using standardized methods to collect various information on household socioeconomic status, nutrition, healthcare access, behavior, and geo-referenced location of the cluster [90].

Children were eligible for inclusion in our study if they met the following criteria: (1) they were under five years old; (2) they were alive at the time of the survey; (3) their anthropometric measurements are valid; (3) geo-referenced information on children's residential locations was available and valid; (4) tropical cyclones information of the child's residential area was available. Exclusion criteria for our study were: (1) children died before the survey; (2) information on anthropometric measurements, residential location, cyclone exposure, or other covariates are missing. To enhance the robustness of our findings, we further excluded countries where less than 5% of children experienced cyclone exposure and with less than 1,000 sample size. This yielded 253,293 children in Bangladesh and India included in the stunting analysis, whereases only 16,331 infants from the Philippines DHS were eligible for birthweight analysis due to data availability.

4.2.2 Outcome Ascertainment of Birthweight and Stunting

We used all eligible DHS surveys in Southern and Southeastern Asian countries as the data sources on child's birthweight and stunting status in our analyses. Child birthweight data were obtained from birth records or from mothers' recall. Anthropometric measurements, including length or height for children, were conducted by DHS-trained interviewers during the survey [90].

To assess stunting status, DHS calculates Height-for-Age Z-scores (HAZ) based on the World Health Organization (WHO) growth standards [91]. In our study, we defined children being stunted as their HAZ falls below -2 SDs from the WHO reference population median. Thus, in our analysis, children with an HAZ less than -2 SDs were classified as stunted (assigned a value of 1), while those above this threshold were considered not stunted (assigned a value of 0).

4.2.3 Exposure Assessment of Tropical Cyclones

4.2.3.1 The Emergency Events Database (EM-DAT)

Information on tropical cyclones was obtained from the Emergency Events Database (EM-DAT) [104]. The EM-DAT is maintained by the Center for Research on the Epidemiology of Disasters (CRED) with the support of the World Health Organization (WHO) and the Belgian Government, and the database contains information on the occurrence and effects of over 22,000 mass natural disasters around the world on a country-level from 2000 to the present day [105]. The database utilizes various sources, including United Nations agencies, national and U.S. governments, International Federation of Red Cross and Red Crescent Societies (IFRC), IGO, reinsurance companies, research institutes, and press agencies [105, 106]. According to the EM-DAT, a tropical cyclone originates over tropical or subtropical waters, and it is characterized by "a warm-core, non-frontal synoptic-scale cyclone with a low-pressure center, spiral rain bands and strong winds". Depending on their location, tropical cyclones are referred to as hurricanes in Atlantic and Northeast Pacific, typhoons in Northwest Pacific, or cyclones in South Pacific and Indian

Ocean [107]. For each tropical cyclone, EM-DAT provides information on the start and end dates of the cyclone, the cyclone-related damage, and the cyclone-related deaths [108]. Though it provides information of the cyclone-affected areas, the lack of geo-coordinates limited our ability to perform spatial linkage.

4.2.3.2 The Geocoded Disasters (GDIS) dataset

The Geocoded Disasters (GDIS) dataset provides spatial geometry in the form of GIS polygons and centroid latitude and longitude coordinates for each administrative entity listed as a disaster location in the EM-DAT database [109]. The GDIS contains spatial information on 39,953 locations for 9,924 unique disasters occurring worldwide up to 2018, facilitating linking the EM-DAT database to other geographic data sources on the subnational level. Therefore, by utilizing the GDIS dataset, we linked the tropical cyclones that occurred between 2000 and 2018 in Bangladesh, India, and the Philippines. Geospatial information on children's residential areas was used to link the DHS datasets with the GDIS dataset. Interviewers in the DHS geo-referenced surveys use global positioning system (GPS) devices to mark the central point of each sampling cluster, and these GPS coordinates were then randomly displaced by up to 2 km in urban clusters, 5 km in 99% of the rural clusters, and 10 km in 1% of the rural clusters to protect the confidentiality of the households [6, 7]. Therefore, to minimize the measurement errors by directly using the point coordinates, we created a 5 km buffer around each DHS cluster to link the cyclones to cluster as recommended by DHS [7].

4.2.3.3 Exposure definition

Children were coded as exposed if any tropical cyclone occurred in their corresponding 5-km buffered DHS clusters during the pre-defined exposure window (same as in Chapter 3), which was one-year preceding birth for birthweight analysis and one year before birth until length/height measurement for childhood stunting.

4.2.4 Statistical Analysis

4.2.4.1 Primary analyses

Bangladesh and India were included in the stunting analysis, whereases only the Philippines was eligible for birthweight analysis due to data availability. To exploit the effects of tropical cyclone on birthweight and stunting, we compared birthweight and stunting probabilities among children exposed to tropical cyclone with children unexposed within the same country over time. Specifically, we deployed fixed effect linear regression model (1) for birthweight and logistic regression model (2) for childhood stunting constructed by Wagner et al. to account for country fixed effect and year fixed effects [43], which are shown in equation below:

$$Y_{itc} = \beta_1 X_{tc} + \mu_l + \varphi_c + \gamma_t + \beta_2 C_{itc} + \varepsilon_{itc} \qquad (1)$$

$$\Pr(Y_{itc}) = \beta_1 X_{tc} + \mu_l + \varphi_c + \gamma_t + \beta_2 C_{itc} + \varepsilon_{itc} \qquad (2)$$

Where Y_{itc} denotes the (1) birthweight or (2) stunting status for child i in year t of country c. X_{tc} is the exposure indicator. The country fixed effects, φ_c, allow us to control unobserved time-invariant confounders specific to each country, and the year fixed effects, γ_t, will account for differences in the outcome over time for the same country during times with and without cyclones. The fixed effects in our model purge away variations in cyclones from other time-invariants and time-trending factors in the country level, which might be correlated with birthweight and stunting. In addition, a series of pre-defined confounders (C_{imtc}), including child's sex (boy or girl), birth order (continuous), mother's age at birth (continuous), mother's education (low: equal or less than primary, high: equal or greater than secondary), household socioeconomic status (poor: the first and second quintile of household wealth index, medium: the third quintile of household health index, rich: the fourth and fifth household wealth index), and place of residence (urban or rural), were adjusted for in all regression models [43, 49, 98]. For birthweight, we additionally added whether child was part of multiple births (yes/no) as a covariate, while child's age (continuous) was included for analyses in childhood stunting. The regression coefficient of X_{mtc}, β_1, represented the change in birthweight and logit of stunting odds comparing children exposed to tropical cyclone with children unexposed. To further account for the two-steps sampling strategy in DHS, we used robust standard errors clustered at the DHS cluster level.

4.2.4.2 Stratified analyses

To assess the effect of heterogeneity by various factors, we performed stratified analyses by child's sex, mother's education, and place of residence. Heterogeneity across groups was assessed by Wald test examining whether the interaction term between the exposure and the factor was significantly different from zero ($p_{heterogeneity}<0.05$).

4.2.4.3 Interaction between tropical cyclones and population conflicts

To explore whether the combined effects of tropical cyclones and population conflicts were significantly greater than either single factor, we assessed the interaction between tropical cyclones and population conflicts on childhood stunting. Similar analysis for birthweight was not conducted due to limited exposure of conflict events in the Philippines. Interaction in multiplicative scale was conducted by including an interaction term in the logistics regression model, while interaction in additive scale was performed by calculating the relative excess risk due to interaction (RERI).

All statistical tests were two-sided. We interpreted statistical significance at $p<0.05$. We performed all analyses using R version 4.1.2 (The R Foundation for Statistical Computing) [99], and the interaction analysis was conducted using the "InteractionR" package [110].

4.3 Results

4.3.1 Tropical Cyclones and Birthweight

Analyses of birthweight included data from 16,331 births in the Philippines DHS from 2003-2017. The demographic profile of the mothers (Table 4-1) indicated an average age of 27.8 years, with 81.73% having completed more than secondary education. Nearly half of the infants (49.18%) were from poor households, and 56.76% resided in rural areas. 170 tropical cyclones were associated with these births (Figure 4-1), and 52.4% of the births were in-utero exposed to at least one cyclone event.

Our findings (Table 4-2) demonstrated that in-utero exposure to tropical cyclones was associated with a reduction in birthweight, with a crude estimate showing a decrease of 20.3g (95% CI -44.3, 3.7). This reduction was greater and statistically significant upon adjustment for confounding variables, indicating a 25.6g decrease in birthweight (95% CI -49.4, -1.7) for infants born to mothers who lived in cyclone-affected regions during pregnancy. Notable reductions were observed among rural residents (-35.3, 95% CI -64.9, -5.7) and mothers without healthcare autonomy (-34.2, 95% CI -58.0, -10.4). However, analysis revealed no statistically significant heterogeneity across groups (Table 4-3 and Figure 4-3).

4.3.2 Tropical Cyclones and Childhood Stunting

The stunting analysis encompassed data from 253,293 children aged 0-5 years in the Bangladesh DHS (2004-2018, n=33,370) and India DHS (2015-2016, n=219,923). A detailed demographic breakdown (Table 4-4) showed that the mean age of children was 2.63 years, with a maternal average age of 25 years. Boys represented 51.62% of the sample, and 75% of them lived in rural areas. Notable differences in child's age, maternal age and education, household economic status, and residency were observed between the two countries, with Indian children generally older and residing in poorer, rural households, despite higher maternal education levels. During our study period, a total of 74 tropical cyclones occurred (Figure 4-2), with 23.8% of the children experiencing at least one cyclone during their childhood.

Children with lifetime exposure to tropical cyclones had 1.29-fold greater odds of stunting (95% CI 1.24, 1.35) compared to unexposed children (Table 4-2). This association was particularly robust in India (OR=1.44, 95% CI 1.37, 1.52), whereas in Bangladesh, the increase was smaller (OR=1.08, 95% CI 1.00, 1.15).

Stratified analyses (Table 4-5 and Figure 4-4) indicated statistically significant heterogeneity by child's sex, maternal education, and place of residence. The negative effects of cyclones were more pronounced in girls (OR=1.35, 95% CI 1.29, 1.42), children living in rural areas (OR=1.33, 95% CI 1.28, 1.39) and whose mother with lower education attainment (OR=1.40, 95% CI 1.34, 1.47).

Analyses addressing the interaction between tropical cyclones and population conflicts on stunting (Table 4-6) yielded an OR of 1.69 for children exposed to both cyclones and conflicts, relative to those with no exposure. However, this interaction was not statistically significant, either on a multiplicative (OR=0.91, 95% CI 0.91, 1.03, $p_{interaction}$=0.1291) or additive scale (RERI=-0.02, 95% CI -0.12, 0.07).

4.4 Discussion

This study examined birthweight and childhood stunting in response to tropical cyclones. Specifically, we identified a marked reduction in birthweight among children with intrauterine exposure to tropical cyclones in the Philippines, and greater odds of stunting among children in cyclone-affected regions compared to children in unaffected areas in Bangladesh and India. In addition, results from the stratified analyses suggested children born to mothers with lower education in rural areas may be the most vulnerable group to be stunted after cyclone exposure.

Our findings expand extant literature, which has primarily focused on single country or single cyclone event [62, 74-79, 111, 112]. A meta-analysis addressing tropical cyclones' impact on birthweight indicated mixed results [113], with four studies reporting statistically significant associations between cyclone exposure and lower birthweight [74-77] but no association for two studies conducted in the United

States [111, 112]. Similarly, research on childhood stunting has shown variable outcomes. Though one study conducted in Honduras suggested that tropical cyclone exposure was associated with decreased HAZ scores [79], two studies performed in Bangladesh demonstrated inconsistent results [62, 78]. By leveraging GPS data that included all tropical cyclones from 2000-2018, our study not only corroborate the adverse effects of tropical cyclones on stunting among children in Bangladesh but also extends these findings to children in other Asian countries like the Philippines and India.

Despite being limited to a few countries due to data availability, to our knowledge, this study is the first study to evaluate the impacts of tropical cyclones on birthweight and stunting in Southern and Southeastern Asia over an extended period from 2000 to 2018. The use of GPS data allowed for a more accurate identification of affected regions than previous studies that relied on self-reported cyclone exposure [74-79], minimizing exposure misclassification. Moreover, our analyses explored whether different demographic factors, such as child’s sex, maternal education level, and place of residence, may influence the impact of cyclones on nutritional outcomes. Moreover, we assessed the combined impacts of tropical cyclones and population conflicts, which to our knowledge has not been considered previously.

Despite these strengths, our study is not without limitations. First, the inclusion of only three countries limits the scope of our study and our ability to generalize our findings to other Asian countries. Also, the absence of data on the magnitudes of some cyclones constrained our ability to analyze effects by cyclone intensity. Finally, the cross-sectional study design of DHS and the lack of data on potential mediating factors limited our ability to examine the underlying mechanisms linking tropical cyclones to children’s nutritional status.

In conclusion, our findings provide empirical evidence on the adverse effects of tropical cyclones on the birthweight and stunting of children, particularly for children born to mothers with lower education in rural areas. Therefore, interventions aiming at mitigating these impacts should be prioritized to advance toward achieving the SDG of Zero Hunger. Future research, encompassing more countries and employing longitudinal designs, is crucial to fully understand the dynamics and mechanisms through which tropical cyclones affect children’s nutritional status, enabling the global health community to formulate effective strategies to protect vulnerable populations from climate-related adversities. However, the cumulative evidence on the adverse effects of climate change related-severe weather events, among other adverse impacts, warrant immediate action limiting CO2 emissions and scale-up of mitigation and adaption measures targeting vulnerable populations .

CHAPTER 5. HYPOTHETICAL INTERVENTIONS ADDRESSING POPULATION CONFLICTS AND TROPICAL CYCLONES IN RELATION TO BIRTHWEIGHT AND STUNTING

5.1 Introduction

According to the results from Chapter 3, exposure to population conflicts, regardless of the intensity and duration of them, was associated with decreased birthweight and increased odds of childhood stunting among children in Sub-Saharan African countries during 1980-2020. Though international aid continuous to be essential to improve the health of children in conflict-affected zones, efforts to reduce or eventually eliminate conflict events should be made given conflicts' significant negative effects on child health.

Furthermore, our analyses suggested negative impacts of tropical cyclones on birthweight and stunting, providing evidence on the association between climate change and child health. Currently, interventions on cyclone risk reduction mostly focuses on reducing vulnerability by improving infrastructure and preparedness for individual cyclones, providing shelters and necessary aids to communities affected, changing and planning decisions, and increasing public education and cyclone detection [114]. Programs and interventions aiming to improve individual's resilience and adaptability to cyclones have showed improved and positive results [115, 116]. Specifically, communities in Bangladesh have achieved resilience characteristics, including having better access to infrastructure, services, and economic opportunities, improved ability in managing available resources, and more knowledgeable on healthy behaviors, after implementation of a program called "Vulnerability to Resilience (V2R)" from 2013 [115]. However, primary interventions aiming to directly reduce cyclone intensity or even prevent cyclone formation (Table 5-1), may be a better approach that reduce the intensity and frequency of tropical cyclones., recent studies have aimed to develop interventions that directly reduce cyclone intensity or even prevent cyclone formation [114].

While several studies have been conducted to evaluate the association of population conflicts and tropical cyclones on birthweight and childhood stunting, there has been a lesser focus on developing the inferential framework on these public health questions. Questions emphasizing potentially measurable health impacts of interventions, such as “How much could we improve child health in a country if we had intervened on occurrence of conflict events and tropical cyclones, or reducing people’s vulnerability to these events?”, remain to date unanswered. Among causal inferential methodologies, g-computation is a useful tool to explore the potential impact of interventions on outcome of interest [117]. Utilizing simulation, g-computation is applied to calculate estimates that would be observed under hypothetical interventions (e.g., all conflict events were eliminated), thus evaluating the impact of interventions on the health of children. Compared to association estimates, results from causal inferential framework can directly inform public health action and provide more interpretable conclusions [118].

In this study, we utilized the g-computation to estimate the change in average birthweight and stunting prevalence following hypothetical interventions that reduce children’s exposure to population conflicts and tropical cyclones in Sub-Saharan Africa and Asia during 1980-2020. By evaluating the impacts of conflicts and cyclones interventions on child health, our study aims to provide guidance for future intervention and policy implementation to achieve the Sustainable Development Goals (SDGs).

5.2 Methods

5.2.1 Study Population

The study populations for this study were (1) 146,229 births from 17 Sub-Saharan countries born between 1990-2020 for conflicts and birthweight analysis; (2) 225,605 children from 20 Sub-Saharan African countries’ DHS in 1990-2020 for conflicts and stunting analysis; (3) 16,331 births in 2003-2017 the Philippines DHS for tropical cyclones and birthweight analysis; and (4) 253,293 children aged 0-5 years in the 2004-2018 Bangladesh DHS (n=33,370) and 2015-2016 India DHS (n=219,923) for tropical cyclones and stunting analysis.

5.2.2 Exposure Assessment and Outcome Ascertainment

Exposures in this study include population conflicts and tropical cyclones. Detailed information on assessment of the exposure variables can be found in Chapter 2 and 3. For study outcomes, birthweight and childhood stunting, the definition and variable creation methods are the same as in Chapter 2.

5.2.3 Statistical Analysis

We used the g-computation algorithm (applied to the parametric g-formula) to predict the potential mean birthweight and stunting prevalence under various hypothetical scenarios that would achieve reducing and mitigating the impacts of conflict and tropical cyclone. We first fitted the fixed-effect linear regression models of the outcome (birthweight or stunting status) on population conflicts or tropical cyclones adjusting for the selected covariates in Aim 1 and Aim 2:

$$Y_{itc} = \beta_1 X_{tc} + \varphi_c + \gamma_t + \beta_2 C_{itc} + \beta_3 X_{tc} \times C_{itc} + \varepsilon_{itc}$$

Where Y is the birthweight or stunting status for child *i* in year *t* of country *c*. X_{tc} is the exposure indicator of whether the child was exposed to population conflicts or tropical cyclones within the exposure window. φ_c and γ_t represent dummy variables for country and year, respectively. Interaction terms that showed significance in the test of heterogeneity in Chapter 3 and 4 were included in the corresponding models.

We then used the regression coefficients obtained from these models to predict birthweight and stunting prevalence under the different hypothetical scenarios. We obtained the marginal mean differences by taking the difference between the predicted potential mean birthweight and stunting prevalence under the various hypothetical interventions (in which the exposure distributions were altered so that less proportion of the population would be exposed to the risk factor) and the birthweight and stunting prevalence under no intervention (nature course, in which the exposure distributions remained the same as in the original sample). Standard errors and 95% confidence intervals were obtained via bootstrapping with 1,000 repetitions with replacement. We performed all analyses using R version 4.1.2 (The R Foundation for Statistical Computing) [99].

5.3 Results

5.3.1 Population Conflicts and Birthweight

The final dataset of birthweight comprised 146,229 births from 17 Sub-Saharan countries born between 1990-2020. A summary of demographic characteristics was presented in Table 3-1 and Table 3-2. 58% of the included births were boys, and 44.1% of them lived in urban areas. The mother's mean age at childbirth was 27.3 years old, and 41.6% of them had a higher education level (completed ≥ secondary schooling). In the observed dataset, 28.8% of the children had in-utero population conflicts exposure.

