

## ABSTRACT

Title of Dissertation:

MULTILEVEL ANALYSES OF  
CHILDHOOD MALNUTRITION AND  
TEMPERATURE EXTREMES IN KENYA,  
BURKINA FASO, NEPAL, AND  
PAKISTAN: EXAMINING INDIVIDUAL  
AND CONTEXTUAL FACTORS

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Geographical Sciences

This dissertation investigates the multifaceted determinants of child malnutrition amidst escalating climate change and rapid nutrition transitions across Sub-Saharan Africa and South Asia. Focusing on Burkina Faso, Kenya, Nepal, and Pakistan, the research first explores how temperature extremes both heat and cold interact with household variables to influence child stunting. The analysis reveals that the impact of climate anomalies on child growth is heavily mediated by local environmental conditions and social resources. While access to electricity, improved water, and sanitation consistently serves as a critical buffer, the specific health risks associated with temperature fluctuations differ markedly by region. Notably, the study uncovers significant associations between cold anomalies and increased stunting risk in specific contexts,

broadening the climate-health discourse beyond heat stress alone.

Complementing this environmental analysis, the dissertation examines the "double burden" of malnutrition, characterized by the coexistence of child stunting and maternal overweight within the same households. The findings demonstrate that this dual burden manifests heterogeneously, driven by divergent patterns of wealth, urbanization, and maternal education. In several contexts, socioeconomic gains were linked to rising maternal obesity without fully resolving child undernutrition, complicating traditional poverty-reduction narratives. Collectively, these chapters highlight that malnutrition is shaped by a complex interplay of climatic stressors and sociodemographic shifts. The study concludes that addressing these disparities requires moving beyond one-size-fits-all interventions toward integrated, context-specific policies capable of tackling both the environmental roots of undernutrition and the emerging complexities of the nutrition transition.

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**by**

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**Dissertation submitted to the Faculty of the Graduate School of the  
University of Maryland, College Park, in partial fulfillment  
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# Dedication

*To my parents*

*Michael Mansfield and Gwendolyn Mansfield*

## **Foreword**

Chapters 2-4 contain jointly authored work in which Tavis Mansfield is the primary author. The materials presented have been published, submitted, or are in preparation for publication in peer-reviewed journals with contributions from Drs. Molly Brown and Meredith Gore in Chapter 2 and Dr. Molly Brown in subsequent chapters.

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## **1.0 Introduction**

### ***1.1 Definition and Understanding Causes of Child Malnutrition***

Pediatric malnutrition, or child undernutrition, occurs when children lack enough energy, protein, or essential nutrients during their early years (Ge and Chang 2001). Child malnutrition can cause long-lasting harm to growth, development, and overall health (Mehta et al. 2013; Arthur et al. 2015). Child growth serves as a ubiquitous indicator of children's nutritional status. The initial 1000 days of life, spanning from birth to 23 months, represent a pivotal period characterized by accelerated physical and cognitive maturation. Malnutrition during this critical juncture can yield enduring repercussions on a child's developmental trajectory, amplifying susceptibility to morbidity and mortality (de Onis and Branca 2016).

Anthropometrics, which combine height, weight and age of the child at different points in the first 1000 days, commonly serve as proxies for assessing undernutrition (Black et al. 2013; Georgiadis and Penny 2017). Wasting is characterized by low weight-for-height, often indicating recent and severe weight loss, though it can endure over an extended period. It typically manifests when an individual lacks sufficient quality and quantity of food intake and/or experiences frequent or prolonged illnesses. In children, wasting is linked to a heightened risk of mortality if not adequately addressed. Stunting, on the other hand, is defined as low height-for-age and results from chronic or recurrent undernutrition, commonly associated with poverty, maternal malnutrition, frequent illness, and inadequate early-life feeding and care. Stunting hampers children from reaching their full physical and cognitive potential. Underweight is described as low weight-for-age. An underweight child may exhibit stunting, wasting, or both

(WHO 2009a). Mitigating malnutrition stands as a paramount global health imperative, resonating with various objectives delineated within the United Nations' Sustainable Development Goals (SDGs). This is highlighted within Goal 2 - Zero Hunger which explicitly prioritizes endeavors to eradicate hunger and foster sustainable agricultural practices (De Pereira and Charvet 2025).

Child malnutrition affects approximately one in five children worldwide and plays a pivotal role in nearly half of all childhood fatalities on a global scale (Black et al. 2013; Tesema et al. 2021; Asmare et al. 2025). In the global landscape of 2022, 149 million children under the age of five were identified as stunted, indicative of impaired growth relative to their age. Additionally, 45 million children were categorized as wasted, denoting a deficiency in weight relative to their height, while 37 million were deemed overweight (WHO 2024). Shedding light on the determinants of child malnutrition, a systematic review conducted by Katoch (2022) revealed a constellation of influential factors (Katoch 2022). These include maternal education, household income, maternal nutritional status, the age of the child, access to sanitation facilities within the household, family size, birth order, and the child's birth weight. Moreover, the study emphasized the pivotal roles of breastfeeding practices, caregiving behaviors, characteristics of the cooking area and fuel utilized, the child's gender, and the socioeconomic status of the family in shaping nutritional outcomes. As the climate changes, adapting the agricultural, economic and political context in which investments in social safety nets that protect human health will be important to improve these prevalence rates (Tirado et al. 2022).

## ***1.2 Climate Variations in Africa***

Examining escalating global temperature trends reveals profound implications for human

populations, with ramifications for low-income nations, notably in Sub-Saharan Africa. This region stands out for high rates of child malnutrition on a global scale. Hence, an examination of malnutrition distribution within Sub-Saharan Africa's sub-regions becomes imperative to pinpoint the most afflicted areas (Simwanza et al. 2023; de Sherbinin 2011; Saidu and Danielson 2024). Additionally, a nuanced analysis of the intersection between climate extremes, encompassing heatwaves and cold snaps, and these vulnerable populations is warranted (Li et al. 2025; Choudhary et al. 2025). Recent studies employing computational models (Schilling et al. 2020; Haile et al. 2020), indicate changes in climate that reflect disadvantaged socioeconomic groups are likely to encounter heightened severity of temperature extremes at earlier junctures compared to their affluent counterparts (Conte Keivabu and Cozzani 2022; Chambers 2020), a trend perpetuated by ongoing global greenhouse emissions (IPCC 2022a; Harrington et al. 2016). Moreover, (Herold et al. 2017) demonstrated that if the current pace of temperature extreme variations persists unabated in low-income nations, the frequency of hot days experienced annually could potentially triple within a span of two decades, in stark contrast to the baseline period of 1961–1990. Although there has been extensive research on child malnutrition rates in Sub-Saharan Africa and the projected distribution of heat waves throughout the continent, scant consideration has been given to the consequences of cold extremes in Northern African nations. This oversight is significant, as populations within low-income countries may face heightened vulnerability to adverse health effects resulting from climatic extremes. Even short periods of low temperature can affect health outcomes, particularly when rising mean temperatures reduce the resilience of households to hot and cold anomalies (Lavados et al. 2018; Qiao et al. 2015; Choi and Ailshire 2025).

The sub-Saharan African region has experienced an increase from 181 million malnourished

individuals in 2010 to approximately 222 million by 2016 (Adeyeye et al. 2023). By 2020, this number escalated even further, with up to 264.2 million people in Sub-Saharan Africa experiencing undernourishment, accounting for around 24.1% of the population, marking the highest prevalence of undernourishment globally (FAO 2025). Although the total number of undernourished people worldwide is projected to decline by 2030, an estimated 512 million individuals are still expected to experience hunger, with nearly 60 percent residing in Africa (FAO 2025). Multiple factors contribute to the persistence of malnutrition in Sub-Saharan Africa.

While the burden of childhood malnutrition is a global challenge, its impacts are most acutely felt across Sub-Saharan Africa and South Asia, which together account for over 90% of the world's stunted children (FSIN} and (GNAFC)} 2025). In South Asia specifically, the region contains approximately one-third of all global cases of stunting, reflecting a deep-seated crisis of chronic undernutrition (Parajuli and Oldewage-Theron 2025). These regions encompass, among others, pervasive poverty, rapid population growth, inefficient small-scale agricultural practices, limited access to education, the compounding impacts of climate change, systemic corruption, ongoing conflicts and wars, and fluctuations in food prices (Cornia et al. 2016; Ivanov et al. 2020). It is imperative to address these complex and interconnected issues comprehensively to effectively combat malnutrition and foster sustainable development across the region. Several studies have shown that sub-Saharan Africa may experience heightened prevalence rates of child stunting in coming decades, depending on the pace of socioeconomic advancement (Davenport et al. 2017; Tusting, Bradley, et al. 2020; McMahon and Gray 2021).

Despite the multitude of factors influencing a child's health, one area that remains relatively understudied is the influence of climate extremes, especially cold snaps (Amondo et al. 2023;

Thiede and Strube 2020). While research has extensively examined the effects of droughts and heat, cold climatic events have not garnered adequate attention, particularly concerning their impact on geographically vulnerable regions such as Sub-Saharan Africa. In warm climates, cold events can represent abrupt and dramatic departures from typical temperature patterns. Rapid temperature reversals such as sudden shifts from unusually warm conditions to sharp cold spells place significant stress on human populations and ecosystems because there is little time to physiologically, socially, or environmentally adapt to the contrasting extreme (Wu et al. 2025). My research puts both heat waves and cold snaps together in the same analysis so that the impact on human health of these extremes can be assessed. Extreme cold events, often referred to as "cold waves" or "cold snaps," are the result of unusually cold periods (Johnson et al. 2018). The 2008 cold spell in subtropical China stands as a stark reminder of the substantial toll that extreme cold temperatures can exact, with an estimated 148,279 fatalities (Zhou 2014).

Shedding light on the vulnerability of children in South Africa to such climatic phenomena, van Der Walt's (2021) investigation showed the pronounced threat posed by extreme cold temperatures, exacerbated by the nation's inadequate preparedness measures (Van Der Walt and Fitchett 2021). Previous research has shown regions and populations with prevalent infectious diseases experience a seasonal increase in mortality due to high rainfall and rising temperatures. Conversely, moderately low, and extremely high temperatures are associated with increased cardio-respiratory mortality, shaping mortality patterns in areas and subgroups where these diseases are prominent (Burkart et al. 2014; Amegah et al. 2016; P. Li et al. 2025).

### *1.3 Climate Extremes in Asia*

Research has underscored the significance of temperature extremes in tropical climates where

building infrastructure limits protection from their impact, such as that found in Africa, Latin America, and Asia (Parkes et al. 2022; Shively 2017; Iyakaremye et al. 2021). South Asia bears one of the world's heaviest burdens of child malnutrition, with approximately one-third of globally stunted children residing in the region, a prevalence pattern strikingly similar to Sub-Saharan Africa where 34% of children under five remain stunted (Wali et al. 2020; Hosen et al. 2023). This shared vulnerability reflects not only persistent poverty, food insecurity, and limited healthcare access, but also increasingly severe climate impacts that threaten both African and South Asian predominantly agrarian populations (Abebaw 2025; Omokpariola et al. 2025). South Asia faces particularly acute climate risks as temperatures across the region are projected to rise 2-3°C by mid-century under current emissions scenarios. The risk of cold-related injuries underscores the importance of studying the impact of these events within the Asian context (Xi et al. 2025; Min et al. 2021).

Homes in warm-climate regions such as South Asia are designed for heat dissipation rather than cold protection, leaving poor households without adequate heating, insulation, warm clothing, or resources to buffer against cold-related health and economic shocks highlight the need for climate adaptation strategies that account for both heat and cold extremes (Seabi et al. 2025; Akinsanola et al. 2025). By integrating both minimum and maximum temperature anomalies, this dissertation seeks to capture the full spectrum of thermal stressors that may affect children's growth and development. Examining these climatic factors in conjunction with household-level indicators across two South Asian countries provides a more nuanced understanding of how temperature variability, particularly cold climate events, contributes to child stunting. This approach identifies key household characteristics, such as access to electricity, improved

sanitation, and greater wealth, that can act as protective factors against the negative impacts of climatic stress on child health outcomes. There have also been analyses showing the persistent threat posed by cold events despite the backdrop of escalating mean temperatures (Park et al. 2011; Xie et al. 2025) which can result in additional morbidity and mortality among vulnerable populations, as is shown in the following sections.

#### ***1.4 Climate Variations and Human Health***

Climate extremes exert diverse effects on human health across multiple dimensions. They have the potential to cause direct harm, such as injuries or fatalities, and may also indirectly contribute to physical ailments, psychological disorders, property damage, infrastructure disruptions, water contamination, and the resurgence and dissemination of infectious diseases (Forzieri et al. 2017; Martínez Lozada and Leon-Rojas 2025; Borah 2025). These impacts are particularly accentuated within vulnerable demographic segments, including elderly individuals aged 65 and above, children, infants, those with pre-existing or chronic medical conditions, and socially isolated individuals (Basu 2009; Franchini and Mannucci 2015; Amekpor et al. 2025). Previous research has indicated an association between extreme climate occurrences and the accessibility of essential calories and nutrients crucial for children's well-being (Amondo et al. 2023; Mulondo et al. 2025; Jensen and Sørensen 2025). Specifically, their research revealed that droughts led to a substantial reduction in the availability of calories, protein, and zinc, as well as a decline in overall dietary diversity by 67%, 37%, 28%, and 30%, respectively. Moreover, they observed that a 10% decrease in zinc availability corresponded to a decrease in height-for-age z-scores (HAZ) ranging from approximately 0.139 to 0.164 standard deviations, accompanied by an increased likelihood of stunting by 3.1 to 3.5 percentage points. These findings underscore the critical linkages between climate-related extreme events, nutritional deficiencies, and

adverse child health outcomes, emphasizing the opportunities to expand knowledge on protective determinants for comprehensive strategies to mitigate the impact of climate change on malnutrition and child development.

### ***1.5 Cold Snaps and Child Malnutrition***

Koufias and Vinha's (2012) research shows the correlation between adverse temperature variations and the prevalence of child stunting in Mexico, with particularly notable impacts observed in municipalities situated at higher altitudes (Koufias and Vinha 2012). Their findings illuminate the disproportionate burden borne by regions susceptible to significant temperature fluctuations, emphasizing the critical interplay between environmental factors and child nutritional outcomes. In a separate investigation, McMahon and Gray's (2021) study showed the nuanced effects of climate anomalies on child health in South Asia, contrasting the relative impacts of temperature and precipitation irregularities. While their analysis suggests a lesser influence of temperature anomalies compared to precipitation deviations, their findings underscored the multifaceted nature of climate-health interactions (McMahon and Gray 2021). Specifically, their research identifies that extremes of both heat and cold during the formative first two years of life exert detrimental effects on child nutritional well-being, highlighting the vulnerability of this critical developmental period to climatic perturbations.

### ***1.6 Cold Snaps and Mortality***

A study by Bakshi et al (2019) found that in Kenya, a rise in occurrences of cold snaps correlated significantly with elevated mortality rates, whereas in Mali and Malawi, cold snaps were linked with decreased mortality rates (Bakshi et al. 2019). Notably, investigations indicate that cold temperatures can elevate mortality rates in certain southern European nations (Healy

2003). This suggests that the impact of cold temperatures on mortality is influenced by regional variations in acclimatization abilities particularly in warmer climates (Montero et al. 2010; Healy 2003). In the discourse surrounding global warming, heightened attention is typically directed towards the implications of extreme heat rather than extreme cold (Liu et al. 2026; Saravanan et al. 2024). Nevertheless, research has indicated a noteworthy shift in the dynamics of human adaptability to temperature extremes (Bobb et al. 2014; Dear and Wang 2015). While strides have been made in enhancing resilience to heat stress, evidenced by an increasing capacity for adaptation among populations, conversely, the trend towards diminishing adaptation to cold conditions is becoming apparent. This suggests a reversal in the historical trajectory of cold adaptation, warranting careful consideration amidst projections of decreasing frequencies of extreme cold events in the future. Despite forecasts indicating a potential decline in the occurrence of extreme cold events, the significance of cold-related mortality persists as a concern that should not be overlooked in the broader context of climate change mitigation and adaptation strategies.

### ***1.7 Measurement of Climate Extremes***

Kysely et al (2009) provided a definition for a cold spell as a consecutive period of days where the air temperature remained below  $-3.5^{\circ}\text{C}$ . Meanwhile, Hickey (2011) proposed that a cold spell could be identified as "a stretch of 10 consecutive days with minimum air temperatures  $5^{\circ}\text{C}$  or more below the norm." (Hickey 2011). However, employing a singular temperature threshold may not be suitable for a geographically diverse country like Nepal, which encompasses five distinct climate zones. Instead, I plan to utilize the percentile of daily temperatures to delineate a cold spell.