Results from the g-computation (Table 5-2) suggested that the mean birthweight under no intervention (nature course) was 3269.35g (95% CI 3265.45, 3273.12). We observed a statistically significant increase in birthweight for lower percentage of children exposed to conflict events under hypothetical interventions. The population mean difference comparing hypothetical interventions to no intervention were as follows: (1) 20% of the children exposed to conflicts: 1.70g (95% CI: 0.97, 2.44); (2) 10% of the children exposed to conflicts: 2.79g (95% CI: 1.58, 4.02); (3) none of the children exposed to conflicts: 5.57g (95% CI: 3.14, 8.02).

5.3.2 Population Conflicts and Childhood Stunting

A total of 225,605 children from 20 Sub-Saharan African countries' DHS in 1990-2020 were included in the final data for childhood stunting. Demographic characteristics of our study population were presented in Table 3-6 and Table 3-7. In general, the mean age of included children was 2.35 years old, with 50.20% of them were boys, and 27.76% of them lived in urban areas. Mothers of these children had a mean age at childbirth of 27.2 years old, and 24.64% of them completed ≥ secondary education. Among these children, 48.6% were exposed to conflicts during their childhood.

Overall, the mean stunting prevalence among children was 367.19 per 1,000 children in the observed dataset (Table 5-3). While the reduction was not statistically significant if 40% and 30% of them were exposed to population conflicts, the impact of hypothetical interventions resulting in greater reduction of conflict exposure was statistically significant. Specifically, we observed a -2.59 per 1,000 children (95% CI -4.46, -0.65) decrease in stunting prevalence if 20% of the children were exposed to conflict events, and -3.48 per 1,000 children (95% CI -5.34, -1.51 per 1,000 children) and -4.38 per 1,000 children (95% CI -6.26, -2.42 per 1,000 children) reduction in stunting prevalence if 10% and none of the children were exposed to conflict in-utero and during their childhood, respectively.

5.3.3 Tropical Cyclones and Birthweight

A total of 16,331 births from the Philippines 2003-2017 DHS were included in the final data for tropical cyclones and birthweight analyses. Demographic characteristics of our study population were presented in Table 4-1. 52.23% of the included births were boys, and 30.65% and 43.34% of them lived in rich households and urban areas, respectively. The mother's mean age at childbirth was 27.80 years old, and 81.73% of them had a high education level (completed ≥ secondary schooling). Among these children, 52.4% were exposed to tropical cyclones during their lifetime.

According to the g-computation results (Table 5-4), the mean birthweight under no intervention was 3001.00g (95% CI: 2991.48, 3010.75) in the Philippines. Statistically significant increase in birthweight with decreasing level of cyclone exposure was estimated under hypothetical scenario; the greatest increase in birthweight was modeled if none of the children were exposed to tropical cyclones, with the population mean difference comparing hypothetical interventions to no intervention were as follows (Table 5-4): (1) 40% of the children exposed to tropical cyclones: 3.19g (95% CI: 0.56, 5.92); (2) 30% of the children exposed to tropical cyclones: 5.75g (95% CI: 1.03, 10.68); (3) 20% of the children exposed to tropical cyclones: 8.36g (95% CI: 1.49, 15.05); (4) 10% of the children exposed to tropical cyclones: 10.87g (95% CI: 1.92, 20.20); (5) none of the children exposed to tropical cyclones: 13.42g (95% CI: 2.41, 25.00).

5.3.4 Tropical Cyclones and Childhood Stunting

The dataset for tropical cyclones and stunting dataset consisted of 253,293 children from Bangladesh 2004-2018 DHS and India 2015-2016 DHS. A detailed demographic breakdown (Table 4-4) showed that the mean age of children was 2.63 years, with a maternal average age of 25 years. Boys represented 51.62% of the sample, and 75% of them lived in rural areas. Notable differences in child's age, maternal age and education, household economic status, and residency were observed between the two countries, with Indian children generally older and residing in poorer, rural households, despite higher maternal education levels. 23.76% of the included children had experienced at least one tropical cyclone during their childhood.

Under no intervention (Table 5-5), the mean stunting prevalence was 377.33 per 1,000 children (95% CI 375.36, 379.23 per 1,000 children) in Bangladesh and India. We observed a statistically significant decrease in stunting prevalence with decreased level of cyclone exposure among our study population. Specifically, the population mean difference in stunting prevalence comparing hypothetical interventions to no intervention were as follows: (1) 10% of the children exposed to tropical cyclones: -2.31 per 1,000 children (95% CI -2.86, -1.63 per 1,000 children); (2) none of the children exposed to tropical cyclones: -3.99 per 1,000 children (95% CI -4.98, -2.82 per 1,000 children).

5.4 Discussion

This study evaluated the potential impact of hypothetical interventions on population conflicts and tropical cyclones on birthweight and childhood stunting among children under five in low and middle-income countries. Utilizing casual inference methods, specifically g-computation, we predicted birthweight and stunting prevalence under various hypothetical intervention scenarios and contrasted it to the natural course (no intervention) to estimate the potential population impact. Our findings suggested that interventions designed to reduce children's exposure to population conflicts and tropical cyclones could significantly increase birthweight and decrease the likelihood of stunting.

To our knowledge, this is the first study employing g-computation methodology to assess the impact of hypothetical interventions on population conflicts and tropical cyclones on birthweight and childhood stunting. The inclusion of all eligible countries from Sub-Saharan Africa and Southern and Southeastern Asia over the period from 1990 to 2020 provided a relatively large sample size to derive robust results.

To interpret these mean differences as causal, the following assumptions need to be satisfied: (1) no unmeasured confounding; (2) positivity: both exposed and unexposed subjects exist at each level of the confounders; (3) consistency: for each subject, the potential outcome under the observed exposure matches the observed outcome; and (4) no other source of bias [119]. While the first assumption is untestable, we controlled for important potential confounders and included various fixed effects. In terms of the last assumption, we assumed that our models were correctly specified and there were no other sources of bias such as missingness not at random, sparse data, and measurement error. However, it is worth noting that missingness of birthweight data is associated with conflict exposure in Sub-Saharan Africa. The positivity assumption was extensively evaluated, showing that our dataset adequately represented both exposed and unexposed groups across all levels of confounders. Moreover, it is suggested that g-computation is less prone to this issue compared to other causal inference methods [120]. To ensure the consistency assumption is met, we modified only the exposure status among exposed children, presuming negligible spillover effects—that is, the potential outcomes for any child under a particular exposure scenario are assumed not to influence others. Finally, it is worth noting that while our findings contribute to the effort to better understand the role of population conflicts and tropical cyclones on birthweight and childhood stunting, their generalizability to other contexts or regions may be limited.

Given the infeasibility and challenges in conducting randomized controlled trials in this topic, our study illustrated the use of g-computation, a more practical and cost-effective way to examine the role of population conflicts and tropical cyclones in reducing children's malnutrition. Our findings suggest that efforts to reduce the level of population conflicts and tropical cyclones may be an effective strategy to improve the nutritional status of children in low- and middle-income countries in Sub-Saharan Africa and Asia. By demonstrating that such strategies could substantially improve child health outcomes in affected regions, we provide valuable insights for policymakers and practitioners working to combat malnutrition in settings plagued by humanitarian crises and natural disasters.

CHAPTER 6. CONCLUSION AND PUBLIC HEALTH IMPLICATIONS

In this dissertation, the impacts of population conflicts and tropical cyclones on child health outcomes were investigated, specifically birthweight and stunting, in low and middle-income countries, utilizing both empirical and causal inference analyses.

In Aim 1, we revealed that population conflicts significantly decrease birthweight and increase stunting risk in Sub-Saharan Africa, particularly affecting girls and children of mothers with lower education and restricted healthcare autonomy. These findings highlight the necessity for policymakers to focus on enhancing child health in conflict-affected regions, aiming to prevent and mitigate adverse impacts on vulnerable populations.

Analyses in Aim 2 demonstrated significant reduction in birthweight and increase in odds of stunting among children exposed to tropical cyclones in Southern and Southeastern Asia, especially among children in rural areas with less educated mothers. This underscores the critical need for targeted interventions to alleviate the impacts of cyclones.

In Aim 3, we assessed hypothetical interventions addressing population conflicts and tropical cyclones using causal inference methods, namely g-computation, to suggest that reducing exposure to conflicts and cyclones could notably improve birthweight and decrease the stunting prevalence. This research provides a practical, evidence-based approach for policy interventions aimed at improving child nutritional status in affected regions. The innovative use of g-computation offers a viable alternative for evaluating the effectiveness of interventions in a cost-effective manner.

According to the United Nations, ensuring healthy lives and promote well-being for all at all ages, including child health, is one of the Sustainable Development Goals (SDGs) [121]. Moreover, in SDG2 “Zero Hunger” and SDG13 “Climate Action”, they target to end all forms of malnutrition by 2030 and to promote mechanisms for raising capacity for effective climate change-related management in least developed countries, with focus on women, youth, and local and marginalized communities [122, 123]. The integration of these findings with the SDGs emphasizes the urgency of addressing child malnutrition and promoting effective climate change management strategies. Furthermore, this research contributes valuable insights into the high-risk groups and potential mechanisms driving the adverse effects of environmental and social upheavals on child health.

This study not only fills critical gaps in the literature regarding the impacts of population conflicts and tropical cyclones for child health, but also provides a foundation for global public health interventions designed to mitigate these impacts, as well as related action-oriented guidance. As global challenges like international wars and localized conflicts exacerbate vulnerabilities, understanding and addressing the impacts of conflicts on child health through international aid and food assistance program becomes even more critical. The cumulative evidence on the adverse effects of climate change related-severe weather events, among other adverse impacts, warrant immediate action limiting CO_2 emissions and scale-up of mitigation and adaption measures targeting vulnerable populations. By aligning our research aims with global health goals, we aim to inform and inspire policy changes that prioritize the well-being of the world's most vulnerable populations, driving progress towards a healthier, more sustainable future for all children.

TABLES

Table 3-1. Demographic characteristics for all births included in the conflict-birthweight analysis in Sub-Saharan Africa during 1990-2020.

Characteristics	
DHS survey year	2003-2020
No. of births	146,229
No. of births exposed to conflicts, n (%)	42,069 (28.8%)
Birthweight	
Mean (SD)	3,262 (698)
Median (IQR)	3,200 (800)
Sex, n(%)	
Boy	74,356 (50.8%)
Girl	71,873 (49.2%)
Birth order	
Mean (SD)	3.2 (2.2)
Median (IQR)	3.0 (3.0)
Multiple births, n (%)	
Yes	5,099 (3.5%)
Mother's age at childbirth	
Mean (SD)	27.3 (6.5)
Median (IQR)	27.0 (10.0)
Mother's education, n (%)	
Low	85,405 (58.4%)
High	60,824 (41.6%)
Place of residence, n (%)	
Rural	81,659 (55.8%)
Urban	64,470 (44.1%)
Average temperature (Celsius)	
Mean (SD)	23.6 (3.6)
Median (IQR)	23.9 (6.4)
Average rainfall (mm)	
Mean (SD)	1241.0 (508.0)
Median (IQR)	1219.0 (576.0)
Nightlight luminosity	
Mean (SD)	2.4 (5.8)
Median (IQR)	0.05 (1.6)

Table 3-2. Demographic characteristics for births included in the birthweight analysis by country in Sub-Saharan Africa during 1990-2020.

Characteristics	**Angola**	**Burundi**	**Cameroon**	**Congo Democratic**	**Cote d'Ivoire**	**Ethiopia**	**Guinea**	**Kenya**	**Lesotho**
DHS survey year	2015- 16	2010, 2016-17	2004, 2011, 2018	2007, 2013-14	2011-12	2005, 2011, 2016	2005, 2012, 2018	2003, 2008-09, 2014	2004, 2014
No. of births	3,478	11,679	12,441	17,904	1,487	3,536	2,616	15,037	1,321
No. of births exposed to conflicts, n (%)	279 (8.0%)	4,335 (37.1%)	1,480 (11.9%)	7,482 (41.8%)	325 (21.9%)	1,841 (52.1%)	660 (25.2%)	3,086 (20.5%)	125 (9.5%)
Birthweight									
Mean (SD)	3,282 (785)	3,134 (626)	3,397 (731)	3,356 (690)	3,029 (661)	3,236 (765)	3,348 (755)	3,261 (641)	3,074 (581)
Median (IQR)	3,200 (900)	3,000 (700)	3,400 (800)	3,300 (800)	3,000 (800)	3,015 (700)	3,200 (1000)	3,200 (700)	3,000 (800)
Sex, n (%)									
Boy	1,751 (50.3%)	5,990 (51.3%)	6,288 (50.5%)	8,921 (49.8%)	754 (50.7%)	1,802 (51.0%)	1,369 (52.3%)	7,733 (51.4%)	609 (46.1%)
Girl	1,727 (49.7%)	5,689 (48.7%)	6,153 (49.5%)	8,983 (50.2%)	733 (49.3%)	1,734 (49.0%)	1,247 (47.7%)	7,304 (48.6%)	712 (53.9%)
Birth order									
Mean (SD)	3.5 (2.3)	3.6 (2.3)	3.2 (2.2)	3.8 (2.5)	3.5 (2.4)	2.6 (2.0)	3.6 (2.3)	2.9 (2.1)	2.3 (1.6)
Median (IQR)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	2 (2)	3 (3)	2 (3)	2 (2)
Multiple births, n (%)	115 (3.3%)	337 (2.9%)	600 (4.8%)	586 (3.3%)	79 (5.3%)	105 (3.0%)	109 (4.2%)	473 (3.1%)	29 (2.2%)
Mother's age at childbirth									
Mean (SD)	25.9 (6.9)	28.2 (6.5)	26.2 (6.5)	27.1 (6.8)	26.8 (6.8)	26.4 (5.8)	26.8 (7.3)	26.3 (6.2)	25.7 (6.3)
Median (IQR)	25 (11)	27 (10)	25 (9)	26 (10)	26 (11)	26 (8)	26 (11)	25 (8)	24 (10)
Mother's education, n (%)									
Low	2,086 (60.0%)	9,906 (84.8%)	5,894 (47.4%)	10,321 (57.6%)	1,309 (88.0%)	2,106 (59.6%)	2,305 (88.1%)	9,457 (62.9%)	670 (50.7%)
High	1,392 (40.0%)	1,773 (15.2%)	6,547 (52.6%)	7,583 (42.4%)	178 (12.0%)	1,430 (40.4%)	311 (11.9%)	5,580 (37.1%)	651 (49.3%)
Place of residence, n (%)									
Rural	966 (27.8%)	9,310 (79.7%)	5,464 (43.9%)	9,961 (55.6%)	814 (54.7%)	1,019 (28.8%)	1,725 (65.9%)	8787 (58.4%)	949 (71.8%)

Characteristics	**Angola**	**Burundi**	**Cameroon**	**Congo Democratic**	**Cote d'Ivoire**	**Ethiopia**	**Guinea**	**Kenya**	**Lesotho**
Urban	2,512 (72.2%)	2,369 (20.3%)	6,977 (56.1%)	7,943 (44.4%)	673 (45.3%)	2,417 (68.4%)	891 (34.1%)	6,250 (41.6%)	372 (28.2%)
Average temperature (Celsius)									
Mean (SD)	22.6 (1.9)	20.9 (1.4)	24.8 (2.1)	24.1 (2.2)	27.0 (0.61)	21.6 (4.0)	26.2 (1.0)	21.3 (3.6)	14.2 (1.9)
Median (IQR)	22.9 (2.9)	21.4 (2.2)	24.5 (2.2)	25.0 (1.8)	27.1 (0.6)	21.1 (6.3)	26.4 (1.5)	20.7 (3.9)	14.6 (3.7)
Average rainfall (mm)									
Mean (SD)	902 (362)	1,284 (205)	1,791 (639)	1,452 (255)	1,492 (390)	909 (379)	1,988 (543)	1,190 (488)	517 (93)
Median (IQR)	1,019 (511)	1,279 (305)	1,680 (752)	1,451 (240)	1,341 (269)	886 (593)	1,972 (753)	1,122 (702)	556 (138)
Nightlight luminosity									
Mean (SD)	7.0 (8.8)	0.2 (0.67)	3.1 (6.2)	2.6 (7.1)	3.8 (6.9)	4.7 (6.2)	0.2 (0.6)	2.6 (8.1)	0.7 (1.7)
Median (IQR)	2.6 (12.1)	0.005 (0.02)	0.1 (2.2)	0.0 (0.1)	0.2 (4.6)	2.3 (6.6)	0.004 (0.2)	0.07 (0.6)	0.03 (0.5)

Table 3-2 (*continue*). Demographic characteristics for births included in the birthweight analysis by country in Sub-Saharan Africa during 1990-2020.