The concept of heat waves encompasses a broad definition, indicating a period of consecutive days marked by temperatures significantly higher than usual. Such events are not limited to particular seasons and can occur both during the warm season and throughout the year. The characterization of heat waves considers various factors, including minimum temperature ( $T_{min}$ ) and maximum temperature ( $T_{max}$ ), as excessive nighttime temperatures can intensify the severity of the event. Scholars such as Pattenden et al. (2003), Trigo et al. (2005), and Nicholls et al. (2008) have contributed to understanding the multifaceted nature of heat waves. Additionally, the calculation of apparent temperature ( $T_a$ ), commonly known as the "heat index" as per Steadman's work in 1979 and 1984, offers further insights by integrating temperature and relative humidity (Pattenden et al. 2003; Trigo et al. 2005; Steadman 1979; Nicholls et al. 2008). Researchers, such as Deo et al. (2007), may consider apparent temperature when analyzing concurrent extreme weather conditions.

Through establishing a baseline temperature based on averages and accessing the threshold above which a period of sustained high temperatures is considered a heatwave. This threshold can vary depending on geographical location, climate norms, and local context. Considering consecutive days or hours above the established temperature threshold. The spatial extent of the heatwave by monitoring its coverage area. Heatwaves can affect regions ranging from local areas to entire continents. Understanding the geographic scope will help in assessing the impact on the various DHS clusters and implementing appropriate response measures.

Cold waves receive comparatively less research attention, potentially underestimating its impact on vulnerable populations (Qing et al. 2025). However, according to the US National Weather Service, a cold wave is characterized by a swift drop in temperature over a 24-hour period, resulting in temperatures necessitating significantly increased protection for agriculture,

industry, commerce, and social activities. Similar to heatwaves, cold waves can be assessed using daily maximum (Tmax) and minimum (Tmin) temperatures, as well as average temperature. Additionally, they can be quantified by analyzing temperature changes in the 24 hours preceding the event, based on historical data and station specific information regarding onset, duration, and end dates. Cold wave conditions persist for at least two days (WMO. 2020). Spatial analysis of cold waves involves calculating relevant variables within the affected area. This includes determining the percentage of weather stations where temperature thresholds were exceeded, identifying the coordinates of impacted stations, and locating the center with the highest or lowest index values (Moghim and Jahangir 2022).

My dissertation addresses a critical gap in the current understanding of the varying burdens of malnutrition within the context of a rapidly changing climate. While previous research has established broad links between environmental stress and health, I have identified a lack of granular evidence regarding how specific temperature anomalies including both extreme heat and unseasonable cold snaps directly correlate with child stunting. Research Question 1 addresses this issue by investigating the extent to which these anomalies are associated with stunting risks in specific case study countries. Furthermore, I find that current literature often treats climatic shocks as monolithic; therefore, Research Question 2 aims to parse out the nuances of these stressors by identifying which household-level socioeconomic and infrastructural characteristics serve as protective buffers or heighteners of vulnerability.

To further bridge these gaps, Research Question 3 explores the complex interaction between climatic stressors and household conditions to determine how they collectively influence nutritional outcomes in climate-vulnerable settings. Beyond the physical environment, I also address the "dual burden" paradox where maternal overweight and child undernutrition coexist;

Research Question 5 investigates how maternal attributes and community factors drive this phenomenon across diverse low- and middle-income settings. Finally, Research Question 4 ensures my findings are actionable by identifying the specific insights research can offer policymakers and healthcare providers in Africa and Asia to inform resource allocation and targeted interventions.

### ***1.8 Organization of Dissertation***

The primary objective of this dissertation is to investigate the climatic occurrences of cold snaps or extreme cold waves and heatwaves within the context of Sub-Saharan Africa and South Asian Context their impacts on child malnutrition (Figure 1). To achieve this goal, I employed multilevel models, a statistical framework adept at accommodating hierarchical data structures (Das et al. 2019). This methodology will help facilitate novel exploration of various factors contributing to child malnutrition outcomes by permitting the delineation of residual components at each hierarchical level. Through this approach, I elucidate the intricate interplay between climatic phenomena and child malnutrition within Sub-Saharan Africa and Southeast Asia.

The multi-level modeling outcomes help illuminate variables essential for mitigating climate impacts but also help delve into a comprehensive array of factors, including electricity utility, infrastructure investment, and the effectiveness of climate extreme event forecasting. These factors likely hold significant sway over future child health outcomes (Nikita et al. 2024; Fay et al. 2005). The synthesis of findings derived from the analysis of these

variables ideally will offer invaluable insights that can inform future research endeavors at the nexus of health and climate studies.

Insights from this research may advance efficacy of strategies designed to alleviate climate-related vulnerabilities among low-income populations. By more comprehensively understanding the dynamics of household infrastructure and conditions, interventions can be crafted to ensure equitable access to essential cooling facilities during heatwaves or heating provisions during cold waves. Such measures are likely crucial for safeguarding the health and well-being of vulnerable individuals (Boyle et al. 2006; Irwin et al. 2020; Barron and Torero 2017; Byaro et al. 2024)

Exploring factors such as the impact of gender equality and education levels on child stunting and wasting outcomes can help shed light on how countries can better address child health through social policy interventions. Deeper understanding about the interplay between social dynamics and health outcomes can inform efficacy of policies and interventions that better promote holistic well-being and equitable development. Thus, the synthesis of multi-level model outcomes potentially portend potential not only for advancing scientific understanding but also for catalyzing meaningful policy action.

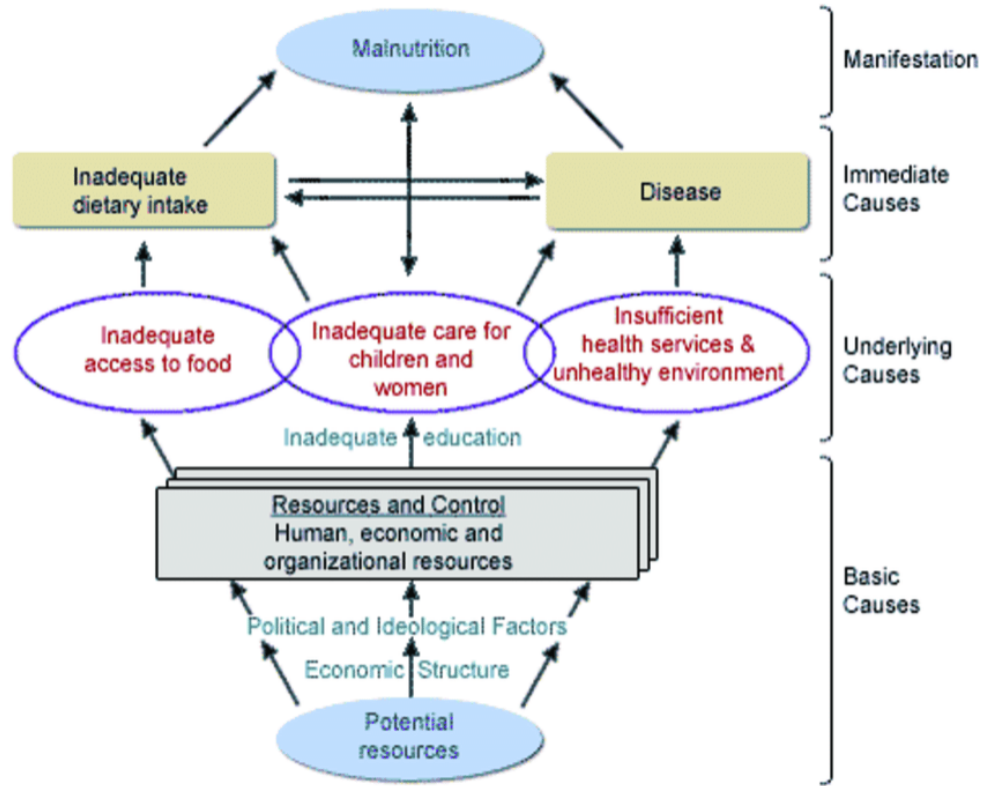


Figure 1.1 UNICEF conceptual framework for causes of child malnutrition (UNICEF 1991).

This dissertation utilizes CHIRTS ERA5 climate data, a product developed by the Climate Hazards Group at the University of California, Santa Barbara (Funk et al. 2019). This dataset amalgamates geospatial satellite infrared temperature data with station and ERA5 reanalysis data sourced from the European Centre for Medium-Range Weather Forecasts (European Centre for Medium-Range Weather Forecasts 2020). Offering a remarkable 5-kilometer resolution, it furnishes temperature data spanning from 1982 to the present day, thereby constituting a vital resource for research endeavors pertaining to climate change, agriculture, and public health.