	Mali	**Nigeria**	**Rwanda**	**Senegal**	**South Africa**	**Uganda**	**Zambia**	**Zimbabwe**
DHS survey year	2006, 2012-13	2003, 2008, 2013, 2018	2005, 2010, 2014-15, 2019-20	2005, 2010-11	2016	2006, 2011, 2016	2007, 2013-14, 2018	2005-06, 2010-11, 2015
No. of births	4,695	24,348	18,847	9,259	2,941	6,815	2,247	7,578
No. of births exposed to conflicts, n (%)	901 (19.2%)	13,349 (54.8%)	3,866 (20.5%)	1,144 (12.4%)	145 (4.9%)	1,608 (23.6%)	215 (9.6%)	1,228 (16.2%)
Birthweight								
Mean (SD)	3,227 (855)	3,280 (677)	3,338 (663)	3,072 (746)	3,078 (653)	3,312 (790)	3,177 (602)	3,128 (595)
Median (IQR)	3,100 (1000)	3,200 (600)	3,300 (800)	3,000 (900)	3,100 (800)	3,200 (800)	3,200 (700)	3,100 (700)
Sex, n (%)								
Boy	2,415 (51.4%)	12,406 (51.0%)	9,591 (50.9%)	4,797 (51.8%)	1,502 (51.1%)	3,472 (50.9%)	1,174 (52.2%)	3,782 (49.9%)
Girl	2,280 (48.6%)	11,942 (49.0%)	9,256 (49.1%)	4,462 (48.2%)	1,439 (48.9%)	3,343 (49.1%)	1,073 (47.8%)	3,796 (50.1%)
Birth order								
Mean (SD)	3.5 (2.3)	3.1 (2.0)	3.0 (2.1)	3.4 (2.3)	2.2 (1.4)	3.7 (2.6)	3.5 (2.3)	2.5 (1.6)
Median (IQR)	3 (3)	3 (3)	2 (3)	3 (4)	2 (2)	3 (3)	3 (3)	2 (2)
Multiple births, n (%)	158 (3.4%)	1,002 (4.1%)	553 (2.9%)	361 (3.9%)	66 (2.2%)	215 (3.2%)	79 (3.5%)	232 (3.1%)
Mother's age at childbirth								
Mean (SD)	26.4 (6.8)	28.6 (6.0)	28.6 (6.4)	27.1 (6.7)	26.8 (6.5)	26.1 (6.5)	26.6 (6.8)	25.9 (6.2)
Median (IQR)	26 (10)	28 (9)	28 (9)	26 (10)	26 (9)	25 (9)	26 (10)	25 (9)
Mother's education, n (%)								
Low	3,847 (81.9%)	5,518 (22.7%)	15,274 (81.0%)	8,305 (89.7%)	299 (10.2%)	4,724 (69.3%)	1,298 (57.8%)	2,086 (27.5%)
High	848 (18.1%)	18,830 (77.3%)	3,573 (19.0%)	954 (10.3%)	2,642 (89.8%)	2,091 (30.7%)	949 (42.2%)	5,492 (72.5%)

	Mali	**Nigeria**	**Rwanda**	**Senegal**	**South Africa**	**Uganda**	**Zambia**	**Zimbabwe**
Place of residence, n (%)								
Rural	2,162 (46.0%)	9,227 (37.9%)	14,403 (76.4%)	4,983 (53.8%)	1,409 (47.9%)	4,726 (69.3%)	1,201 (53.4%)	4,553 (60.1%)
Urban	2,533 (54.0%)	15,121 (62.1%)	4,444 (23.6%)	4,276 (46.2%)	1,532 (52.1%)	2,089 (30.7%)	1,046 (46.6%)	3,025 (39.9%)
Average temperature (Celsius)								
Mean (SD)	28.8 (0.8)	27.2 (0.8)	19.4 (1.3)	28.1 (1.2)	19.1 (2.0)	23.8 (1.6)	22.5 (1.0)	21.7 (1.4)
Median (IQR)	28.5 (1.0)	27.1 (0.7)	19.7 (2.2)	28.0 (1.5)	19.0 (2.7)	23.6 (1.6)	22.3 (1.2)	21.4 (2.2)
Average rainfall (mm)								
Mean (SD)	936 (282)	1,501 (472)	1,144 (194)	723 (268)	474 (165)	1,264 (223)	901 (228)	591 (177)
Median (IQR)	1,014 (381)	1,397 (634)	1,147 (276)	634 (272)	471 (227)	1,253 (284)	908 (372)	597 (239)
Nightlight luminosity								
Mean (SD)	4.0 (5.4)	2.8 (4.7)	1.0 (3.0)	2.3 (5.4)	7.2 (9.9)	1.3 (3.4)	4.3 (8.7)	1.7 (3.0)
Median (IQR)	0.7 (7.2)	0.5 (3.6)	0.02 (0.2)	0.2 (2.4)	2.3 (10.4)	0.008 (0.2)	0.05 (4.8)	0.03 (2.4)

Table 3-3. Change of birthweight to conflict exposure, conflict intensity, and conflict duration among children in Sub-Saharan Africa during 1990-2020.

Exposure Type	**No. of births**	**Crude model**		**Fully adjusted model**[a]	
		Change in birthweight (g) (95% CI)	**p value**	**Change in birthweight (g) (95% CI)**	**p value**
Any conflict exposure	146,229	-27.27 (-38.74, -15.80)	<0.001	-22.26 (-33.38, -11.14)	<0.001
Conflict intensity					
No conflict	104,160	Reference		Reference	
0-3 deaths	12,732	-17.63 (-32.53, -2.73)	0.0204	-14.01 (-28.55, 0.53)	0.0589
4-13 deaths	7,955	-23.19 (-43.09, -3.30)	0.0223	-16.65 (-35.96, 2.66)	0.0910
14-59 deaths	9,187	-12.79 (-32.23, 6.65)	0.1972	-13.32 (-32.06, 5.42)	0.1636
60-1,000 deaths	9,264	-40.05 (-62.28, -17.82)	<0.001	-30.56 (-52.26, -8.86)	0.0058
>1000 deaths	2,931	-89.87 (-125.56, -54.18)	<0.001	-82.23 (-116.65, -47.81)	<0.001
p-trend			<0.001		<0.001
Conflict deaths as a continuous variable per IQR (70 deaths)	146,229	-2.28 (-3.55, -1.01)	<0.001	-1.95 (-3.18, -0.72)	0.0018
Conflict duration					
No conflict	104,160	Reference		Reference	
≤ 1 month	17,022	-16.80 (-30.40, -3.21)	0.0154	-11.61 (-24.82, 1.60)	0.0850
1-6 months	8,418	-25.48 (-45.03, -5.93)	0.0106	-24.50 (-43.28, -5.72)	0.0106
6-12 months	16,629	-40.11 (-57.97, -22.24)	<0.001	-33.25 (-50.62, -15.88)	0.0018
p-trend			<0.001		<0.001
Conflict duration as a continuous variable per month	146,229	-3.83 (-5.58, -2.08)	<0.001	-3.20 (-4.89, -1.50)	<0.001
Conflict type					
State-based conflicts	121,593	-39.80 (-58.30, -21.31)	<0.001	-36.84 (-52.68, -21.00)	<0.001
Non-state conflicts	120,959	-36.58 (-56.20, -16.96)	<0.001	-24.19 (-43.51, -4.87)	0.0142
One-sided violence	129,766	-29.65 (-43.25, -16.06)	<0.001	-23.65 (-36.81, -10.49)	<0.001

All models included country and birth year fixed effects.

[a] The fully adjusted model included child's sex, child's birth order, multiple births, mother's age at childbirth, maternal education level, place of residence, average temperature, average rainfall, and nightlight luminosity.

Table 3-4. Change of birthweight to conflict exposure by child’s sex, mother’s education, place of residence, and women’s autonomy on healthcare decision among children in Sub-Saharan Africa during 1990-2020.

Subgroup	No. of births	Crude model		Fully adjusted model[a]		
		Change in birthweight (g) (95% CI)	**p value**	**Change in birthweight (g) (95% CI)**	**p value**	**P heterogeneity**
Child's sex						
Girls	71,873 (50.8%)	-35.59 (-50.18, -21.00)	<0.001	-29.48 (-43.23, -15.73)	<0.001	
Boys	74,356 (49.2%)	-18.63 (-33.29, -3.98)	0.0127	-15.26 (-29.38, -1.13)	0.0342	0.0977
Mother's education						
Low	85,405 (58.4%)	-26.55 (-41.39, -11.70)	<0.001	-36.52 (-50.56, -22.48)	<0.001	
High	60,824 (41.6%)	-32.59 (-48.96, -16.21)	<0.001	-2.77 (-18.21, 12.66)	0.7249	<0.001
Place of residence						
Rural	81,659 (55.84%)	-22.67 (-38.92, -6.43)	0.0062	-28.03 (-43.43, -12.62)	<0.001	
Urban	64,570 (44.16%)	-32.57 (-48.61, -16.53)	<0.001	-15.65 (-30.59, -0.70)	0.0402	0.2426
Women's autonomy on healthcare decision						
No	50,383 (39.19%)	-38.49 (-57.74, -19.24)	<0.001	-39.66 (-57.68, -21.63)	<0.001	
Yes	78,186 (60.81%)	-17.39 (-31.58, -3.20)	0.0163	-9.49 (-23.09, 4.11)	0.1714	0.0047

All models included country and birth year fixed effects.

[a] The fully adjusted model included child’s sex, child’s birth order, multiple births, mother’s age at childbirth, maternal education level, place of residence, average temperature, average rainfall, and nightlight luminosity.

Table 3-5. Change of birthweight to conflict exposure by country among children in Sub-Saharan Africa during 1990-2020.

		Crude model		**Fully adjusted model[a]**	
Country	**No. of births**	**Change in birthweight (g) (95% CI)**	**p value**	**Change in birthweight (g) (95% CI)**	**p value**
Angola	3,478	-107.98 (-194.93, -21.03)	0.0150	-161.95 (-273.47, -50.44)	0.0044
Burundi	11,679	54.65 (22.73, 86.58)	<0.001	24.82 (-60.7, 55.70)	0.1153
Cameroon	12,441	-84.14 (-129.27, -39)	<0.001	-75.21 (-121.84, -28.58)	0.0016
Congo Democratic Republic	17,904	-124.14 (-158.06, -90.22)	<0.001	-63.83 (-99.18, -28.48)	<0.001
Cote d'Ivoire	1,487	48.27 (-30.68, 127.22)	0.2310	4.94 (-75.56, 85.44)	0.9042
Ethiopia	3,536	-16.82 (-72.1, 38.45)	0.5509	-9.39 (-66.11, 47.32)	0.7454
Guinea	2,616	92.27 (18.41, 166.13)	0.0144	61.20 (-21.93, 144.32)	0.1491
Kenya	15,037	-26.93 (-61.42, 7.56)	0.1259	27.87 (-8.73, 64.47)	0.1356
Lesotho	1,321	-53.20 (-199.09, 92.69)	0.4749	-77.43 (-231.06, 76.19)	0.3234
Mali	4,695	-90.32 (-170.78, -9.86)	0.0278	-52.07 (-137.22, 33.09)	0.2308
Nigeria	24,348	-24.69 (-51.95, 2.56)	0.0758	-3.97 (-30.01, 22.07)	0.7650
Rwanda	18,847	18.43 (-11.29, 48.15)	0.2242	24.35 (-4.42, 53.12)	0.0972
Senegal	9,259	95.62 (36.99, 154.25)	0.0014	-22.77 (-97.72, 52.18)	0.5516
South Africa	2,941	-39.36 (-182.22, 103.5)	0.5892	-31.60 (-175.18, 111.98)	0.6662
Uganda	6,815	-47.93 (-100.69, 4.82)	0.0750	-17.60 (-68.76, 33.55)	0.5000
Zambia	2,247	51.44 (-45.86, 148.74)	0.3002	79.95 (-18.62, 178.52)	0.1120
Zimbabwe	7,578	-23.96 (-66.44, 18.52)	0.2690	-15.67 (-56.08, 24.74)	0.4473

All models included birth year fixed effect.

[a] The fully adjusted model included child's sex, child's birth order, multiple births, mother's age at childbirth, maternal education level, place of residence, average temperature, average rainfall, and nightlight luminosity.

Table 3-6. Demographic characteristics for all children included in the conflict-stunting analysis in Sub-Saharan Africa during 1990-2020.

Characteristics	
DHS survey year	1997-2020
No. of children	225,605
No. of children exposed to conflicts, n (%)	108,448 (48.1%)
No. of stunted children, n (%)	81,882 (36.3%)
Child's sex, n(%)	
Boy	111,449 (50.2%)
Girl	110,597 (49.8%)
Child's age	
Mean (SD)	2.4 (1.5)
Median (IQR)	2.0 (3.0)
Child's birth order	
Mean (SD)	3.8 (2.5)
Median (IQR)	3.0 (3.0)
Mother's age at childbirth	
Mean (SD)	27.2 (6.7)
Median (IQR)	26.4 (9.8)
Mother's education, n (%)	
Low	167,035 (75.2%)
High	55,011 (24.8%)
Place of residence, n (%)	
Rural	159,839 (72.0%)
Urban	62,207 (28.0%)
Average temperature (℃)	
Mean (SD)	24.6 (3.7)
Median (IQR)	25.5 (6.3)
Average rainfall (mm)	
Mean (SD)	1144 (557)
Median (IQR)	1086 (669)
Nightlight luminosity	
Mean (SD)	1.3 (4.4)
Median (IQR)	0.007 (0.2)

Table 3-7. Demographic characteristics for children included in the stunting analysis by country in Sub-Saharan Africa during 1990-2020.

Characteristics	Angola	Burundi	Cameroon	Chad	Congo Democratic Republic	Cote d'Ivoire	Ethiopia	Ghana	Guinea	Kenya	Liberia
DHS survey year	2016	2010-11, 2016-17	2004, 2011, 2018-19	2014-15	2007, 2013-14	2012	1997, 2003, 2008	2003, 2008, 2014	2005, 2012	2003, 2008-09, 2014	2006-07, 2019
No. of children	2,691	8,922	12,455	9,445	10,322	1,613	21,119	3,202	4,971	26,088	2,994
No. of conflict exposed, n (%)	191 (7.1%)	6961 (78.0%)	2439 (19.6%)	1078 (11.4%)	5809 (56.3%)	706 (43.8%)	17374 (82.3%)	684 (21.4%)	1194 (24.0%)	11224 (43.0%)	891 (29.8%)
No. of stunted children, n (%)	1076 (40.0%)	4847 (54.3%)	3855 (31.0%)	3864 (40.9%)	4378 (42.4%)	506 (31.4%)	8428 (39.9%)	1059 (33.1%)	1766 (35.5%)	7631 (29.3%)	1104 (36.9%)
Child's sex, n(%)											
Boy	1,342 (49.9%)	4,490 (50.3%)	6,178 (49.6%)	4,700 (49.8%)	5,071 (49.1%)	788 (48.9%)	1,0691 (50.6%)	1,633 (51.0%)	2,558 (51.5%)	13,164 (50.5%)	1,512 (50.5%)
Girl	1,349 (50.1%)	4,432 (49.7%)	6,277 (50.4%)	4,745 (50.2%)	5,251 (50.9%)	825 (51.2%)	10,428 (49.4%)	1,569 (49.0%)	2,413 (48.5%)	12,924 (49.5%)	1,482 (49.5%)
Child's age											
Mean (SD)	2.8 (1.4)	2.3 (1.5)	2.3 (1.5)	2.6 (1.5)	2.2 (1.5)	2.6 (1.4)	2.3 (1.5)	2.0 (1.5)	2.3 (1.5)	2.4 (1.5)	2.4 (1.5)
Median (IQR)	3.0 (3.0)	2.0 (3.0)	2.0 (3.0)	3.0 (3.0)	2.0 (2.0)	3.0 (3.0)	2.0 (3.0)	2.0 (2.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)
Child's birth order											
Mean (SD)	3.6 (2.3)	3.7 (2.4)	3.6 (2.4)	4.3 (2.6)	4.0 (2.5)	3.8 (2.4)	3.9 (2.5)	3.8 (2.3)	4.0 (2.4)	3.5 (2.3)	3.8 (2.5)
Median (IQR)	3.0 (3.0)	3.0 (3.0)	3.0 (3.0)	4 (4.0)	3.0 (4.0)	3.0 (3.0)	3.0 (4.0)	3.0 (3.0)	4.0 (4.0)	3.0 (3.0)	3.0 (3.0)
Mother's age at childbirth											
Mean (SD)	26.1 (7.2)	28.5 (6.5)	26.2 (6.5)	26.2 (6.6)	27.4 (6.8)	27.2 (6.9)	27.2 (6.5)	29.0 (7.2)	27.3 (7.2)	26.7 (6.4)	27.7 (7.5)
Median (IQR)	24.8 (10.7)	27.7 (9.8)	25.4 (9.5)	25.4 (9.5)	26.5 (10.1)	26.1 (9.9)	26.3 (9.4)	28.1 (10.9)	26.7 (11.0)	25.8 (9.2)	26.8 (11.8)

Characteristics	**Angola**	**Burundi**	**Cameroon**	**Chad**	**Congo Democratic Republic**	**Cote d'Ivoire**	**Ethiopia**	**Ghana**	**Guinea**	**Kenya**	**Liberia**
Mother's education, n (%)											
Low	2,160 (80.3%)	7,837 (87.8%)	8,042 (64.6%)	8,612 (91.2%)	6,754 (65.4%)	1,513 (93.8%)	19,500 (92.3%)	2,761 (86.2%)	4,739 (95.3%)	19,681 (75.4%)	2,579 (86.1%)
High	531 (19.7%)	1,085 (12.2%)	4,413 (35.4%)	833 (8.8%)	3,568 (34.6%)	100 (6.2%)	1,619 (7.7%)	441 (13.8%)	232 (4.7%)	6407 (24.6%)	415 (13.9%)
Place of residence, n (%)											
Rural	1,602 (59.5%)	7,485 (83.9%)	7,209 (57.9%)	7,456 (78.9%)	6,780 (65.7%)	1,108 (68.7%)	17,700 (83.8%)	2,573 (80.4%)	4,069 (81.9%)	18,968 (72.7%)	2,460 (82.2%)
Urban	1,089 (40.5%)	1,437 (16.1%)	5,246 (42.1%)	1,989 (21.1%)	3,542 (34.3%)	505 (31.3%)	3,419 (16.2%)	629 (19.6%)	902 (18.2%)	7,120 (27.3%)	534 (17.8%)
Average temperature (℃)											
Mean (SD)	22.2 (2.0)	20.9 (1.4)	25.3 (2.3)	28.3 (1.1)	24.3 (2.1)	26.9 (0.7)	21.8 (3.7)	28.6 (0.5)	26.2 (1.0)	22.1 (3.8)	26.0 (0.4)
Median (IQR)	22.3 (3.2)	21.4 (2.5)	24.8 (3.0)	28.4 (1.2)	25.1 (1.4)	27.1 (0.8)	21.2 (4.8)	28.5 (0.6)	26.4 (1.5)	21.7 (4.4)	26.0 (0.7)
Average rainfall (mm)											
Mean (SD)	936 (351)	1,279 (203)	1,669 (692)	631 (356)	1,464 (241)	1,541 (419)	979 (420)	1,052 (169)	1,864 (470)	1,129 (530)	2,330 (386)
Median (IQR)	1,055 (495)	1,261 (312)	1,590 (805)	545 (647)	1,460 (224)	1,363 (346)	984 (631)	1,010 (205)	1,802 (679)	1,091 (768)	2,304 (584)
Nightlight luminosity											
Mean (SD)	3.2 (6.8)	0.2 (0.6)	2.1 (5.2)	0.6 (2.9)	1.9 (6.1)	2.5 (5.7)	0.8 (3.0)	0.8 (2.4)	0.1 (0.4)	1.5 (6.3)	0.1 (0.2)
Median (IQR)	0.002 (2.0)	0.004 (0.02)	0.01 (0.8)	0.0 (0.003)	0.0 (0.007)	0.05 (1.2)	0.002 (0.06)	0.02 (0.2)	0.0008 (0.007)	0.03 (0.1)	0.0 (0.01)

Table 3-7 (*continue*). Demographic characteristics for children included in the stunting analysis by country in Sub-Saharan Africa during 1990-2020.

Characteristics	**Madagascar**	**Mali**	**Nigeria**	**Rwanda**	**Senegal**	**South Africa**	**Uganda**	**Zambia**	**Zimbabwe**
DHS survey year	2009	2006, 2012-13	2003, 2008,2013, 2018	2005, 2010-11, 2014-15, 2019-20	2005, 2011	2016	2006, 2011	2013-14	2005, 2010-11, 2015
No. of children	3,559	15,025	56,495	14,896	4,761	1,068	2,812	11,137	12,030
No. of conflict exposed, n (%)	1,277 (35.9%)	5,565 (37.0%)	41,922 (74.2%)	5,911 (39.7%)	792 (16.6%)	311 (29.1%)	1,108 (39.4%)	1,327 (11.9%)	2,961 (24.6%)
No. of stunted children, n (%)	1,619 (45.5%)	1,619 (10.8%)	5,502 (9.7%)	20,910 (140.4%)	6,055 (127.2%)	1,193 (111.7%)	279 (9.9%)	4,318 (38.8%)	3,492 (29.0%)
Child's sex, n(%)									
Boy	1,815 (51.0%)	7,583 (50.5%)	28,280 (50.1%)	7,476 (50.2%)	2,512 (52.8%)	537 (50.3%)	1,395 (49.6%)	5,572 (50.0%)	5,967 (49.6%)
Girl	1,744 (49.0%)	7,442 (49.5%)	28,215 (49.9%)	7,420 (49.8%)	2,249 (47.2%)	531 (49.7%)	1,417 (50.4%)	5,565 (50.0%)	6,063 (50.4%)
Child's age									
Mean (SD)	2.8 (1.5)	2.2 (1.5)	2.3 (1.5)	2.5 (1.5)	2.6 (1.5)	2.3 (1.5)	2.2 (1.5)	2.4 (1.5)	2.2 (1.5)
Median (IQR)	3.0 (2.0)	2.0 (2.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (2.0)	2.0 (3.0)	2.0 (2.0)
Child's birth order									
Mean (SD)	3.7 (2.5)	4.1 (2.6)	3.9 (2.6)	3.4 (2.2)	3.8 (2.5)	2.3 (1.5)	4.2 (2.6)	3.8 (2.5)	2.8 (1.8)
Median (IQR)	3.0 (3.0)	4.0 (4.0)	3.0 (3.0)	3.0 (3.0)	3.0 (3.0)	2.0 (2.0)	4.0 (4.0)	3.0 (3.0)	2.0 (3.0)
Mother's age at childbirth									
Mean (SD)	26.4 (7.2)	26.7 (6.9)	27.6 (6.8)	29.1 (6.4)	27.2 (6.9)	27.0 (6.6)	27.1 (6.5)	26.9 (6.8)	26.3 (6.4)
Median (IQR)	25.3 (10.9)	25.8 (10.2)	26.8 (9.8)	28.3 (9.6)	26.2 (10.3)	26.3 (9.9)	26.2 (9.4)	26.2 (10.3)	25.3 (9.3)

Characteristics	**Madagascar**	**Mali**	**Nigeria**	**Rwanda**	**Senegal**	**South Africa**	**Uganda**	**Zambia**	**Zimbabwe**
Mother's education, n (%)									
Low	2,973 (83.5%)	14,082 (93.7%)	37,278 (66.0%)	12,812 (86.0%)	4,444 (93.3%)	135 (12.6%)	2,322 (82.6%)	7,497 (67.3%)	4,287 (35.6%)
High	586 (16.5%)	943 (6.3%)	19,217 (34.0%)	2,084 (14.0%)	317 (6.7%)	933 (87.4%)	490 (17.4%)	3,640 (32.7%)	7,743 (64.4%)
Place of residence, n (%)									
Rural	3,145 (88.4%)	10,742 (71.5%)	37,726 (66.8%)	12,111 (81.3%)	3,396 (71.3%)	584 (54.7%)	2,354 (83.7%)	7,090 (63.7%)	8,426 (70.0%)
Urban	414 (11.6%)	4,283 (28.5%)	18,769 (33.2%)	2,785 (18.7%)	1,365 (28.7%)	484 (45.3%)	458 (16.3%)	4,047 (36.3%)	3,604 (30.0%)
Average temperature (°C)									
Mean (SD)	22.5 (2.5)	29.0 (0.9)	27.4 (1.0)	19.6 (1.4)	28.3 (1.0)	19.2 (2.0)	24.0 (1.7)	22.4 (1.1)	21.9 (1.6)
Median (IQR)	22.5 (4.1)	29.0 (1.2)	27.4 (1.0)	19.7 (2.2)	28.3 (1.2)	19.1 (2.5)	24.3 (1.6)	22.3 (1.4)	21.7 (2.6)
Average rainfall (mm)									
Mean (SD)	1,441 (634)	744 (321)	1,271 (585)	1,152 (191)	760 (268)	473 (166)	1,260 (254)	918 (236)	576 (181)
Median (IQR)	1,353 (727)	767 (534)	1,163 (701)	1,144 (272)	693 (303)	471 (242)	1,265 (281)	937 (395)	570 (246)
Nightlight luminosity									
Mean (SD)	0.1 (0.6)	1.5 (3.8)	1.4 (3.6)	0.7 (2.6)	1.0 (2.7)	5.9 (9.0)	0.5 (2.3)	3.1 (7.6)	1.3 (2.6)
Median (IQR)	0.0 (0.01)	0.0 (0.05)	0.02 (0.5)	0.02 (0.1)	0.02 (0.5)	1.6 (8.0)	0.002 (0.02)	0.007 (1.8)	0.007 (1.3)

Table 3-8. The association of conflict exposure, conflict intensity, and conflict duration on stunting among children in Sub-Saharan Africa during 1990-2020.

Exposure type	No. of children	Crude model[a]		Fully adjusted model[b]	
		OR (95% CI)	p value	OR (95% CI)	p value
Any conflict exposure	225,605	1.14 (1.10, 1.18)	<0.001	1.13 (1.09,1.17)	<0.001
Conflict intensity					
No conflict	115,880	Reference		Reference	
0-7 deaths	32,685	1.08 (1.04, 1.13)	<0.001	1.07 (1.04,1.13)	<0.001
8-25 deaths	23,105	1.28 (1.21, 1.34)	<0.001	1.26 (1.19,1.32)	<0.001
26-110 deaths	24,178	1.08 (1.01, 1.13)	0.0061	1.07 (1.01,1.12)	0.0175
111-1,000 deaths	24,452	1.25 (1.18, 1.33)	<0.001	1.22 (1.16,1.30)	<0.001
>1000 deaths	5,305	1.13 (1.04, 1.23)	0.0052	1.09 (1.00,1.18)	0.0455
p-trend			<0.001		<0.001
Conflict deaths as a continuous variable per IQR (137 deaths)	225,605	1.00 (0.998, 1.001)	0.8783	1.00 (0.9979,1.0009)	0.4064
Conflict duration					
No conflict	115,880	Reference		Reference	
≤ 1 year	54,565	1.13 (1.09, 1.17)	<0.001	1.14 (1.09, 1.18)	<0.001
1-2 years	18,658	1.04 (0.99, 1.10)	0.1126	1.04 (0.98, 1.09)	0.0272
2-3 years	15,188	1.35 (1.28, 1.43)	<0.001	1.35 (1.28, 1.43)	<0.001
≥ 3years	21,314	1.16 (1.09, 1.23)	<0.001	1.15 (1.09, 1.22)	<0.001
p-trend			<0.001		<0.001
Conflict duration as a continuous variable per year	225,605	1.02 (1.01, 1.04)	<0.001	1.02 (1.01, 1.03)	0.0032
Conflict type					
State-based conflicts	166,507	1.16 (1.10, 1.22)	<0.001	1.13 (1.08, 1.19)	<0.001
Non-state conflicts	179,498	1.16 (1.10, 1.22)	<0.001	1.13 (1.07, 1.18)	<0.001
One-sided violence	184,736	1.13 (1.09, 1.18)	<0.001	1.12 (1.07, 1.17)	<0.001

All models included country and year fixed effect.

[a] The crude model adjusted for child's age.

[b] The fully adjusted model included child's sex, child's birth order, child's age, mother's age at childbirth, maternal education level, place of residence, average temperature, average rainfall, and nightlight luminosity.

Table 3-9. Association between conflict exposure and stunting by child’s sex, mother’s education, place of residence, and women’s autonomy on healthcare decision among children in Sub-Saharan Africa during 1990-2020.

Subgroup	No. of children	Crude model[a]		Fully adjusted model[b]		Test of heterogeneity
		OR (95% CI)	p value	OR (95% CI)	p value	
Child's sex						
Girls	112,341	1.47 (1.41, 1.54)	<0.001	1.14 (1.10, 1.19)	<0.001	0.0144
Boys	113,264	1.33 (1.27, 1.39)	<0.001	1.09 (1.05, 1.14)	<0.001	
Mother's education						
Low	170,008	1.44 (1.38, 1.49)	<0.001	1.14 (1.09, 1.18)	<0.001	<0.001
High	55,597	1.25 (1.17, 1.35)	<0.001	1.14 (1.06, 1.23)	0.6223	
Place of residence						
Rural	162,984	1.44 (1.39, 1.50)	<0.001	1.14 (1.09, 1.18)	<0.001	<0.001
Urban	62,621	1.28 (1.19, 1.37)	<0.001	1.13 (1.05, 1.21)	0.1653	
Women's autonomy on healthcare decision						
No	101,008	1.44 (1.37, 1.52)	<0.001	1.09 (1.03, 1.15)	<0.001	0.2943
Yes	96,035	1.37 (1.30, 1.44)	<0.001	1.15 (1.09, 1.21)	<0.001	

All models included country and year fixed effect.

[a] The crude model adjusted for child’s age.

[b] The fully adjusted model included child’s sex, child’s birth order, child’s age, mother’s age at childbirth, maternal education level, place of residence, average temperature, average rainfall, and nightlight luminosity.

Table 3-10. The association between conflict exposure and risk of stunting by country among children in Sub-Saharan Africa during 1990-2020.

Country	**No. of children**	**Crude model**[a]		**Fully adjusted model**[b]	
		OR (95% CI)	**p value**	**OR (95% CI)**	**p value**
Angola	2,691	0.77 (0.36, 1.63)	0.4942	0.70 (0.31, 1.60)	0.4020
Burundi	8,922	1.20 (1.03, 1.41)	0.0216	1.20 (1.03, 1.40)	0.0215
Cameroon	12,455	1.21 (1.03, 1.41)	0.0181	1.17 (1.00, 1.38)	0.0508
Chad	9,445	1.32 (0.98, 1.77)	0.0041	1.29 (0.96, 1.72)	0.0870
Congo Democratic Republic	10,322	1.28 (1.06, 1.54)	0.0086	1.27 (1.05, 1.52)	0.0120
Cote d'Ivoire	1,613	0.84 (0.64, 1.08)	0.1752	1.03 (0.76, 1.40)	0.8418
Ethiopia	21,119	1.14 (1.01, 1.28)	0.0313	1.08 (0.97, 1.22)	0.1706
Ghana	3,202	1.48 (1.00.1, 20)	0.0099	1.44 (1.08, 1.92)	0.0135
Guinea	4,971	0.84 (0.69, 1.03)	0.0947	0.84 (0.69, 1.02)	0.0823
Kenya	26,088	1.11 (1.01, 1.22)	0.0256	1.13 (1.03, 1.23)	0.0130
Liberia	2,994	1.26 (0.95, 1.67)	0.1061	1.29 (0.98, 1.70)	0.0723
Madagascar	3559	0.89 (0.67, 1.18)	0.4253	0.92 (0.68, 1.24)	0.5863
Mali	15,025	1.21 (1.03, 1.42)	0.0203	1.20 (1.02, 1.41)	0.0245
Nigeria	56,495	1.12 (1.04, 1.20)	0.0016	1.08 (1.01, 1.16)	0.0215
Rwanda	14,896	1.09 (0.96, 1.24)	0.1802	1.11 (0.98, 1.26)	0.0980
Senegal	4,761	1.37 (0.90, 2.09)	0.1401	1.36 (0.90, 2.05)	0.1486
South Africa	1,068	1.09 (0.11, 11.05)	0.9403	1.05 (0.11, 10.02)	0.9641
Uganda	2,812	0.97 (0.69, 1.38)	0.8842	0.94 (0.66, 1.35)	0.7489
Zambia	11,137	1.72 (1.04, 2.84)	0.0333	1.59 (0.89, 2.84)	0.1186
Zimbabwe	12,030	1.35 (1.18, 1.55)	<0.001	1.40 (1.22, 1.60)	<0.001

All models included year fixed effect.

[a] The crude model adjusted for child's age.

[b] The fully adjusted model included child's sex, child's birth order, child's age, mother's age at childbirth, maternal education level, place of residence, average temperature, average rainfall, and nightlight luminosity.

Table 3-11. Association between population conflicts and stunting among children at five years old and all children in Sub-Saharan African countries during 1990-2020.

Exposure type	Children five years old		All children	
	No. of children (%)	OR (95% CI)	No. of children (%)	OR (95% CI)
Any conflict exposure	17,036	1.11 (1.02, 1.22)	225,605	1.13 (1.09, 1.17)
Conflict intensity				
No conflict	7,224 (42.4%)	Reference	115,880 (51.4%)	Reference
1-7 deaths	2,606 (15.3%)	1.06 (0.94, 1.19)	32,685 (14.5%)	1.08 (1.04,1.13)
8-25 deaths	2,158 (12.7%)	1.19 (1.05, 1.36)	23,105 (10.2%)	1.26 (1.19, 1.32)
26-110 deaths	2,080 (12.2%)	1.15 (1.01,1.31)	24,178 (10.7%)	1.07 (1.01, 1.12)
111-1,000 deaths	2,301 (13.5%)	1.07 (0.94,1.23)	24,452 (10.8%)	1.22 (1.16, 1.30)
>1000 deaths	667 (3.9%)	1.09 (0.90,1.33)	5,305 (2.4%)	1.09 (1.00, 1.18)
Conflict duration				
No conflict	7,224 (42.4%)	Reference	115,880 (51.4%)	Reference
≤ 1 year	4,098 (24.1%)	1.15 (1.04, 1.27)	54,565 (24.2%)	1.12 (1.08, 1.17)
1-2 years	977 (5.7%)	1.10 (0.92, 1.31)	18,658 (8.3%)	1.03 (0.98, 1.09)
2-3 years	939 (5.6%)	1.09 (0.93, 1.29)	15,188 (6.7%)	1.33 (1.26, 1.41)
≥ 3years	3,798 (22.3%)	1.09 (0.98, 1.23)	21,314 (9.4%)	1.13 (1.06, 1.19)

Table 3-12. Demographic characteristics of infants included in study analysis vs. with birthweight data missing in Sub-Saharan Africa during 1990-2020.

Characteristics	Infants with missing birthweight (n = 234,703)	Infants with birthweight available (n = 146,229)
No. of infants exposed to conflicts, n (%)	90,259 (38.5%)	42,069 (28.8%)
Conflict intensity, n (%)		
No conflict	144,444 (61.5%)	104,160 (71.2%)
0-3 deaths	19,512 (8.3%)	12,732 (8.7%)
4-13 deaths	14,083 (6.0%)	7,955 (5.4%)
14-59 deaths	22,227 (9.5%)	9,187 (6.3%)
60-1,000 deaths	28,340 (12.1%)	9,264 (6.3%)
>1000 deaths	6,097 (2.6%)	2,931 (2.0%)
Conflict duration, n (%)		
No conflict	144,444 (61.5%)	104,160 (71.2%)
≤ 1 month	29,948 (12.8%)	17,022 (11.6%)
1-6 months	17,398 (7.4%)	8,418 (5.8%)
6-12 months	42,913 (18.3%)	16,629 (11.4%)
Sex, n(%)		
Boy	118,853 (50.6%)	74,356 (50.8%)
Girl	115,850 (49.4%)	71,873 (49.2%)
Birth order		
Mean (SD)	4.04 (2.58)	3.22 (2.20)
Median (IQR)	4 (4)	3 (3)
Multiple births, n (%)	7,379 (3.1%)	5,099 (3.5%)
Mother's age at childbirth		
Mean (SD)	27.1 (6.92)	27.3 (6.51)
Median (IQR)	26 (10)	27 (10)
Mother's education, n (%)		
Low	196,228 (83.6%)	85,405 (58.4%)
High	38,475 (16.4%)	60,824 (41.6%)
Place of residence, n (%)		
Rural	188,833 (80.5%)	81,659 (55.8%)
Urban	45,870 (19.5%)	64,470 (44.1%)

Characteristics	**Infants with missing birthweight (n = 234,703)**	**Infants with birthweight available (n = 146,229)**
Average temperature (Celsius)		
Mean (SD)	25.4 (3.54)	23.6 (3.64)
Median (IQR)	26.9 (4.90)	23.9 (6.38)
Average rainfall (mm)		
Mean (SD)	1106 (510)	1241 (508)
Median (IQR)	1031 (627)	1219 (576)
Nightlight luminosity		
Mean (SD)	0.69 (2.90)	2.43 (5.78)
Median (IQR)	0.004 (0.06)	0.048 (1.57)

Table 4-1. Demographic characteristics for all births in the Philippines included in the tropical cyclone-birthweight analysis.

Characteristics	**Philippines**
DHS survey year	2003, 2008, 2017
No. of children	16,331
No. of children exposed to tropical cyclones, n (%)	8,562 (52.4%)
Birthweight	
Mean (SD)	3,001 (643)
Median (IQR)	3,000 (700)
Child's sex, n (%)	
Boys	8,530 (52.2%)
Girls	7,801 (47.8%)
Child's birth order	
Mean (SD)	2.77 (1.98)
Median (IQR)	2.00 (3.00)
Multiple births, n (%)	
Yes	239 (1.5%)
Mother's age at childbirth	
Mean (SD)	27.80 (6.50)
Median (IQR)	27.20 (9.75)
Mother's education level, n (%)	
Low	2,984 (18.3%)
High	13,347 (81.7%)
Place of residence, n (%)	
Rural	9,269 (56.8%)
Urban	7,062 (43.2%)
Household socioeconomic status, n (%)	
Poor	8,032 (49.2%)
Middle	3,294 (20.2%)
Rich	5,005 (30.6%)

Table 4-2. Association between tropical cyclones, birthweight, and stunting among children in the Philippines, Bangladesh, and India during 2000-2018.

Birthweight

Country	No. of births	Crude model		Fully adjusted model[a]	
		Birthweight change (g) (95% CI)	p value	Birthweight change (g) (95% CI)	p value
Philippines	16,331	-20.30 (-44.27, 3.67)	0.097	-25.55 (-49.43, -1.66)	0.0360

Childhood stunting

Country	No. of children	Crude model		Fully adjusted model[b]	
		OR (95% CI)	p value	OR (95% CI)	p value
Bangladesh	33,370	1.29 (1.21, 1.39)	<0.001	1.08 (1.00, 1.15)	0.0366
India	219,923	1.98 (1.88, 2.08)	<0.001	1.44 (1.37, 1.52)	<0.001
Total	253,293	1.69 (1.62, 1.76)	<0.001	1.29 (1.24, 1.35)	<0.001

All models included country and year fixed effects.

[a] The fully adjusted model included child's sex, child's birth order, multiple births, mother's age at childbirth, maternal education level, place of residence, and household socioeconomic status.

[b] The fully adjusted model included child's sex, child's age, child's birth order, mother's age at childbirth, maternal education level, place of residence, and household socioeconomic status.

Table 4-3. Change of birthweight to tropical cyclone exposure by child's sex, mother's education, and place of residence among children in the Philippines during 2000-2018.