Likewise, this study leverages CHIRPS, a satellite-derived precipitation dataset renowned for its superior spatial coverage compared to traditional gauge data, enabling a more precise assessment

of wet and dry conditions (Rivera et al. 2019). Previous research by (Funk et al. 2015) demonstrated the utility of CHIRPS in calculating the Standardized Precipitation Index (SPI), thereby enhancing our understanding of drought dynamics. This comprehensive suite of data facilitates a deeper comprehension of climatic variations in Africa, with the potential to inform targeted societal responses within the region.

Inspired by the methodology employed by (Grace et al. 2015), my investigation will establish a connection between environmental variables and a child's prenatal environment by utilizing the child's birthdate and the geographical coordinates of the Demographic and Health Survey (DHS) sampling clusters. To account for spatial disparities, each study links each child's birth weight record to environmental data within a 10-kilometer radius around the sampling cluster, encompassing the period one year prior to, and inclusive of, the child's birthdate across trimesters 0–3. Each child included in the analysis will possess its own climate data time series encompassing temperature and SPI, thereby capturing the unique environmental exposures and nutritional status of each individual.

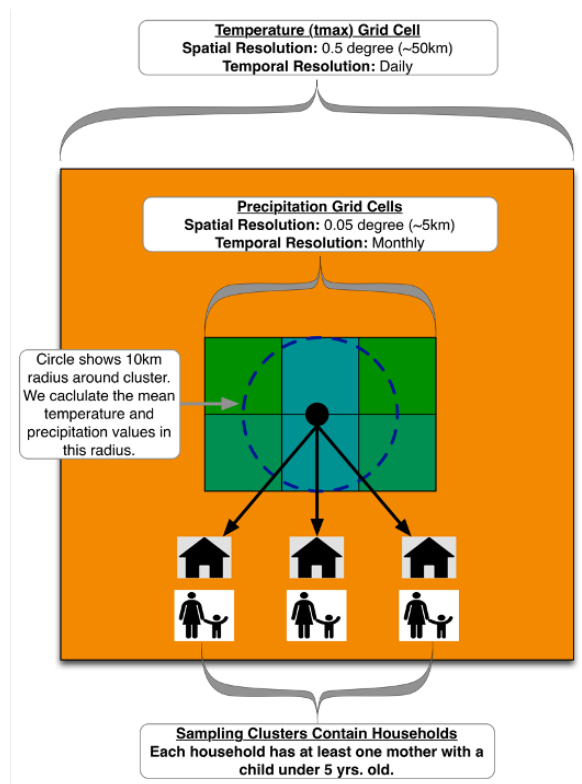


Figure 1.2 Precipitation, Temperature and Cluster Dynamics (Grace et al. 2015)

Considering the paramount importance of population health and the significant impact of exposure to extreme temperatures, the proposed research design will employ a multi-level model that will permit me to look at the impact of climate extremes at the household levels to accommodate correlated or clustered observations across spatial, non-spatial, and/or temporal dimensions (Figure 1.2). This approach is particularly relevant when considering causal processes that operate simultaneously at multiple levels (Diez Roux 2002; Subramanian 2004; Liu et al. 2025; Anderson and Bell 2011). This design, which will be elaborated upon further in subsequent sections, offers a comprehensive framework for observing and analyzing various determinants. By utilizing a multi-level approach, the study aims to capture the intricate interplay between individual-level factors, community characteristics, and broader environmental

influences. This inclusive methodology facilitates a nuanced assessment of the diverse factors influencing health outcomes in relation to temperature exposure, enabling a more thorough understanding of the complexities involved to usher in household relevant policies.

## **2.0 Child Stunting Amid Hot and Cold Temperature Anomalies in Burkina Faso and Kenya**

### ***2.0 Introduction***

Global climate change is projected to continue influencing the frequency and intensity of temperature shocks, including cold spells and heatwaves. While such events occur worldwide, their impacts are often more severe in Sub-Saharan Africa, where changing environmental conditions have rendered historically consistent climate patterns increasingly unpredictable (Clarke et al. 2022; Barry et al. 2018). Warming across the African continent is expected to exceed the global average, with projections indicating an increase of 3–6 °C by the end of the century under high-emissions scenarios, and Sub-Saharan Africa identified as the most vulnerable region due to its limited capacity to adapt to or mitigate climate change (Ofori et al. 2021) . Within this context, East Africa is projected to experience a rise in annual mean temperature of approximately 2 °C toward midcentury (2021–2050) under the RCP8.5 and SSP5-8.5 scenarios surpassing the global average increase of about 1.5 °C and to face more frequent and severe climate extremes, including droughts with significant social and environmental impacts (Choi et al. 2023; Gebremeskel et al. 2019). Exposure to the current and predicted temperature extremes during childhood may lead to lasting health consequences, including impaired physical growth, cognitive development, and increased susceptibility to disease (Phalkey et al. 2015; Ebi 2008)

Stunting, or child undernutrition, is defined as low height-for-age and results from chronic or recurrent undernutrition, commonly associated with poverty, maternal malnutrition, frequent

illness, and inadequate early-life feeding and care. Malnutrition during the first 1000 days can yield enduring repercussions on a child's developmental trajectory (Cusick and Georgieff 2016), amplifying susceptibility to morbidity and mortality (de Onis and Branca 2016). Anthropometric metrics commonly serve as proxies for assessing both individual child undernutrition and as an indicator of the food security status of a community (Duggan 2010; Webb et al. 2021). Stunting, which is the focus of this paper, hampers children from reaching their full physical and cognitive potential and therefore has significant individual and social costs. Mitigating malnutrition stands as a paramount global health imperative, resonating with various objectives delineated within the United Nations' Sustainable Development Goals (SDGs) particularly Goal 2 “Zero Hunger” which highlights the role of climate shocks as well as the rising cost of living. As infrastructure evolves and environmental conditions shift, the opportunity to prevent child malnutrition lies in forward-thinking investments in water, sanitation and hygiene (WASH) and comprehensive preparedness efforts (Patlán-Hernández et al. 2022; van Cooten et al. 2019).

Climate change has the potential to elevate rates of malnutrition (Bunyavanich et al. 2003). Changes in the physical environment may further intensify alterations within the social environment, as disparities in gender equity and access to resources become more pronounced in response to changing material conditions. Exposure to temperature anomalies can impact child health through multiple interconnected pathways. Studies indicate that exposure to cold indoor environments can negatively affect children’s health outcomes (Janssen et al. 2023; Advice 2024). During cold weather, children’s bodies lose heat more rapidly than it can be generated, which depletes energy reserves and increases the risk of hypothermia, defined as a core body temperature below 95°F (35°C). Young children are particularly vulnerable because of their higher surface-area-to-body-mass ratio and limited ability to regulate body temperature

(Bytowski and Squire 2003). Low ambient temperatures also trigger physiological stress, as veins and arteries constrict and blood becomes more viscous, elevating cardiac workload and mirroring some of the cardiovascular strain observed under heat exposure (Zhang et al. 2014). Elevated heat levels may directly cause heat stress in young children, who are physiologically more vulnerable to extreme temperatures (Thiede and Strube 2020). Indirectly, rising temperatures can increase the prevalence of vector-borne diseases such as malaria and dengue (Caminade and Jones 2016), which disproportionately affect children in low-resource settings. Rising average temperatures can have immediate effects, such as those seen during natural disasters and extreme events like floods, hurricanes, droughts, and heat waves, as well as gradual impacts over time, including reduced water availability, soil degradation, loss of arable land, and heightened pollution (Rossati 2017; Moore et al. 2015). Additionally, temperature extremes can undermine the well-being and productivity of adults within the household, reducing their capacity to provide adequate care, nutrition, and supervision for children (Mueller and Gray 2018; Nelson et al. 2024).