Subgroup		Crude model		Fully adjusted model[b]		
	No. of children	Birthweight change (g) (95% CI)	p value	Birthweight change (g) (95% CI)	p value	p heterogeneity
Child's sex						
Girls	7,801	-20.39 (-54.36, 13.59)	0.2398	-15.86 (-45.89, 14.16)	0.3005	
Boys	8,530	-19.95 (-53.45, 13.56)	0.2435	-29.94 (-60.09, 0.21)	0.0519	0.9612
Mother's education						
Low	2,984	-22.36 (-81.39, 36.68)	0.4582	-26.59 (-79.40, 26.21)	0.3237	
High	13,347	-22.00 (-47.04, 3.03)	0.0852	-22.50 (-46.15, -1.14)	0.0621	0.7811
Place of residence						
Rural	9,269	-45.87 (-78.45, -13.30)	0.0059	-35.32 (-64.89, -5.74)	0.0192	
Urban	7,062	2.24 (-33.19, 37.67)	0.9013	-7.69 (-38.80, 23.42)	0.6282	0.2571
Women's autonomy on healthcare decision						
No	947	55.48 (-36.77, 147.72)	0.2391	52.61 (-30.55, 135.77)	0.2149	
Yes	14,533	-31.96 (-57.21, -6.71)	0.0132	-34.19 (-57.97, -10.42)	0.0048	0.1337

All models included birth year fixed effects.

[b] The fully adjusted model included child's sex, child's birth order, multiple births, mother's age at childbirth, maternal education level, place of residence, and household economic status.

Table 4-4. Demographic characteristics for all children included in the tropical cyclone-stunting analysis in Bangladesh and India.

Characteristics	**Total**	**Bangladesh**	**India**
DHS survey year	2004-2018	2004, 2007, 2011, 2014, 2017-18	2015-16
No. of children	253,293	33,370	219,923
No. of children exposed to tropical cyclones, n (%)	60,189 (23.8%)	10,709 (32.1%)	49,480 (22.5%)
No. of children being stunted, n (%)	26,250 (10.4%)	4,741 (14.2%)	21,509 (9.8%)
Child's sex, n (%)			
Boys	130,746 (51.6%)	17,094 (51.2%)	113,652 (51.7%)
Girls	122,547 (48.4%)	16,276 (48.8%)	106,271 (48.3%)
Child's age			
Mean (SD)	2.6 (1.5)	2.5 (1.5)	2.7 (1.5)
Median (IQR)	3.0 (3.0)	2.0 (3.0)	3.0 (3.0)
Child's birth order			
Mean (SD)	2.3 (1.5)	2.4 (1.6)	2.3 (1.5)
Median (IQR)	2.0 (2.0)	2.0 (2.0)	2.0 (2.0)
Mother's age at childbirth			
Mean (SD)	25.0 (5.1)	23.7 (5.8)	25.1 (4.9)
Median (IQR)	24.2 (6.4)	22.8 (8.0)	24.2 (6.3)
Mother's education level, n (%)			
Low	115,419 (45.6%)	16,474 (49.4%)	98,945 (45.0%)
High	137,874 (54.4%)	16,896 (50.6%)	120,978 (55.0%)
Place of residence, n (%)			
Rural	189,964 (75.0%)	22,654 (67.9%)	167,310 (76.1%)
Urban	63,329 (25.0%)	10,716 (32.1%)	52,613 (23.9%)
Household socioeconomic status, n (%)			
Poor	122,189 (48.2%)	13,789 (41.3%)	108,400 (49.3%)
Middle	50,562 (20.0%)	6,303 (18.9%)	44,259 (20.1%)
Rich	80,542 (31.8%)	13,278 (40.8%)	67,264 (30.6%)

Table 4-5. Association between tropical cyclone exposure and stunting by child's sex, mother's education, and place of residence among children in Bangladesh and India during 2000-2018.

Subgroup		Crude model[a]		Fully adjusted model[b]		
	No. of children	OR (95% CI)	p value	OR (95% CI)	p value	p-heterogeneity
Child's sex						
Girls	122,547	1.26 (1.22, 1.30)	<0.001	1.35 (1.29, 1.42)	<0.001	
Boys	130,746	1.21 (1.22, 1.30)	<0.001	1.24 (1.19, 1.30)	<0.001	<0.001
Mother's education						
Low	115,419	1.34 (1.27, 1.42)	<0.001	1.40 (1.34, 1.47)	<0.001	
High	137,874	1.29 (1.22, 1.36)	<0.001	1.17 (1.12, 1.23)	<0.001	<0.001
Place of residence						
Rural	63,329	1.32 (1.26, 1.38)	<0.001	1.33 (1.28, 1.39)	<0.001	
Urban	189,964	1.16 (1.06, 1.26)	0.0022	1.15 (1.08, 1.23)	<0.001	<0.001
Women's autonomy on healthcare decision						
No	23,692	1.11 (1.01, 1.21)	0.0311	1.19 (1.10, 1.28)	<0.001	
Yes	47,281	1.19 (1.11, 1.28)	<0.001	1.13 (1.06, 1.21)	<0.001	0.2651

All models included country and year fixed effects.

[a] The crude model included child's age as a covariate.

[b] The fully adjusted model included child's sex, child's age, child's birth order, mother's age at childbirth, maternal education level, place of residence, and household socioeconomic status.

Table 4-6. Interaction between tropical cyclones and population conflicts on childhood stunting among children in Bangladesh and India during 2000-2018.

	Tropical cyclone absent	**Tropical cyclone present**
	OR (95% CI)	**OR (95% CI)**
Population conflicts absent	1.00 (Reference)	1.41 (1.26, 1.59)
Population conflicts present	1.31 (1.24, 1.38)	1.69 (1.58, 1.80)
Interaction in multiplicative scale: ROR = 0.91 (0.81, 1.03), p value = 0.1291		
Interaction in additive scale: RERI = -0.02 (-0.12, 0.07)		

The model included child's sex, child's age, child's birth order, mother's age at childbirth, maternal education level, place of residence, and household socioeconomic status as covariates.

Table 5-1. Summary of cyclone interventions.

Cyclone intervention	Underlying mechanism	Strength	Limitations
Cloud seeding [124]	Seeding clouds with silver iodide to perturb surface pressure through heat release, triggering wall migration.	Previously well-developed, medium logistical ease.	Limited effectiveness; hypotheses invalidated by advancements in cloud physics and vortex dynamics.
Sea surface temperature modification [125]	Lowering sea surface temperatures to reduce evaporation, impacting cyclone intensity and genesis.	Theoretically could target cyclone intensity effectively.	High logistical difficulty and costs; effectiveness questionable under realistic conditions.
High-altitude Particle Injection [126]	Injecting particles to modify the temperature gradient between upper and lower atmosphere, affecting cyclone energy pathways.	Potential to modify atmospheric energy pathways.	Significant logistical challenges; potential widespread negative environmental impacts.
Aerosol Injection [127-130]	Utilizing aerosols to affect cyclone dynamics through radiative and cloud interactions, potentially altering convection and precipitation.	High research level and potentially high effectiveness with appropriate targeting.	Uncertain impacts on cyclone dynamics; potential negative side effects like altered rainfall patterns.

Table 5-2. Population impacts of hypothetical interventions on population conflicts in relation to birthweight of children in Sub-Saharan African countries during 1990-2020.

Hypothetical scenario	Mean birthweight (g)[a]	95% CI	Mean difference (g)	95% CI
28.8% of children exposed to conflicts (no intervention)	3269.35	(3265.45, 3273.12)	Reference	
20% of children exposed to conflicts	3271.08	(3267.13, 3274.84)	1.70	(0.97, 2.44)
10% of children exposed to conflicts	3272.16	(3268.13, 3276.02)	2.79	(1.58, 4.02)
None of the children exposed to conflicts	3274.96	(3270.09, 3279.46)	5.57	(3.14, 8.02)

The model included child's sex, child's birth order, child's age, mother's age at childbirth, maternal education level, place of residence, average temperature, average rainfall, nightlight luminosity, country, and birth year as covariates.

Table 5-3. Population impacts of hypothetical interventions on population conflicts in relation to stunting prevalence of children in Sub-Saharan African countries during 1990-2020.

Hypothetical scenario	**Mean prevalence [a] (per 1000 children)**	**95% CI**	**Mean difference (per 1000 children)**	**95% CI**
48.6% of children exposed to conflicts (no intervention)	367.19	(365.25, 369.05)	Reference	
40% of children exposed to conflicts	366.39	(365.93, 366.90)	-0.78	(-2.63, 1.18)
30% of children exposed to conflicts	365.49	(365.04, 365.98)	-1.69	(-3.54, 0.25)
20% of children exposed to conflicts	364.59	(364.14, 365.08)	-2.59	(-4.46, -0.65)
10% of children exposed to conflicts	363.69	(363.25, 364.17)	-3.48	(-5.34, -1.51)
None of the children exposed to conflicts	362.79	(362.36, 363.27)	-4.38	(-6.26, -2.42)

The model included child's sex, child's age, child's birth order, child's age, mother's age at childbirth, maternal education level, place of residence, average temperature, average rainfall, nightlight luminosity, country, and year as covariates.

Table 5-4. Population impacts of hypothetical interventions on tropical cyclones in relation to birthweight of children in the Philippines during 2000-2018.

Hypothetical scenario	Mean birthweight (g)[a]	95% CI	Mean difference (g)	95% CI
52.4% exposed of the children exposed to tropical cyclones (no intervention)	3001.00	(2991.48, 3010.75)	Reference	
40% exposed of the children exposed to tropical cyclones	3004.26	(2994.11, 3014.34)	3.19	(0.56, 5.92)
30% exposed of the children exposed to tropical cyclones	3006.81	(2995.93. 3018.14)	5.75	(1.03, 10.68)
20% exposed of the children exposed to tropical cyclones	3009.29	(2997.92, 3021.72)	8.36	(1.49, 15.50)
10% exposed of the children exposed to tropical cyclones	3011.79	(2998.67, 3025.38)	10.87	(1.92, 20.20)
None of the children exposed to tropical cyclones	3014.40	(2999.95, 3029.86)	13.42	(2.41, 25.00)

[a] The model included child's sex, child's birth order, child's age, mother's age at childbirth, maternal education level, place of residence, , household wealth index, and birth year as covariates.

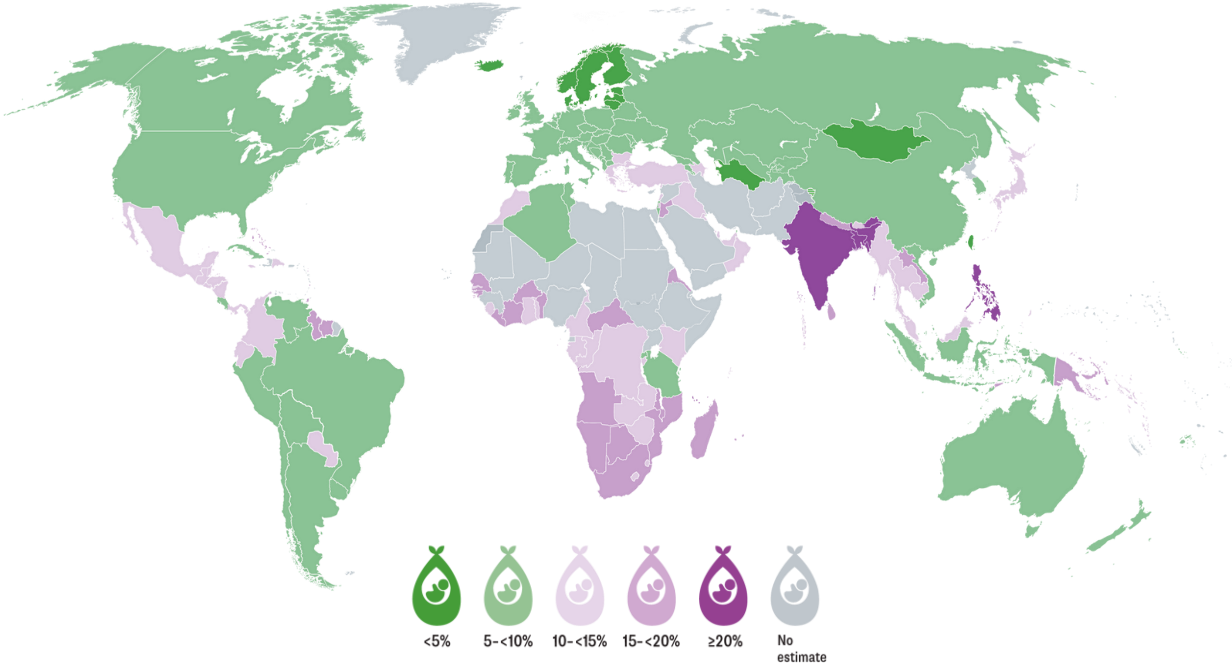
Table 5-5. Population impacts of hypothetical interventions on tropical cyclones in relation to stunting prevalence of children in Bangladesh and India during 2000-2018.

Hypothetical scenario	Mean prevalence (per 1000 children)[a]	95% CI	Mean difference (per 1000 children)	95% CI
23.8% of the children exposed to tropical cyclones (no intervention)	377.33	(375.36, 379.23)	Reference	
10% of the children exposed to tropical cyclones	375.08	(373.03, 377.04)	-2.31	(-2.86, -1.63)
None of the children exposed to tropical cyclones	373.40	(371.19, 375.58)	-3.99	(-4.98, -2.82)

[a] The model included child's sex, child's age, child's birth order, child's age, mother's age at childbirth, maternal education level, place of residence, household wealth index, country, and year as covariates.

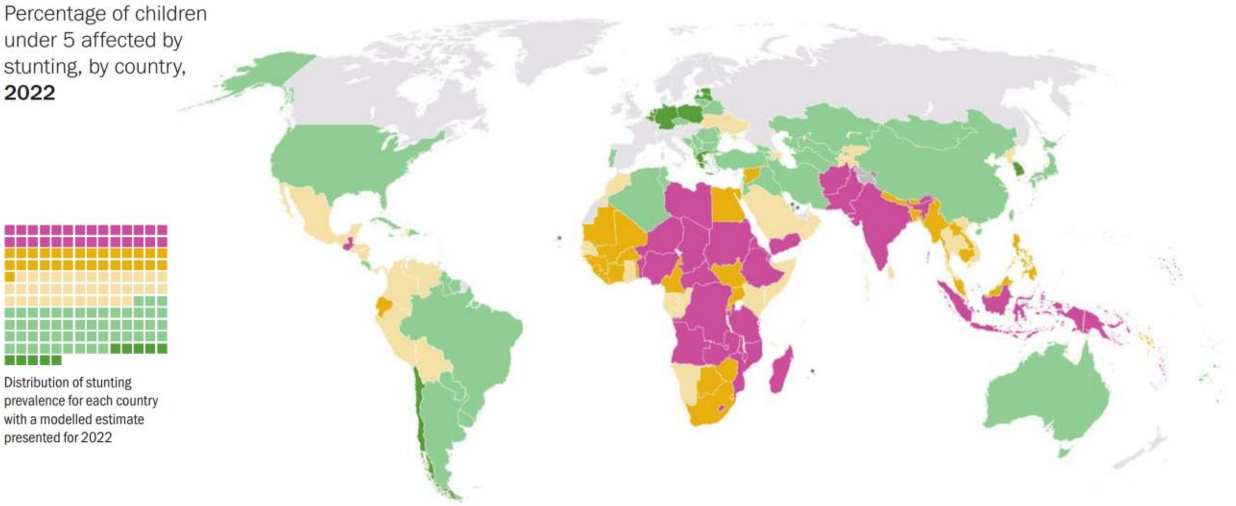
FIGURES

Figure 1-1. Low birthweight prevalence by country and region in 2020.



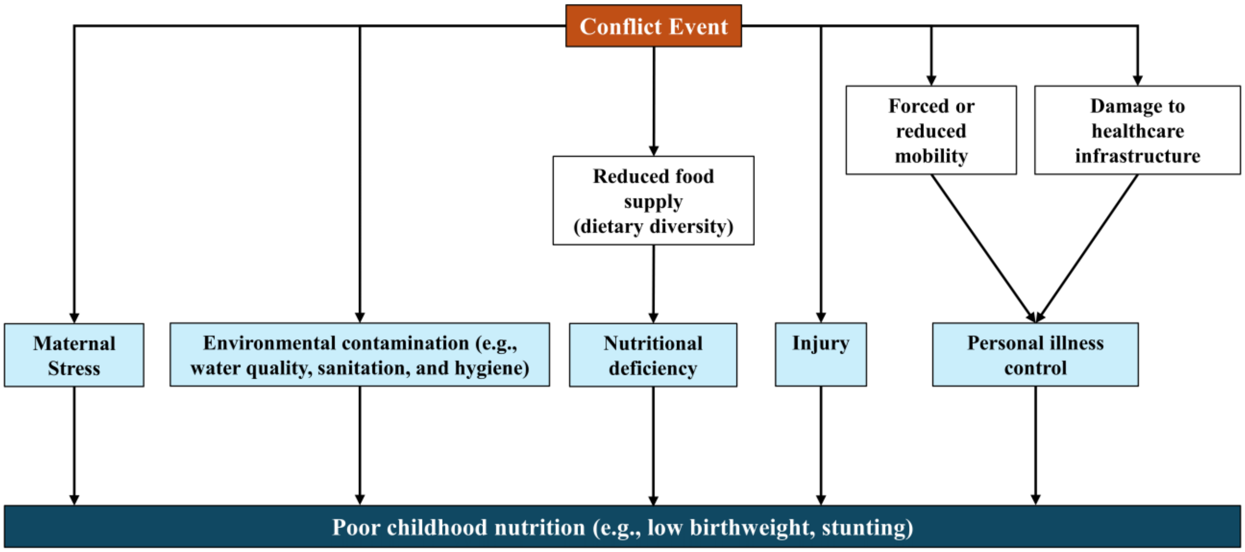
Source: UNICEF-WHO Low birthweight estimates, 2023 [5].

Figure 1-2. Percentage of children under five that were stunted by country in 2022.



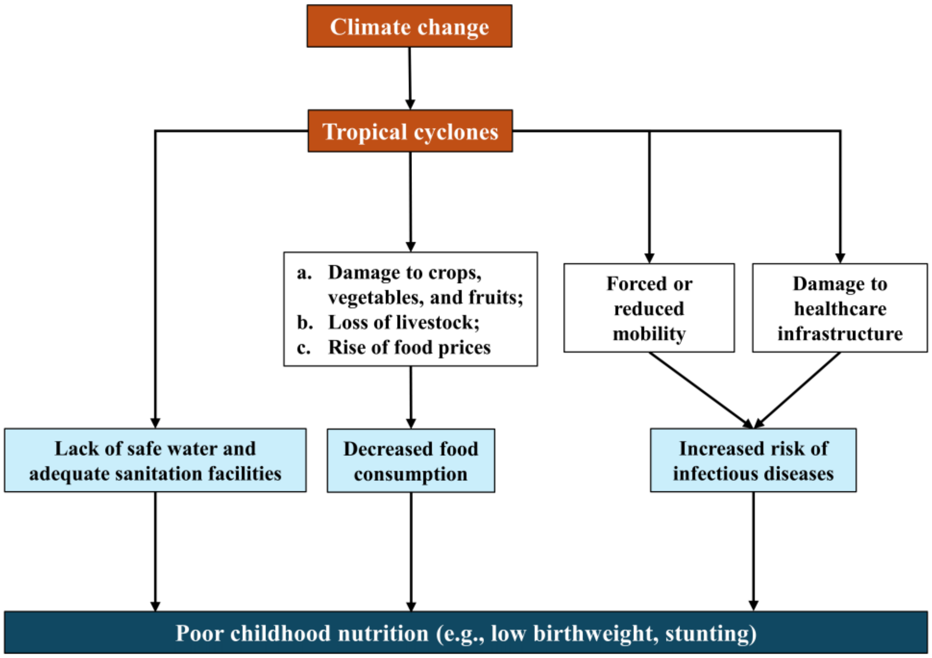
Source: Levels and trends in child malnutrition, UNICEF / WHO / World Bank Group Joint Child Malnutrition Estimates [24].

Figure 1-3. Conceptual framework of underlying mechanisms from population conflicts to childhood nutritional status.



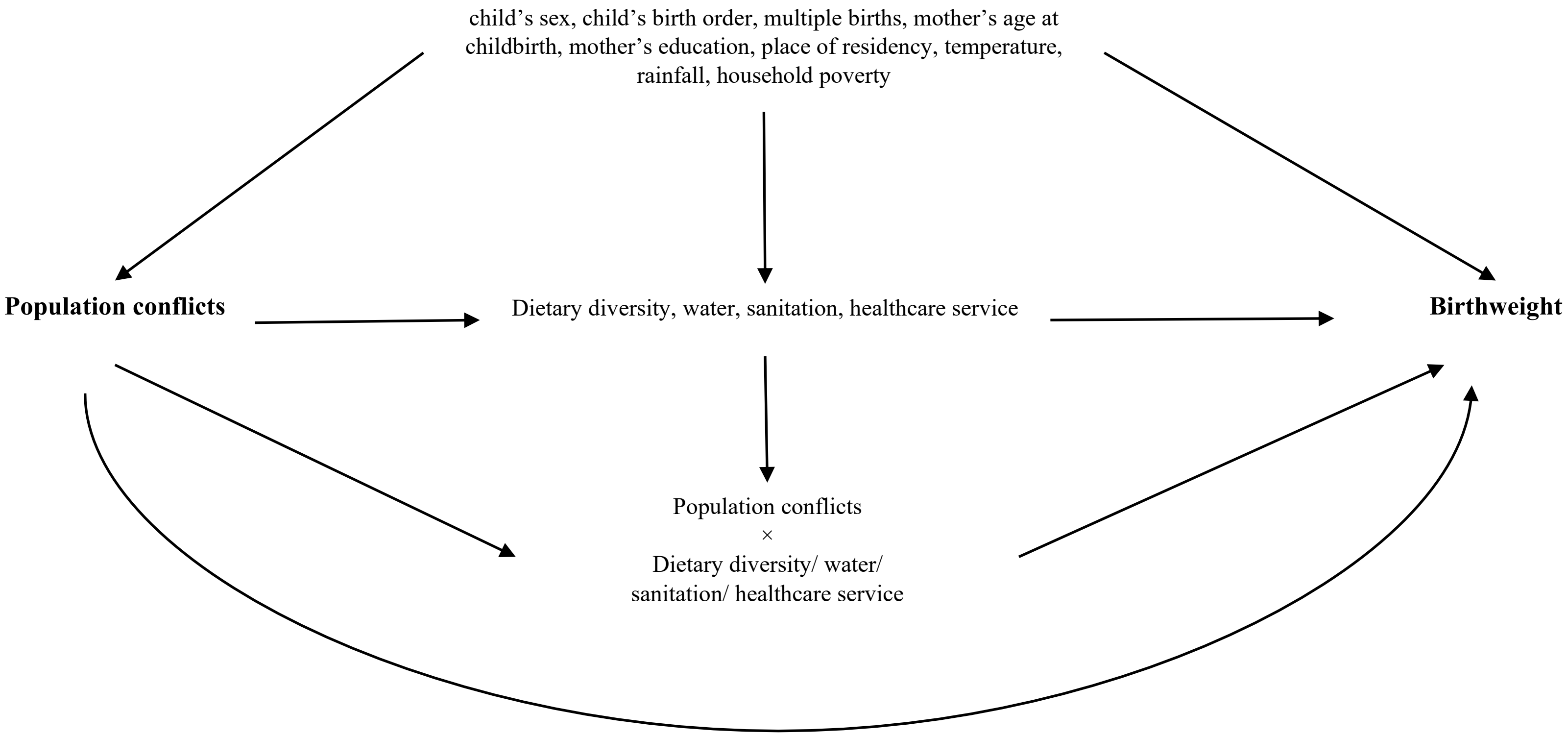
Source: Acharya, Yubraj, et al. "Exposure to conflict-related violence and nutritional status of children in Iraq." SSM-Population Health 11 (2020): 100585. [45]

Figure 1-4. Conceptual framework of underlying mechanisms from tropical cyclones to childhood nutritional status.



Source: Paul, S.K., B.K. Paul, and J.K. Routray, Post-Cyclone Sidr nutritional status of women and children in coastal Bangladesh: an empirical study. Natural hazards, 2012. 64: p. 19-36.[62]

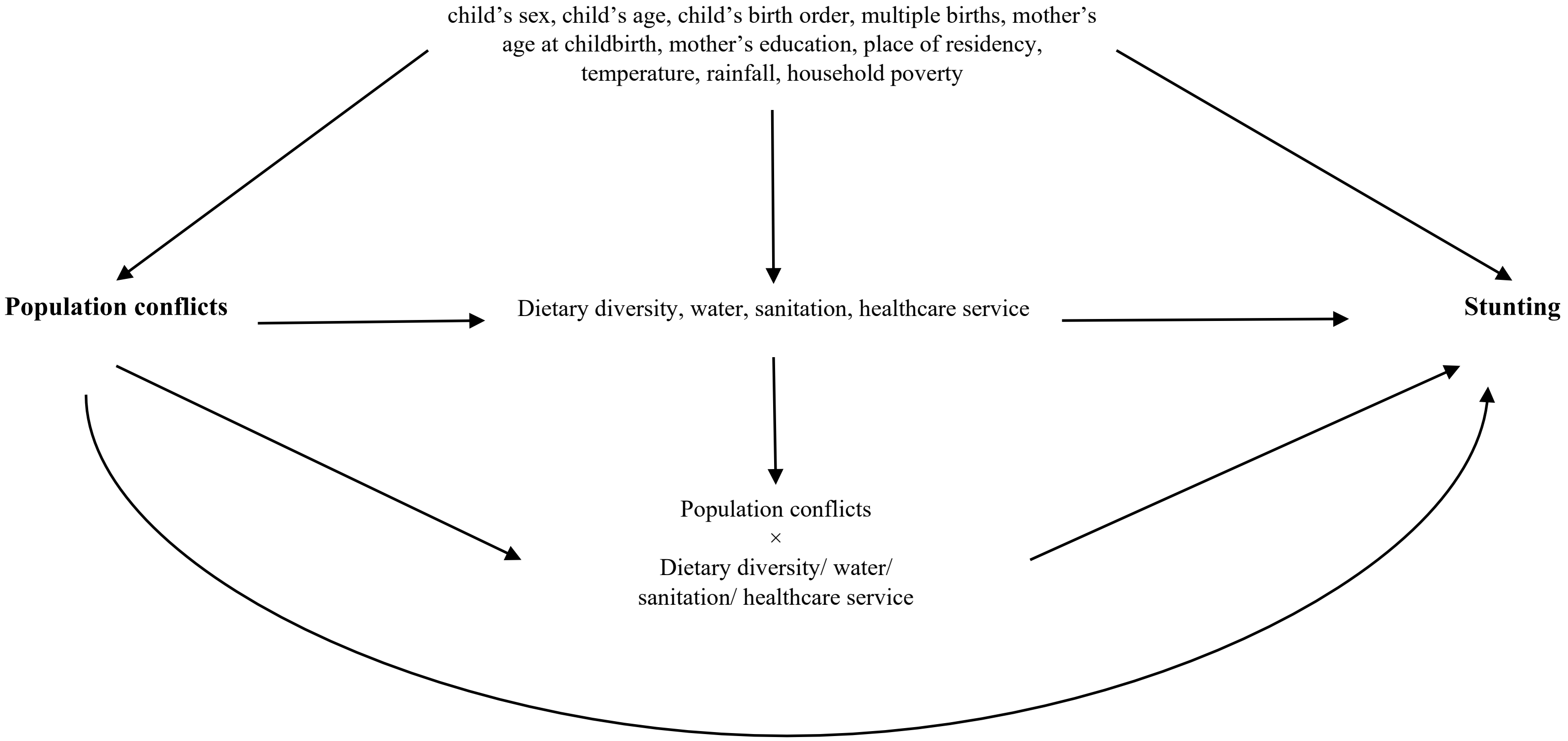
Figure 2-1. DAG of the association between population conflicts and birthweight.



Effect estimate modifiers: child’s sex, mother’s education, mother’s autonomy on healthcare, place of residence

Abbreviations: DAG, directed acyclic graph.

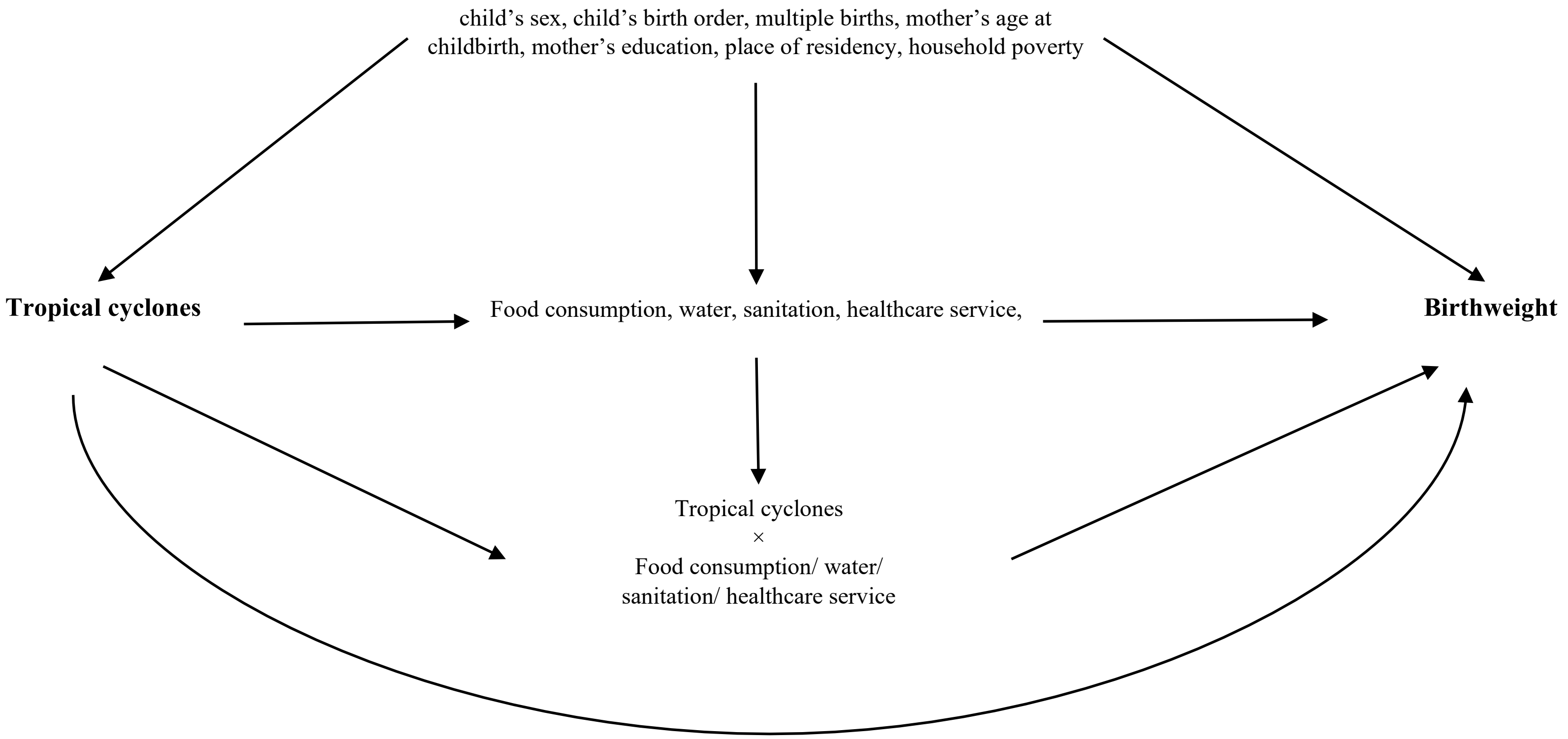
Figure 2-2. DAG of the association between population conflicts and childhood stunting.



Effect estimate modifiers: child's sex, mother's education, mother's autonomy on healthcare, place of residence

Abbreviations: DAG, directed acyclic graph.

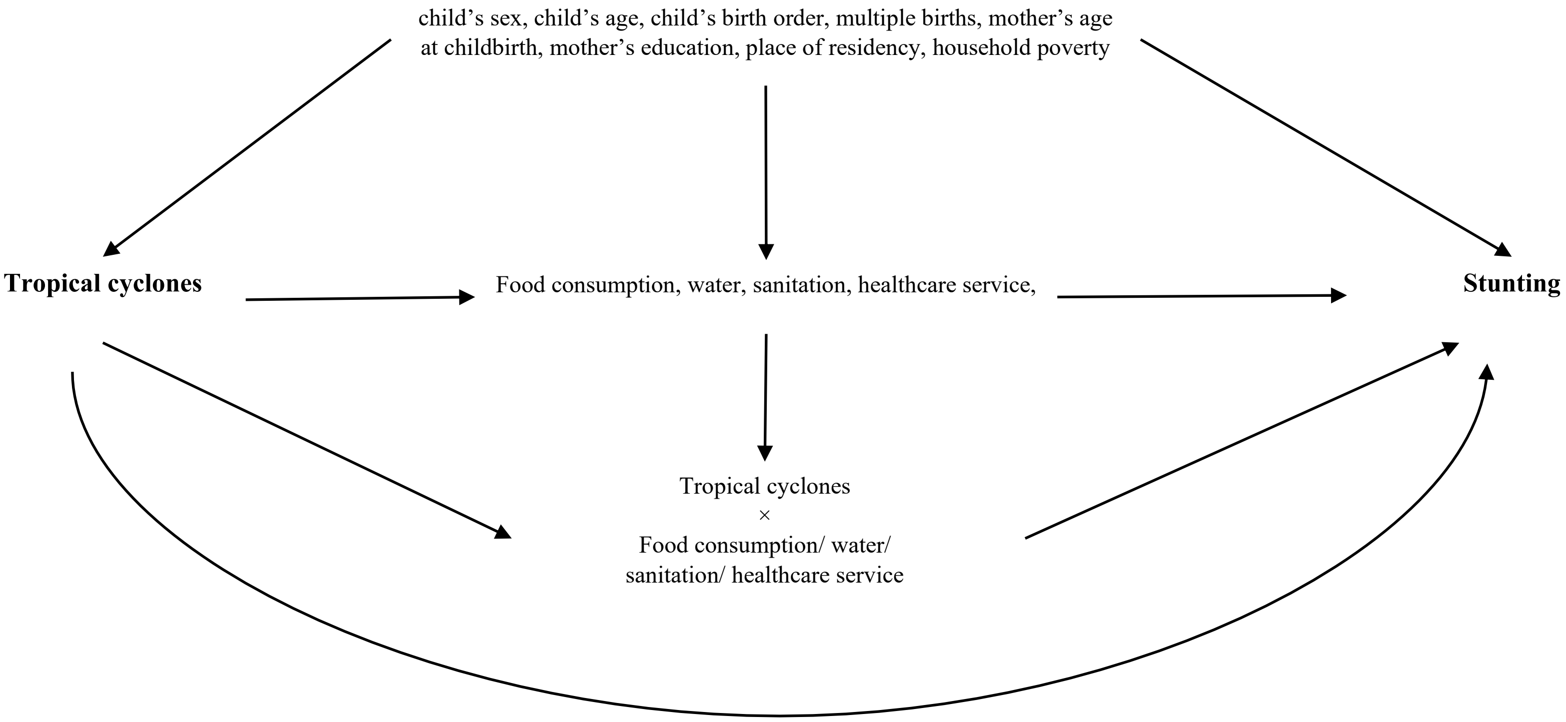
Figure 2-3. DAG of the association between tropical cyclones and birthweight.



Effect estimate modifiers: child’s sex, mother’s education, place of residence

Abbreviations: DAG, directed acyclic graph.

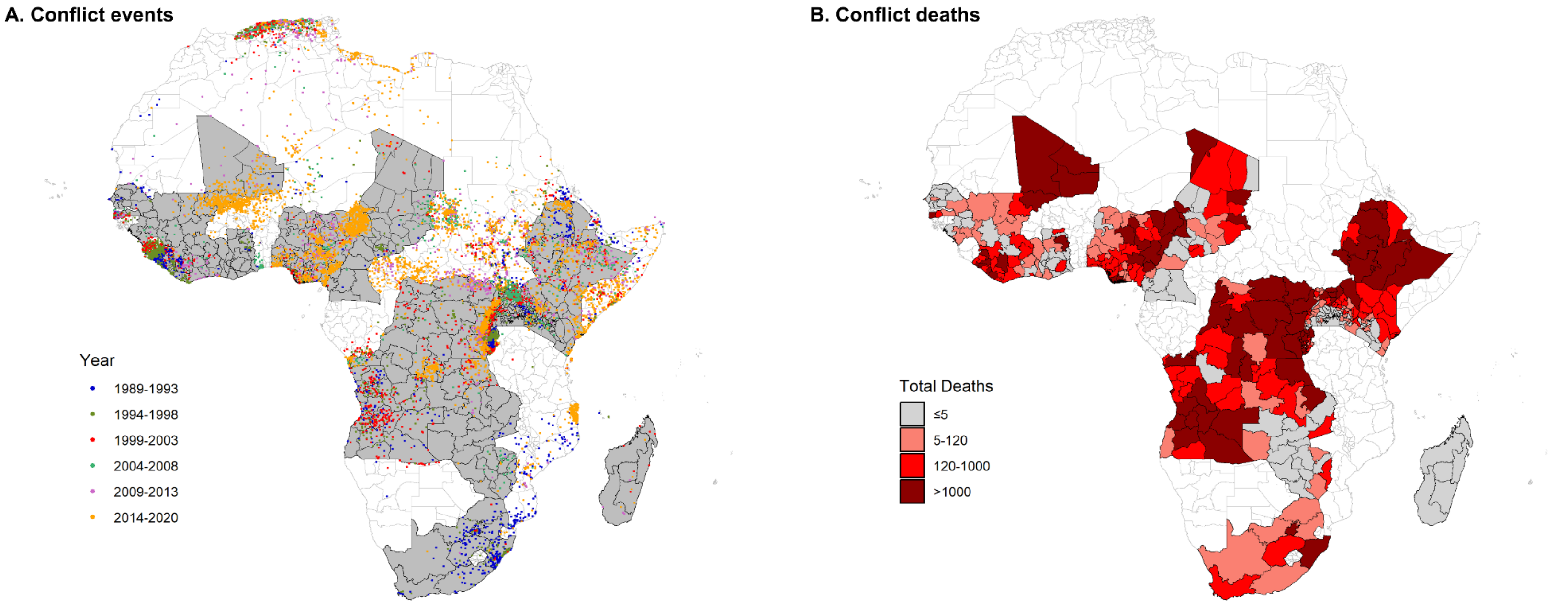
Figure 2-4. DAG of the association between tropical cyclones and childhood stunting.