Understanding resource and infrastructure accessibility at the household level informs how climate anomalies may impact health outcomes within a household. One study highlighted the complex relationship between urbanization and childhood health outcomes in Africa (Ameye and De Weerd 2020). While it is widely recognized that children in urban regions generally experience better health outcomes, the degree of urbanization in a given region plays a critical role. It has been reported that average energy poverty levels remain high globally, with prevalence rates of 54% in Sub-Saharan Africa, 41% in South Asia, and 23% in Latin America and the Caribbean (Karmaker et al. 2022). Their study also demonstrated that energy poverty

undermines childhood development by affecting living standards and child health. In Kenya, energy poverty is a persistent challenge, particularly in rural areas. Highlighting this distinction a study found that its negative health impacts are more pronounced in rural households than in urban ones (Ang'u et al. 2023) . Similarly, in Burkina Faso, a study identified limited access to modern cooking fuels as a key driver of household energy deprivation, which disproportionately affects girls' school attendance compared to boys (Compaore et al. 2024). These infrastructural influences are also true when considering sanitation and water accessibility as some research has found it to have detrimental effects on child growth and development from sustained exposure to enteric pathogens but also due to wider social and economic mechanisms (Cumming and Cairncross 2016).

Burkina Faso and Kenya serve as valuable case studies for examining the relationship between child malnutrition and temperature extremes due to their distinct climates and socio-economic contexts. Burkina Faso, located in the Sahel region, frequently experiences extreme heat and prolonged dry spells, which negatively affect food security and contribute to malnutrition, particularly in rural areas reliant on subsistence agriculture (Dasgupta and Robinson 2023). Kenya, with its more varied climate, faces both droughts in arid regions and flooding in more humid areas, exacerbating food insecurity and malnutrition in vulnerable populations (Grace et al. 2022, 2012). Both countries suffer from high rates of child malnutrition, making them ideal for studying how temperature extremes impact nutrition. This was showcased in the Food Security Information Network (2024) which found that about 25%-50% of Kenya's population was experiencing acute food insecurity and Burkina Faso's population was estimated to be 10%-25% acutely food insecure(FSIN)} and (GNAFC)} 2025). This study also includes analysis on the impact of cold anomalies in these countries, which are typically very warm (Ryti et al. 2016).

Here I examine the relationship between both cold and hot temperature extremes and child nutrition health outcomes in low-income settings. Specifically, I investigate whether such events, including heat and cold anomalies, are associated with increased risk of child undernutrition by comparing the impact of these anomalies across these two diverse African countries with differing climatic and economic contexts. The study explores how socioeconomic factors, such as household wealth and access to infrastructure like electricity and safe water, may buffer or exacerbate these effects. Comparative analysis allows for the incorporation of key features identified in previous multilevel studies within a single investigation of two countries exhibiting elevated rates of child malnutrition. By focusing on two climate and health vulnerable contexts, the study also seeks to identify potential pathways for intervention and policy development(Grace et al. 2022; Bakhtsiyarava et al. 2018). Lastly, it considers whether there are differential impacts between urban and rural settings, aiming to understand how location-based disparities may influence children’s vulnerability to climate-related nutritional stress.

## ***2.1 Previous Research***

Historically, extreme variations in temperatures have broadly proven to impact child health (Agostoni et al. 2023; van der Merwe et al. 2022; Brown et al. 2020). Policy makers concerned about extreme temperature variation focus on several interrelated health, social, infrastructure and governance issues. Key areas of concern include increased risk of heat- and cold-related illness (e.g., children are more physiologically vulnerable to temperature extremes, less ability to regulate body temperature, and have increased risk of illness from exposure)(Azan et al. 2025); nutritional and security impacts (e.g., disrupted agriculture and food systems can reduce household income and food access)(Wheeler and von Braun 2013). Within the current era of

global climate change countries will experience heatwaves and cold shocks both often being defined by either exceeding the average temperature of a region or falling significantly below.

### **Heat**

A previous study based on data from Demographic and Health Surveys (DHS) across sub-Saharan Africa including Kenya and Burkina Faso findings revealed that monthly mean daytime land surface temperatures exceeding 35°C were significantly associated with increased odds of wasting, underweight, and concurrent stunting with wasting (Tusting, Gething, et al. 2020). Interestingly, the odds of stunting alone were lower at these extreme temperatures, compared to temperatures below 30°C. These findings underscore the broader implications of rising global temperatures for population health, particularly in vulnerable regions such as sub-Saharan Africa, where child malnutrition remains alarmingly prevalent (Mackay 2008; Davenport et al. 2017; Thiede and Strube 2020; Klapka et al. 2024). Recent modeling studies suggest that climate change induced heat impacts causing extreme temperatures disproportionately impacts socioeconomically disadvantaged groups (Schilling et al. 2020; Haile et al. 2020), who are likely to experience severe temperature extremes sooner than wealthier populations (Conte Keivabu and Cozzani 2022; Chambers 2020). This trend is expected to continue under current levels of greenhouse gas emissions (IPCC 2022b; L. J. Harrington et al. 2016). For instance, (Herold et al. 2017) projected that if current warming trends persist, the annual frequency of hot days in low-income countries could triple within two decades, compared to the 1961–1990 baseline. The prevalence of undernutrition among children under five in Sub-Saharan Africa (SSA) is estimated at 34.59%, affecting nearly one-third of the region's young population (Worku et al. 2025). While global progress in reducing child undernutrition has been driven largely by significant improvements in South-Eastern Asia, Southern Asia—particularly with updated data

from India—and South America, this trajectory stands in sharp contrast to the persistent and, in some cases, worsening hunger observed across much of Africa and in Western Asia (FAO 2024). In SSA, the enduring burden of malnutrition reflects a multifaceted nexus of determinants, including entrenched poverty, protracted conflict, structural food insecurity, and the growing influence of climate variability and extreme weather events.

### **Cold**

Much of the existing literature overlooks the health impacts of cold extremes in the Sub-Saharan African context, a gap of particular concern given the heightened vulnerability of these populations to climate stress (Zhang et al. 2022; Vizzy and Cook 2012). Existing studies tend to focus on Northern Africa and the country of South Africa, often emphasizing the role of elevation (Walt and Fitchett 2021; Chikoore et al. 2024; Crossett and Metz 2017)

The impact of cold temperature events on child health remains understudied. One study by (Andalón 2016) found that between 1999 and 2008, approximately 1.5 million births in Colombia were exposed to moderate cold shocks during the first and second trimesters, resulting in a reduction in birth length by 0.014 -- 0.018 cm. (Hongoli and Hahn 2023) found that in Tanzania, for children under five born between 2003 and 2015, a 10-percentage-point increase in days with temperatures below 15°C (one standard deviation below the long-term average) was associated with a 2.0 and 1.4 percentage-point increase in the probability of stunting and severe stunting, respectively—equivalent to 5.5% and 9.7% of the mean rates. They also observed significant effects of second-trimester in utero exposure on child stunting and wasting. (Ogasawara and Yumitori 2019) found that in Japan, early-life exposure to cold waves led to stunting in both boys and girls, with estimated height reductions of 0.8 cm for boys and 0.6 cm for girls in Japan's coldest northeastern regions. The study highlights prenatal exposure as

particularly significant for boys and postnatal exposure for girls. The effects of cold waves appeared more pronounced in warmer regions than in colder areas (Ogasawara and Yumitori 2019; Seltenrich 2015).

### ***2.3 Data and Methods***

Here I used the 2022 Demographic and Health Survey data from Kenya and 2021 in Burkina Faso, along with temperature data from the Climate Hazards Center InfraRed Temperature with Station data (CHIRTS) five kilometer global dataset. Below I describe the data and methods used.

#### **Data**

This study focuses on Kenya and Burkina Faso, utilizing the most recent Demographic and Health Surveys (DHS) rounds conducted in 2022 and 2021, respectively. The analysis centers on the child recode file, which provides detailed information on child health outcomes. Specifically, the study examines stunting, two critical indicators of child malnutrition.

In the 2022 Kenya Demographic and Health Survey (KDHS)(Knbs 2022), the sample included 1,692 clusters, with 25 households selected per cluster, totaling 42,300 households. However, some clusters contained fewer than 25 households; in such cases, all households within those clusters were selected. For the 2021 Burkina Faso Demographic and Health Survey (DHS)(INSD 2023), included 6,344 children from 600 sampled clusters from a total sample size of 13,251 households. Due to differences in sample size and data quality between the two countries' DHS surveys, the analytic sample was reduced by excluding non-relevant demographic groups (children under 24 months of age and adults) and observations with missing values (KNBS and ICF. 2023, INSD and ICF. 2023).