Effect estimate modifiers: child’s sex, mother’s education, place of residence

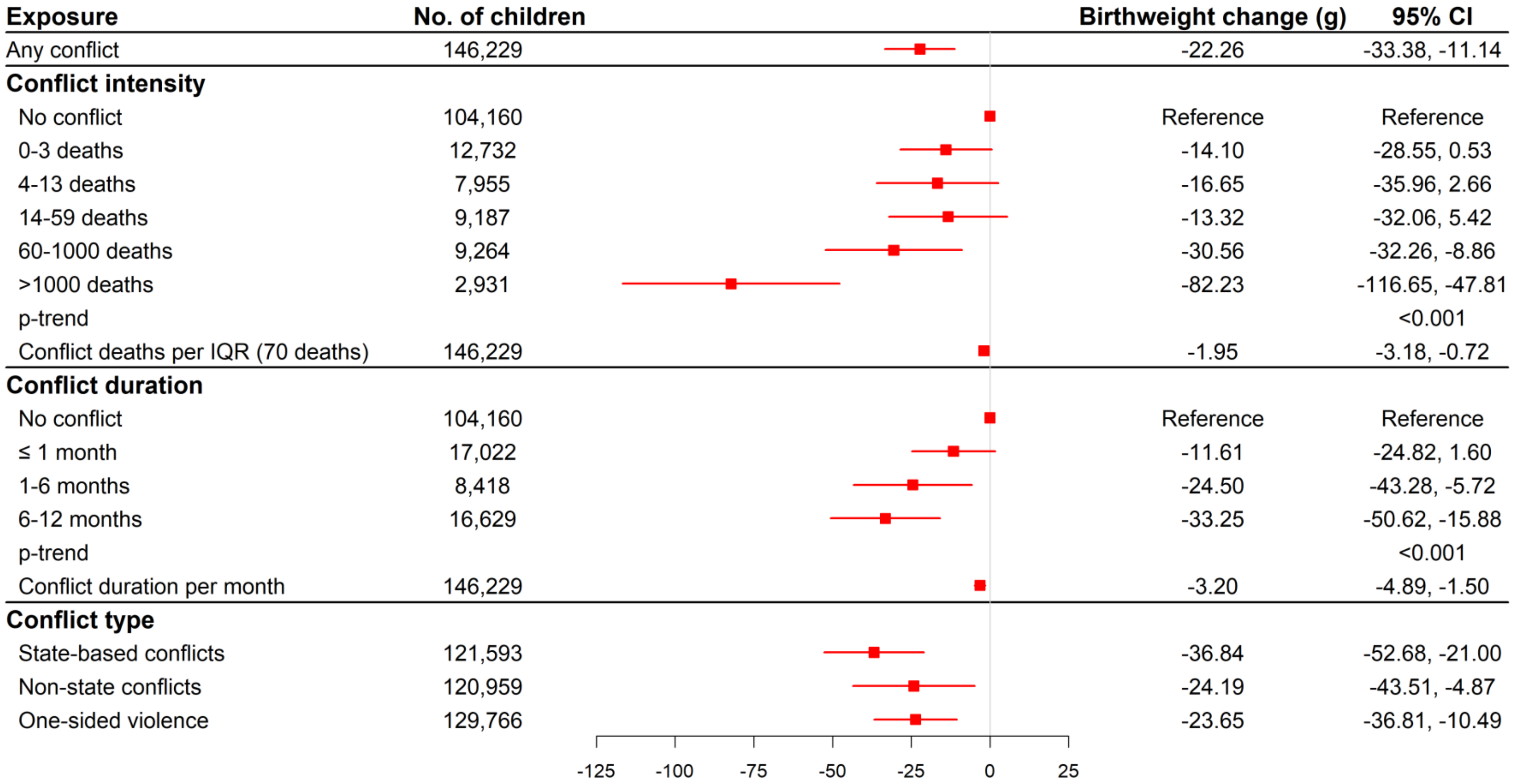
Abbreviations: DAG, directed acyclic graph.

Figure 3-1. Conflict events and conflict deaths in Sub-Saharan Africa during 1989-2020.



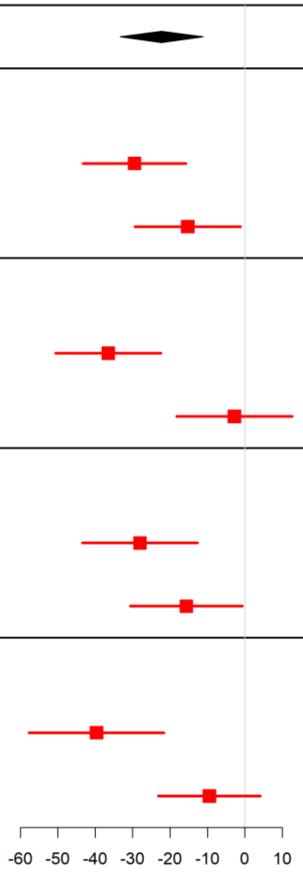
Regions highlighted in grey are countries included in this study.
Source: the Uppsala Conflict Data Program.

Figure 3-2. Forest plot of change of birthweight to conflict exposure, conflict intensity, and conflict duration among children in Sub-Saharan Africa during 1990-2020.



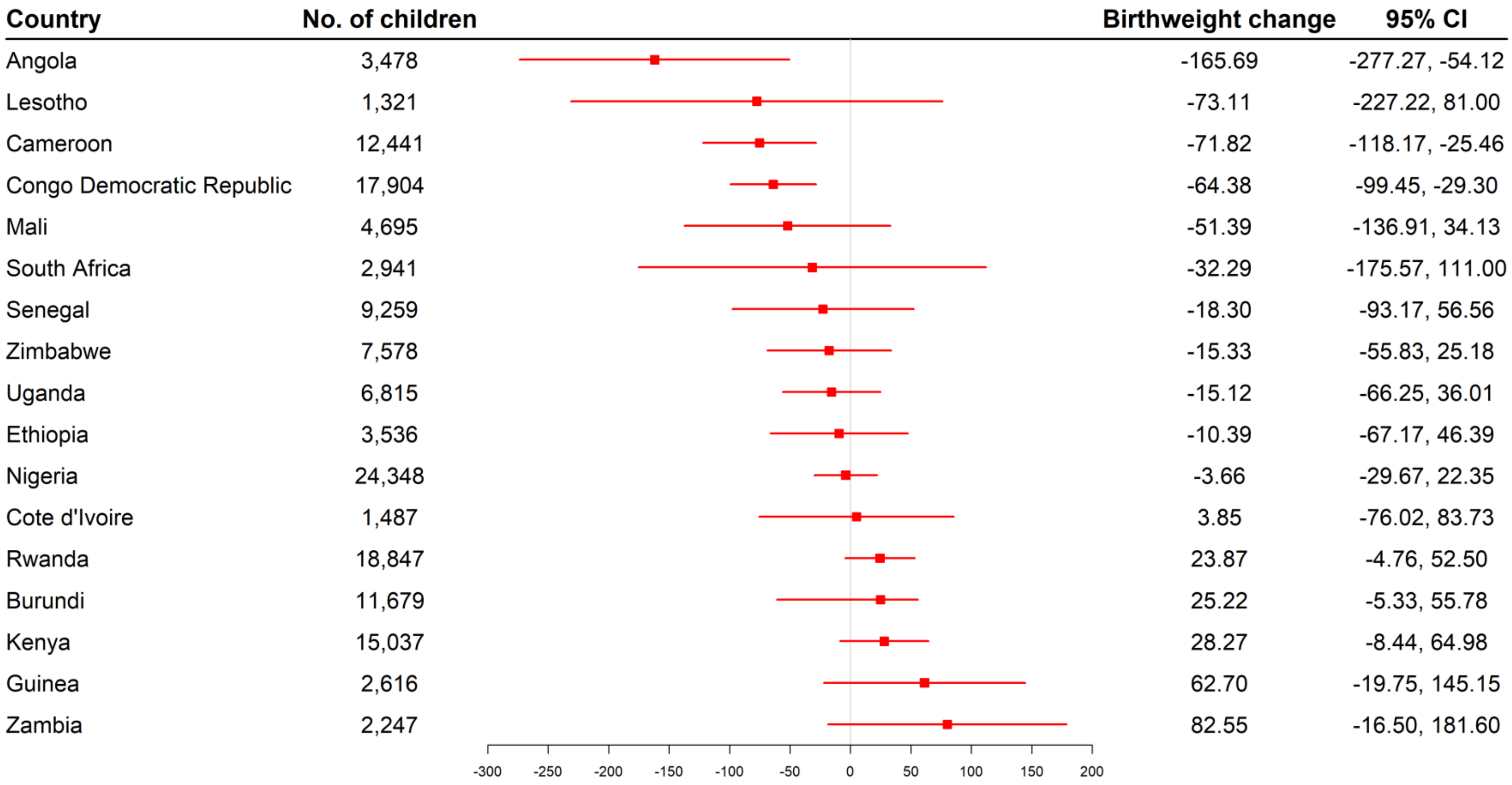
Exposure	No. of children	Birthweight change (g)	95% CI
Any conflict	146,229	-22.26	-33.38, -11.14
Conflict intensity			
No conflict	104,160	Reference	Reference
0-3 deaths	12,732	-14.10	-28.55, 0.53
4-13 deaths	7,955	-16.65	-35.96, 2.66
14-59 deaths	9,187	-13.32	-32.06, 5.42
60-1000 deaths	9,264	-30.56	-32.26, -8.86
>1000 deaths	2,931	-82.23	-116.65, -47.81
p-trend			<0.001
Conflict deaths per IQR (70 deaths)	146,229	-1.95	-3.18, -0.72
Conflict duration			
No conflict	104,160	Reference	Reference
≤ 1 month	17,022	-11.61	-24.82, 1.60
1-6 months	8,418	-24.50	-43.28, -5.72
6-12 months	16,629	-33.25	-50.62, -15.88
p-trend			<0.001
Conflict duration per month	146,229	-3.20	-4.89, -1.50
Conflict type			
State-based conflicts	121,593	-36.84	-52.68, -21.00
Non-state conflicts	120,959	-24.19	-43.51, -4.87
One-sided violence	129,766	-23.65	-36.81, -10.49

Figure 3-3. Forest plot of change of birthweight to conflict exposure by child's sex, mother's education, place of residence, and women's autonomy on healthcare decision among children in Sub-Saharan Africa during 1990-2020.



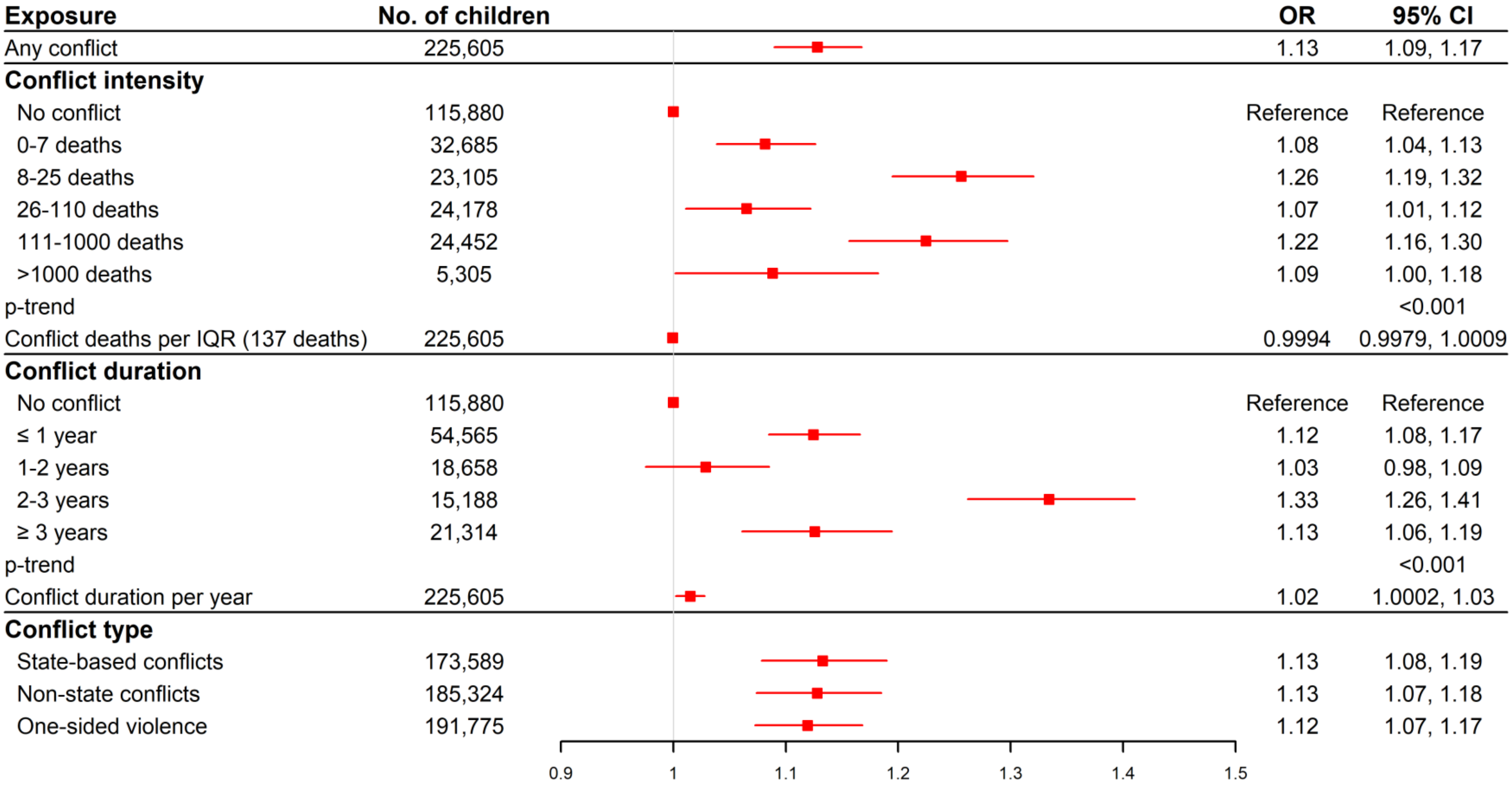
Subgroup	No. of children (%)	Exposed to conflicts (%)	Birthweight change	95% CI	p-heterogeneity
Overall	**146,229**	**42,069 (28.77%)**	**-22.26**	**-33.38, -11.14**	
Child's sex					
Girls	71,873 (49.15%)	20,782 (28.91%)	-29.48	-43.23, -15.73	
Boys	74,356 (50.85%)	21,287 (28.63%)	-15.26	-29.38, -1.13	0.0977
Mother's education					
Low	85,405 (58.40%)	22,679 (26.55%)	-36.52	-50.56, -22.48	
High	60,824 (41.60%)	19,390 (31.88%)	-2.77	-18.21, 12.66	<0.001
Place of residence					
Rural	81,659 (55.84%)	21,405 (26.21%)	-28.03	-43.43, -12.62	
Urban	64,570 (44.16%)	20,664 (32.00%)	-15.65	-30.59, -0.70	0.2426
Women's empowerment on healthcare					
No	50,383 (39.19%)	14,209 (28.20%)	-39.66	-57.68, -21.63	
Yes	78,186 (60.81%)	23,817 (30.46%)	-9.49	-23.09, 4.11	0.0047

Figure 3-4. Forest plot of change of birthweight to conflict exposure by country among children in Sub-Saharan Africa during 1990-2020.



Country	No. of children	Birthweight change	95% CI
Angola	3,478	-165.69	-277.27, -54.12
Lesotho	1,321	-73.11	-227.22, 81.00
Cameroon	12,441	-71.82	-118.17, -25.46
Congo Democratic Republic	17,904	-64.38	-99.45, -29.30
Mali	4,695	-51.39	-136.91, 34.13
South Africa	2,941	-32.29	-175.57, 111.00
Senegal	9,259	-18.30	-93.17, 56.56
Zimbabwe	7,578	-15.33	-55.83, 25.18
Uganda	6,815	-15.12	-66.25, 36.01
Ethiopia	3,536	-10.39	-67.17, 46.39
Nigeria	24,348	-3.66	-29.67, 22.35
Cote d'Ivoire	1,487	3.85	-76.02, 83.73
Rwanda	18,847	23.87	-4.76, 52.50
Burundi	11,679	25.22	-5.33, 55.78
Kenya	15,037	28.27	-8.44, 64.98
Guinea	2,616	62.70	-19.75, 145.15
Zambia	2,247	82.55	-16.50, 181.60

Figure 3-5. Forest plot of the association of conflict exposure, conflict intensity, and conflict duration on stunting among children in Sub-Saharan Africa during 1990-2020.



Exposure	No. of children	OR	95% CI
Any conflict	225,605	1.13	1.09, 1.17
Conflict intensity			
No conflict	115,880	Reference	Reference
0-7 deaths	32,685	1.08	1.04, 1.13
8-25 deaths	23,105	1.26	1.19, 1.32
26-110 deaths	24,178	1.07	1.01, 1.12
111-1000 deaths	24,452	1.22	1.16, 1.30
>1000 deaths	5,305	1.09	1.00, 1.18
p-trend			<0.001
Conflict deaths per IQR (137 deaths)	225,605	0.9994	0.9979, 1.0009
Conflict duration			
No conflict	115,880	Reference	Reference
≤ 1 year	54,565	1.12	1.08, 1.17
1-2 years	18,658	1.03	0.98, 1.09
2-3 years	15,188	1.33	1.26, 1.41
≥ 3 years	21,314	1.13	1.06, 1.19
p-trend			<0.001
Conflict duration per year	225,605	1.02	1.0002, 1.03
Conflict type			
State-based conflicts	173,589	1.13	1.08, 1.19
Non-state conflicts	185,324	1.13	1.07, 1.18
One-sided violence	191,775	1.12	1.07, 1.17

Figure 3-6. Forest plot of association between conflict exposure and stunting by child's sex, mother's education, place of residence, and women's autonomy on healthcare decision among children in Sub-Saharan Africa during 1990-2020.