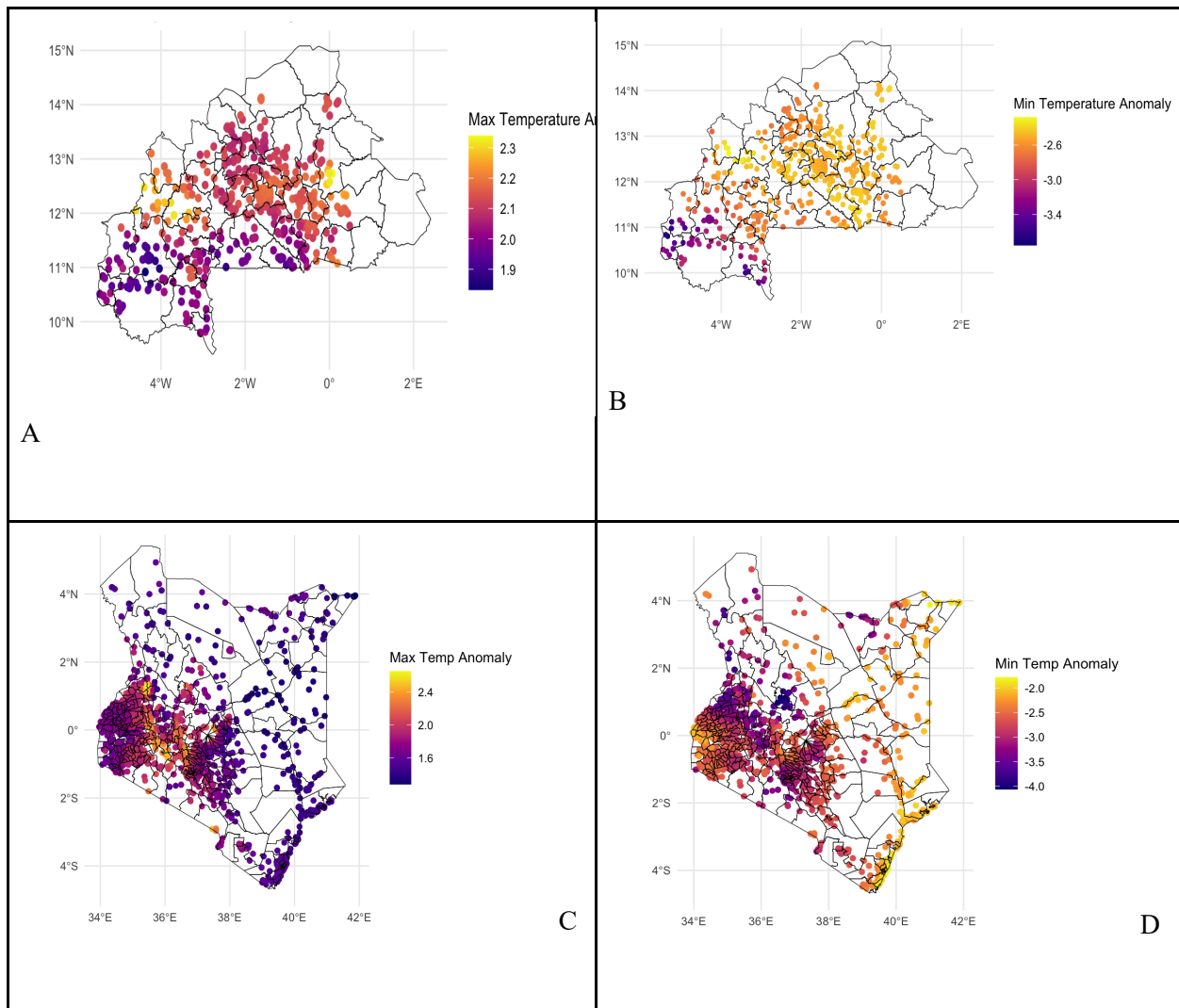


Figure 2.1 **A.** Observations in Burkina Faso average hot temperature anomalies positive anomalies in 2016-2021. **B.** Observations in Burkina Faso cold temperature anomalies, with negative anomalies in 2016–2021. **C.** Observations in Kenya hot temperature anomalies, with positive anomalies in 2017–2022. **D.** Observations in Kenya cold temperature anomalies, with negative anomalies in 2017–2022

Key socio-demographic variables including, child’s age in months, wealth index, urban/rural residence and the sex of the child. Also development related variables such as access to electricity, source of drinking water and type of toilet facilities available to the household. These

variables are selected based on their established associations with child health outcomes and their availability in the DHS datasets.

Each DHS cluster was linked to a reference timeline of daily maximum (Tmax) and minimum (Tmin) temperatures extending from the survey date to 59 months prior. For this analysis, I restricted the climate data to the five years preceding each survey: through 2022 for Kenya and 2021 for Burkina Faso. Climate data is sourced from the Climate Hazards InfraRed Temperature with Stations (CHIRTS) dataset for temperature. The climate variables are linked to DHS cluster locations, enabling an assessment of the relationship between climate variability and child health outcomes across both countries.

Childhood malnutrition was assessed using stunting among children under five. Stunting was selected over other indicators such as wasting or underweight, which are sensitive to short-term factors like illness or inadequate feeding. In contrast, stunting provides a more stable measure of chronic malnutrition, reflecting long-term deficits in linear growth (de Onis and Branca 2016).

## ***2.4 Methods***

Cold snaps and heatwaves have been defined based on the duration of days in which temperatures fall below or rise above the average temperature for a given region (Oliveira et al. 2022). In this study, to account for spatial heterogeneity, heatwaves and cold snaps will be defined relative to the average temperature patterns specific to each case study country.

Environmental exposures have been determined by aligning temperature increases or decreases with the child's age and the timing of these climatic events, capturing the relevant exposure

window up to the child's age at the time of the survey. Heatwave intensity has been a stronger predictor of heatwave-related mortality than duration. According to the literature, hot days are typically defined as temperatures reaching 30 degrees Celsius or exceeding the 98th percentile for at least three consecutive days. (Cliffer et al. 2024),(Davenport et al. 2020), (Xu et al. 2016) . Cold weather shocks have been defined as a minimum temperature falling more than one standard deviation below the long-term average (Hongoli and Hahn 2023). While the incidence of environmental heat and cold exposure (EHCE) generally declined across most regions between 1990 and 2019, some areas experienced an increase. The most significant rise occurred in Southern sub-Saharan Africa, followed by Eastern sub-Saharan Africa (He et al. 2025).

To capture climate anomalies experienced by children aged 24 to 59 months, I calculated standardized z-scores for both maximum and minimum temperature values. Specifically, I utilized the CHIRTSmax ERA5 dataset for daily maximum temperatures. These climate time series were spatially linked to each DHS cluster by matching geolocated DHS cluster coordinates with the corresponding grid cells from the CHIRTSmax datasets. This approach allowed us to assess how cumulative exposure to temperature anomalies may be associated with child stunting risk in different regions. Age stratification is conducted by isolating children into a group of 24–59 months of age. This approach facilitates a more precise analysis of how exposure to climate extremes may influence stunting and outcomes (Alderman and Headey 2018).

For each cluster, I extracted the relevant time window representing the 24 months from birth to age 24 months—an age range that encompasses critical early-life exposure to climate variability. This study then computed monthly mean anomalies relative to short-term historical averages relevant to the children's age range and transformed these values into z-scores. This standardization allowed us to identify periods of unusually high or low temperatures relative to

local norms, enabling consistent comparisons across diverse ecological zones (Brown et al. 2014). These temperature z-scores served as continuous indicators of climate extremes, with higher positive values reflecting hotter or drier-than-normal conditions.

### **Model specification**

A multilevel logistic regression model was employed (Gelman and Hill 2006), accounting for the nested structure of children within DHS clusters by including random intercepts. The design allows for the estimation of associations between environmental exposures and child health outcomes, while adjusting for key covariates such as age, sex, electricity access, water source, sanitation, and urban/rural residence (Grace et al. 2020). Temperature anomalies were calculated using the cumulative maximum values within the maximum average temperatures across the clusters as well as using the minimum values within the minimum average temperatures (Brown et al. 2014). I converted all household relevant variables into binary values in order to indicate the presence or absence of factors such as electricity, approved water source, wealth and sanitation.

## ***2.5 Results***

I used a specified model assessing the effects of extreme maximum and minimum temperature exposure on the probability of stunting, with the objective of determining whether particular climatic conditions are associated with increases in the prevalence of acute malnutrition. This modeling framework enabled us to evaluate how deviations at both ends of the temperature spectrum influence child nutritional outcomes and to identify potential thresholds beyond which climate stressors may significantly elevate health risks.