Subgroup	No. of children (%)	Exposed to conflicts (%)	OR	95% CI	p-heterogeneity
Overall	**225,605**	**109,725 (48.64%)**	**1.13**	**(1.09, 1.17)**	
Child's sex					
Girls	112,341	54,784 (48.77%)	1.14	(1.10, 1.19)	
Boys	113,264	54,941 (48.51%)	1.09	(1.05, 1.14)	0.0144
Mother's education					
Low	170,008	83,226 (48.95%)	1.14	(1.09, 1.18)	
High	55,597	26,499 (47.66%)	1.14	(1.07, 1.17)	<0.001
Place of residence					
Rural	162,984	78,755 (48.32%)	1.14	(1.09, 1.18)	
Urban	62,621	30,970 (49.46%)	1.13	(1.05, 1.21)	<0.001
Women's empowerment on healthcare					
No	101,008	46,635 (46.17%)	1.09	(1.03, 1.15)	
Yes	96,035	51,533 (53.66%)	1.15	(1.09, 1.21)	0.2943

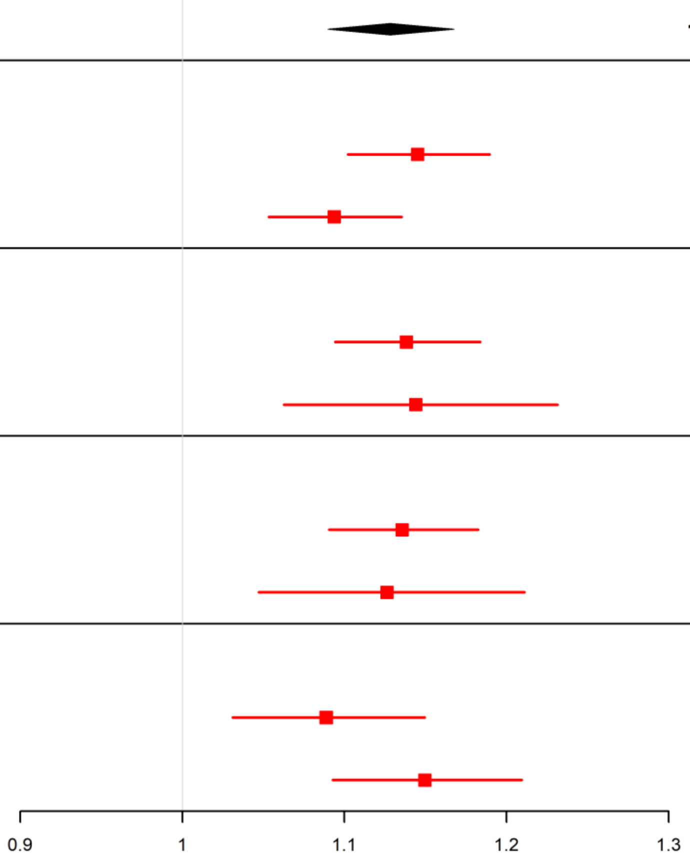
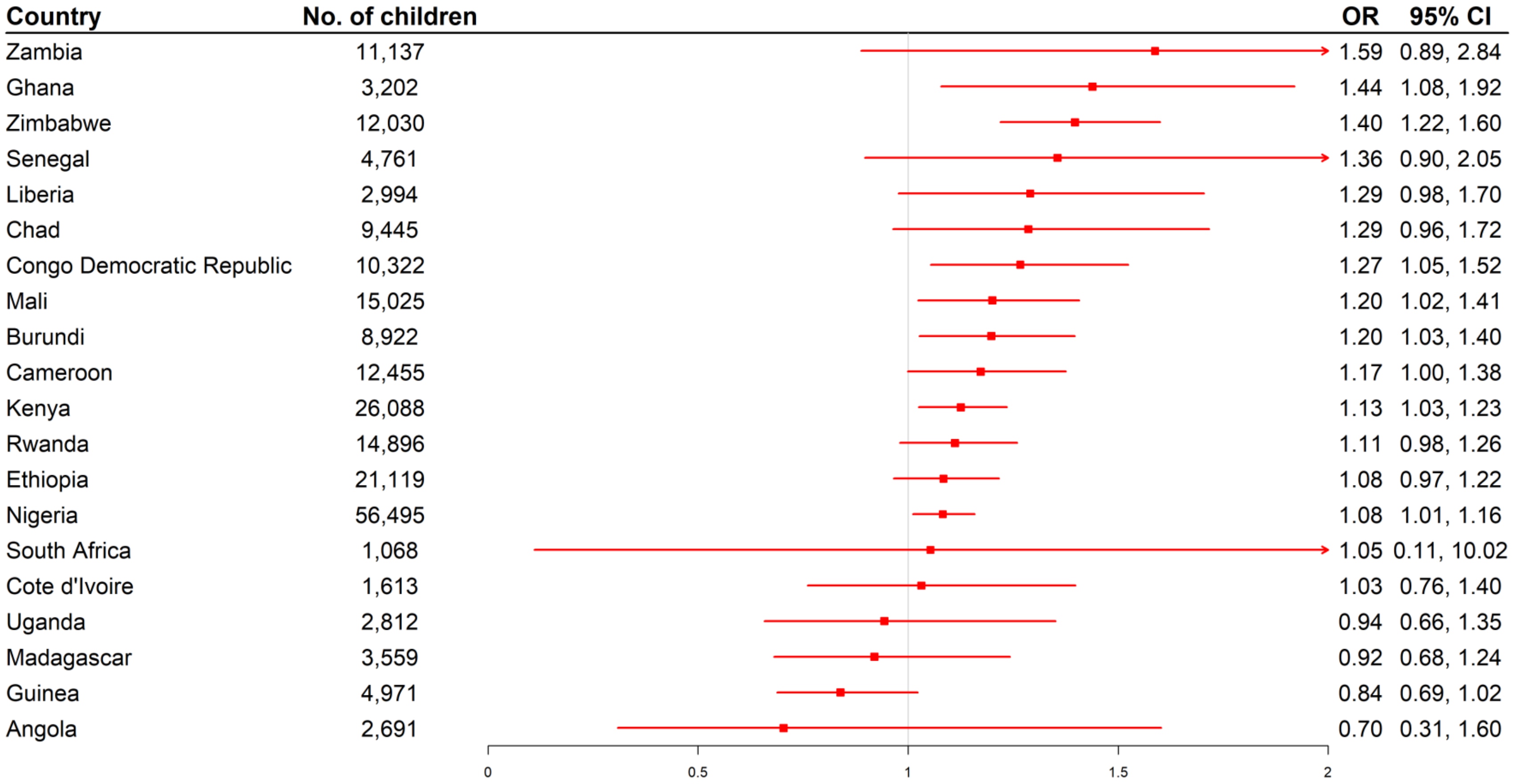


Figure 3-7. Forest plot of association between conflict exposure and stunting by country among children in Sub-Saharan Africa during 1990-2020.



Country	No. of children	OR	95% CI
Zambia	11,137	1.59	0.89, 2.84
Ghana	3,202	1.44	1.08, 1.92
Zimbabwe	12,030	1.40	1.22, 1.60
Senegal	4,761	1.36	0.90, 2.05
Liberia	2,994	1.29	0.98, 1.70
Chad	9,445	1.29	0.96, 1.72
Congo Democratic Republic	10,322	1.27	1.05, 1.52
Mali	15,025	1.20	1.02, 1.41
Burundi	8,922	1.20	1.03, 1.40
Cameroon	12,455	1.17	1.00, 1.38
Kenya	26,088	1.13	1.03, 1.23
Rwanda	14,896	1.11	0.98, 1.26
Ethiopia	21,119	1.08	0.97, 1.22
Nigeria	56,495	1.08	1.01, 1.16
South Africa	1,068	1.05	0.11, 10.02
Cote d'Ivoire	1,613	1.03	0.76, 1.40
Uganda	2,812	0.94	0.66, 1.35
Madagascar	3,559	0.92	0.68, 1.24
Guinea	4,971	0.84	0.69, 1.02
Angola	2,691	0.70	0.31, 1.60

Figure 4-1. Number of tropical cyclones in the Philippines during 2000-2018.

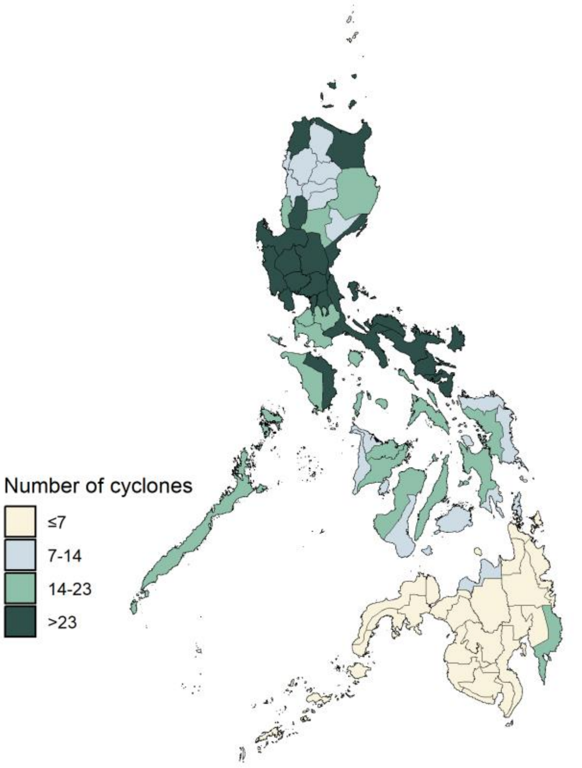


Figure 4-2. Number of tropical cyclones in Bangladesh and India during 2000-2018.

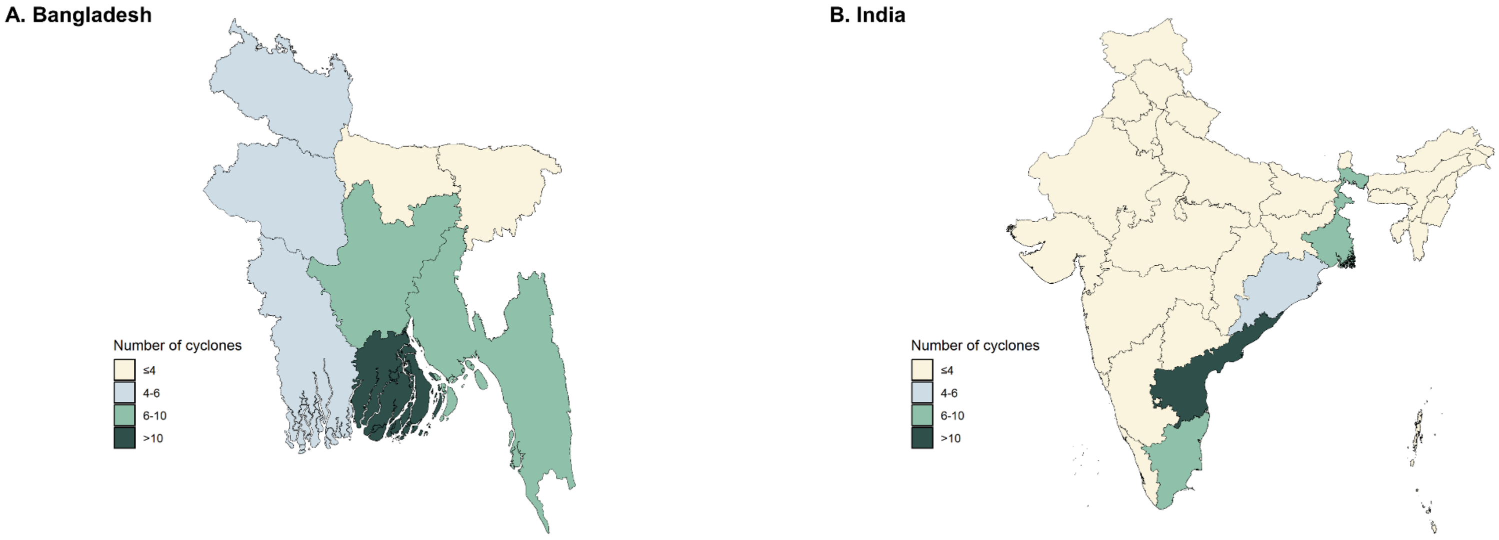


Figure 4-3. Forest plot of association between cyclone exposure and birthweight change by child's sex, mother's education, place of residence, and women's autonomy on healthcare decision among children in the Philippines during 2000-2018.

Subgroup	No. of children (%)	Exposed to cyclones (%)	Birthweight change	95% CI	p-heterogeneity
Overall	**16,331**	**8,562 (52.43%)**	**-25.55**	**-49.43, -1.66**	
Child's sex					
Girls	7,801 (47.77%)	4,071 (52.19%)	-15.86	-45.89, 14.16	
Boys	8,530 (52.23%%)	4,491 (52.65%)	-29.94	-60.09, 0.21	0.9612
Mother's education					
Low	2,984 (18.27%)	1,366 (45.78%)	-26.59	-79.40, 26.21	
High	13,347 (81.73%)	7,196 (53.91%)	-22.50	-46.15, 1.14	0.7811
Place of residence					
Rural	9,269 (56.76%)	4,564 (49.24%)	-35.32	-64.89, -5.74	
Urban	7,062 (43.24%)	3,998 (56.61%)	-7.69	-38.80, 23.42	0.2571
Women's empowerment on healthcare					
No	9,47 (6.12%)	457 (48.26%)	52.61	-30.55, 135.77	
Yes	14,533 (93.88%)	7,590 (52.23%)	-34.19	-57.97, -10.42	0.1337

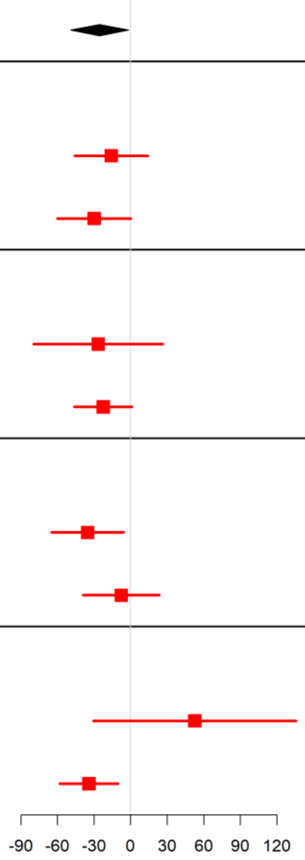
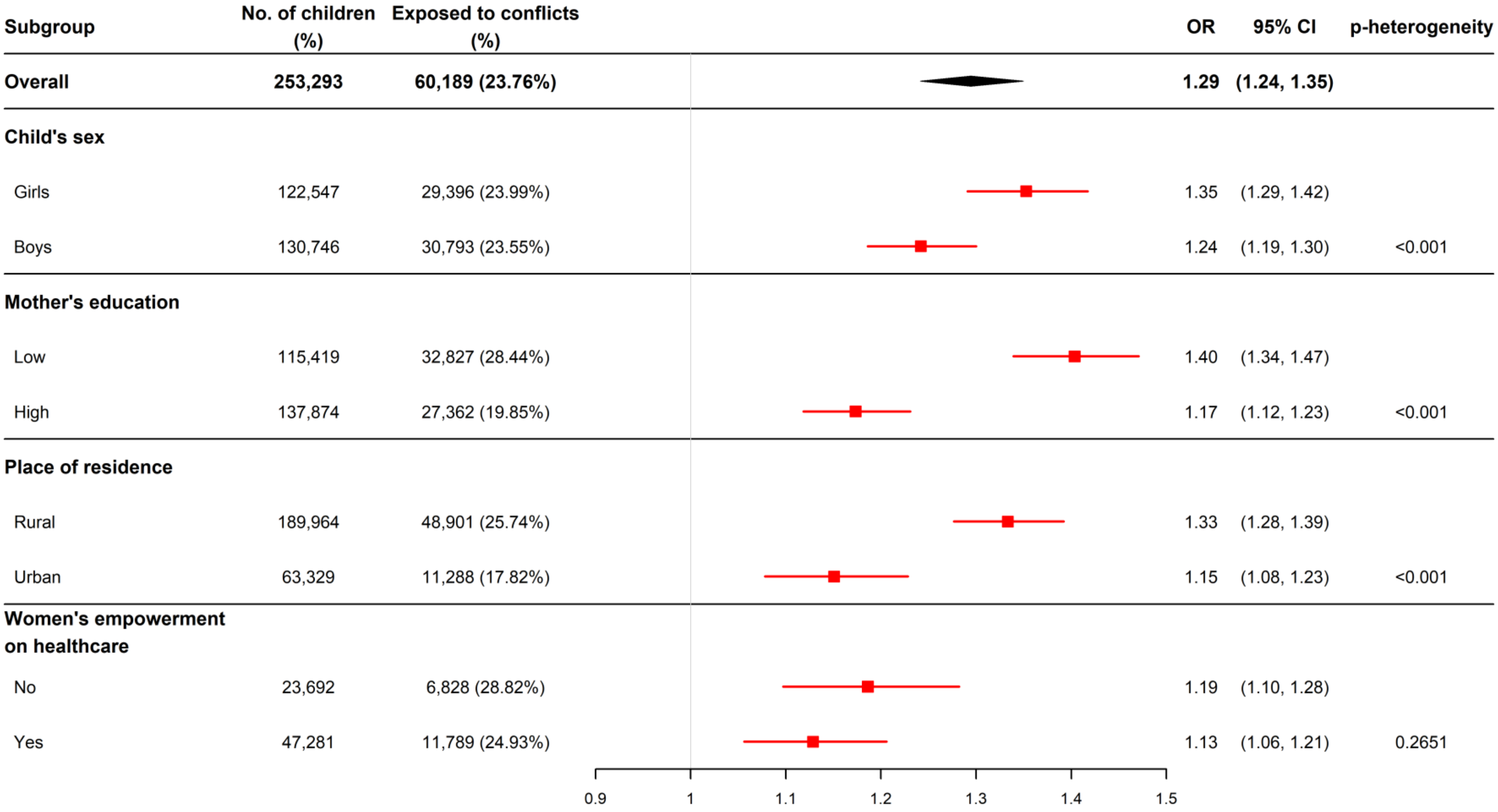


Figure 4-4. Forest plot of association between cyclone exposure and stunting by child’s sex, mother’s education, place of residence, and women’s autonomy on healthcare decision among children in Bangladesh and India during 2000-2018.



Subgroup	No. of children (%)	Exposed to conflicts (%)	OR	95% CI	p-heterogeneity
Overall	**253,293**	**60,189 (23.76%)**	**1.29**	**(1.24, 1.35)**	
Child's sex					
Girls	122,547	29,396 (23.99%)	1.35	(1.29, 1.42)	
Boys	130,746	30,793 (23.55%)	1.24	(1.19, 1.30)	<0.001
Mother's education					
Low	115,419	32,827 (28.44%)	1.40	(1.34, 1.47)	
High	137,874	27,362 (19.85%)	1.17	(1.12, 1.23)	<0.001
Place of residence					
Rural	189,964	48,901 (25.74%)	1.33	(1.28, 1.39)	
Urban	63,329	11,288 (17.82%)	1.15	(1.08, 1.23)	<0.001
Women's empowerment on healthcare					
No	23,692	6,828 (28.82%)	1.19	(1.10, 1.28)	
Yes	47,281	11,789 (24.93%)	1.13	(1.06, 1.21)	0.2651

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