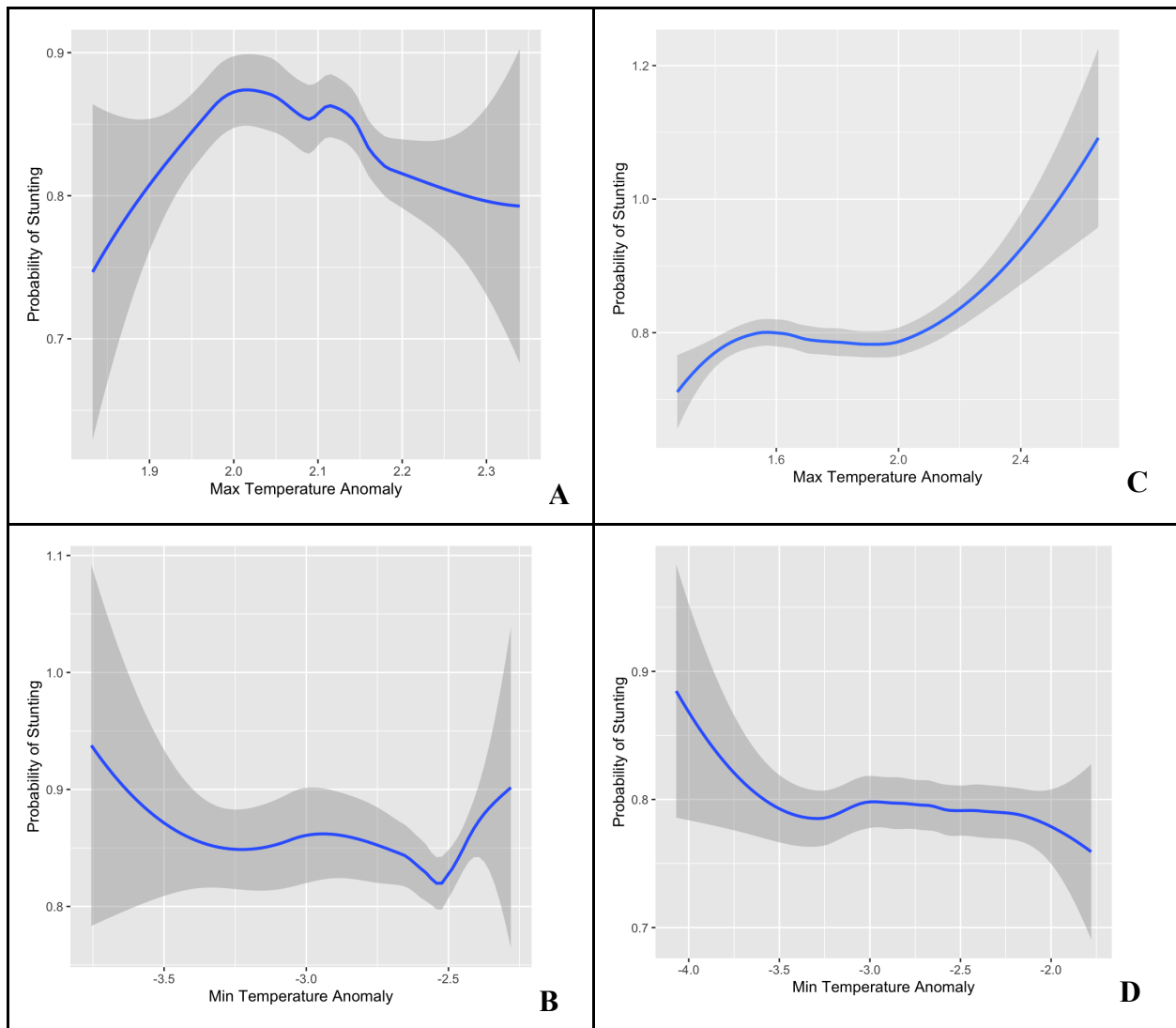


**Figure 2.2** Modeled relationships between temperature anomalies and the probability of child stunting (ages 24–59 months), showing **(A)** Burkina Faso average maximum temperature anomalies (2016–2021), **(B)** Burkina Faso average minimum temperature anomalies (2016–2021), **(C)** Kenya average maximum temperature anomalies (2017–2022), and **(D)** Kenya average minimum temperature anomalies (2017–2022).

Figure 2 presents relationships between temperature anomalies exposure and the probability of stunting among children in Burkina Faso (A and B) and 25–59 months in Kenya (C and D). For Burkina Faso, Panel A shows that the probability of stunting initially increases with maximum temperature anomalies before leveling off and declining at higher anomaly values which may reflect regional survivalhood and adaptability (Millogo et al. 2019; Arisco et al. 2023) , while

Panel B indicates that minimum temperature anomalies are generally associated with a lower probability of stunting, with a slight increase at the most extreme cold deviations. In Kenya, Panel C demonstrates a strong positive association between maximum temperature anomalies and stunting probability, particularly at higher anomaly values, whereas Panel D shows that higher minimum temperature anomalies are associated with a gradual decrease in the probability of stunting as well as the shaded areas indicating greater uncertainty at the extremes of observed temperature anomalies.

Given the likelihood that the most pronounced effects occur at the extremes of the temperature distribution, we employ a generalized linear multivariate regression model to capture and quantify these relationships. This approach allows us to examine not only the direct association between temperature anomalies and child stunting, but also the interaction effects between climatic variables and key household factors such as access to safe water, electricity, and improved sanitation that may either exacerbate or mitigate the observed impacts. By modeling these interactions, we aim to better understand how environmental and socio-economic determinants jointly influence stunting risk.

| Predictor                          | Burkina Faso (BF) | OR    | Kenya (KE) | OR    |
|------------------------------------|-------------------|-------|------------|-------|
| Electricity Access                 | -0.498 *          | 0.608 | -0.069     | 0.933 |
| Water Source                       | 0.139             | 1.15  | -0.166 .   | 0.847 |
| Child Age (Months)                 | -0.188 *          | 0.829 | -0.294 *** | 0.745 |
| Child Sex                          | -0.067            | 0.935 | -0.159 *   | 0.853 |
| Residence (Urban)                  | 0.628 **          | 1.874 | -0.023     | 0.977 |
| Sanitation Improved                | 0.039             | 1.04  | -0.316 *** | 0.729 |
| Minimum Temperature (Cold Anomaly) | 0.766 .           | 2.151 | 0.170 .    | 1.186 |

|                                    |          |       |            |       |
|------------------------------------|----------|-------|------------|-------|
| Maximum Temperature (Heat Anomaly) | -2.564 * | 0.077 | 1.026 ***  | 2.79  |
| Wealth (Binary)                    | -0.014   | 0.986 | -0.548 *** | 0.578 |
| # of Observations                  | 1384     |       | 5097       |       |

\*\*\*  $p < 0.001$  , \*\*  $p < 0.01$  , \*  $p < 0.05$  , .  $p < 0.1$  , no mark = not significant

**Table 2.2 Comparative Analysis of Kenya and Burkina with Predictors of Stunting**

\*\*\* $p < 0.001$ ; \*\* $p < 0.01$ ;  $p < 0.05$ .

Results from exposure to climate anomalies are presented in Table S1 (full model specification results found in Table S1). This table presents a comparative analysis of predictors of child stunting for children aged 24–59 months in Burkina Faso (BF) and Kenya (KE). Climate anomalies also show differing impacts: cold anomalies (minimum temperature) have a marginally positive relationship with stunting in both countries ( $p < 0.1$ ), whereas heat anomalies (maximum temperature) significantly decrease stunting in BF ( $\beta = -2.564$ ,  $p < 0.05$ ) but increase it in Kenya ( $\beta = 1.026$ , \*\* $p < 0.001$ ). Electricity access is significantly associated with reduced stunting in BF ( $\beta = -0.498$ ,  $p < 0.05$ ), suggesting that households with electricity may have better living conditions or access to resources. In Kenya, this variable was not statistically significant. Water source is also not significant in either country, although Kenya shows a marginal negative effect ( $p < 0.1$ ). Child age is a significant predictor in both countries, with older children being less likely to be stunted within this surveyed population, particularly in Kenya ( $\beta = -0.294$ , \*\* $p < 0.001$ ). Child sex has a mild protective effect in Kenya ( $\beta = -0.159$ ,  $p < 0.05$ ), indicating possible gender-based differences in stunting. Rural residence is positively associated with stunting in BF ( $\beta = 0.628$ , \* $p < 0.01$ ), may reflect disparities within urban settings, while it is not significant in

Kenya. Improved sanitation is significantly associated with lower stunting in Kenya ( $\beta = -0.316$ ,  $**p < 0.001$ ), but not in BF. Finally, wealth is a strong protective factor against stunting in Kenya ( $\beta = -0.548$ ,  $**p < 0.001$ ), but not significant in BF. These results highlight how socioeconomic and environmental predictors of child stunting vary across contexts.

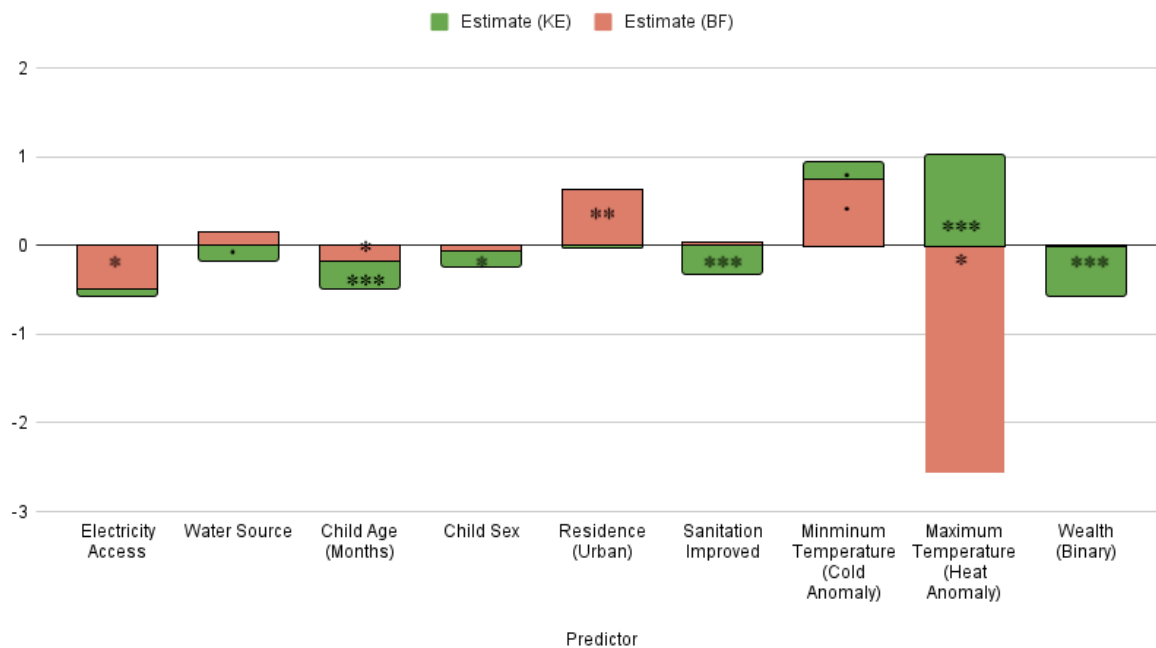


**Figure 2.3** Comparative Analysis of Estimates of Kenya and Burkina Faso

Shown in Figure 3 is a divergence is seen in the climate-related predictors. In Kenya, higher maximum temperature anomalies are associated with increased stunting, suggesting that heat stress may harm child growth. Conversely, in Burkina Faso, the relationship is reversed: higher maximum temperatures appear to reduce stunting odds, a counterintuitive result that may reflect unobserved confounders (Table S1). Minimum temperature anomalies are marginally significant and positive in both contexts, hinting at a potential need for researchers to look at adaptation

capacity for colder temperatures or extreme precipitation events in increasing nutritional risk within the African context.

| Country      | Random Intercept Variance              | AIC    | BIC    | Log Likelihood | Observations | Clusters |
|--------------|----------------------------------------|--------|--------|----------------|--------------|----------|
| Burkina Faso | $\sim 0$<br>( $1.41 \times 10^{-13}$ ) | 1242.3 | 1294.6 | -611.1         | 1384         | 380      |
| Kenya        | 0.1199                                 | 5035.2 | 5100.5 | -2507.6        | 5097         | 1523     |

**Table 2.1 Fitness of Models from model results**

## ***2.6 Discussion and Conclusion***

The relationship between stunting and climate is influenced by factors such as the intensity and timing of climate-related shocks, along with local geographical conditions and the characteristics of both the child and household (Skoufias and Vinha 2012); (“Environmental Risk Factors and Child Nutritional Status and Survival in a Context of Climate Variability and Change” 2014)). The findings from these models underscore the importance of country-specific policy approaches, as the household-level factors that influence child stunting and growth vary across socio-economic and environmental contexts. What mitigates stunting in one setting may be less relevant or even counterintuitive in another.

Demographic and Health Survey (DHS) data continue to shed light on potential household-level interventions that may improve child health outcomes, particularly for children under five. One such intervention is investment in electricity access, especially renewable energy options which are often more cost-effective and sustainable in low-resource settings. Though this variable was statistically significant in one case study country, it highlights the need for development-oriented

interventions. Limited access to electricity has been linked to reduced life expectancy, higher infant mortality rates, increased per capita health expenditures, and overall poorer health outcomes (Ajide et al. 2022). Additionally, the divide between urban and rural areas underscores enduring wealth inequalities that shape household living conditions and, in turn, children's early-life exposures (Ajide et al. 2022; Fotso 2006). Beyond financial disparities, geographic differences are evident, with the model's results indicating that rural disadvantage is more pronounced in Burkina Faso than in Kenya. Understanding that both heatwaves and cold snaps can shape a child's life early on makes them both important to consider when observing future climate adaptation and/or mitigation strategies to implement.

The observed reduction in the probability of stunting across countries particularly with the child sex variable underscores the nuanced influence of gender dynamics on child health outcomes. This pattern is consistent with findings from prior studies. For instance, (Picbougoum et al. 2023) reported that in Burkina Faso, the prevalence of underweight and stunting among children is significantly shaped by demographic factors, particularly the sex of the child. Their study further identified critical determinants of undernutrition, including ethnic background, household economic status, the number of children under five residing in the household, and proximity to health facilities. These variables collectively reflect entrenched socio-economic and structural barriers to adequate child nutrition. Complementing these findings, (Yaya et al. 2020), in a comprehensive analysis of Demographic and Health Surveys (DHS) data from 30 sub-Saharan African countries including Kenya demonstrated that women's socio-demographic profiles and levels of empowerment (measured through decision-making autonomy, attitudes toward domestic violence, and personal experiences of violence) were significantly associated with child

nutritional outcomes, specifically stunting and underweight, with results statistically significant at  $p < 0.001$ .

Globally, the pediatric health implications of exposure to extreme temperatures continue to be observed throughout the scientific literature. This study contributes to a growing body of evidence demonstrates that children are uniquely vulnerable to these conditions, as one scoping review highlighting a broad range of adverse outcomes, including preterm birth, low birth weight, emergency visits for asthma, heat-related illnesses, and impaired school performance, underscoring the pervasive impacts of rising temperatures on child health and development (Schapiro et al. 2024). Complementing this, a narrative review of pediatric and perinatal outcomes found that maternal heat exposure elevates risks of pre-eclampsia, gestational diabetes, and preterm birth, while children themselves experience heightened risks of heatstroke, dehydration, renal impairment, respiratory and gastrointestinal infections, as well as cognitive and mental health disturbances (Principi et al. 2025). Systematic reviews further emphasize the association between heatwave exposure in infants and young children and increased incidence of renal disease, respiratory conditions, electrolyte imbalance, and fever (Xu et al. 2014).

Expanding on these findings, a broader scoping review revealed consistent correlations between high ambient temperatures and a spectrum of pediatric morbidities, including heat-related illness, dehydration, gastrointestinal symptoms, infectious diseases, asthma, and injuries (Uibel et al. 2022). Collectively, this literature points to extreme heat and cold as a multifaceted and growing threat to child health across developmental stages.

In conclusion, this study identifies a range of predictors associated with child stunting among children aged 24 to 59 months in Burkina Faso and Kenya. Notably, exposure to extreme heat

anomalies emerged as a significant risk factor in both contexts, reinforcing existing evidence that climate-induced heat events are increasingly prevalent and particularly consequential for young children. In addition to climatic influences, several socio-demographic and infrastructural variables including urban versus rural residence, child sex, access to electricity, and availability of safe drinking water were found to influence nutritional outcomes to varying degrees. These determinants point to structural inequities that can be mitigated through targeted policy interventions at both the local and national levels. With sustained investment in infrastructure, public health systems, and nutrition-focused programs, the burden of child stunting and broader malnutrition is likely to decline over time.



### **3.0 Assessing The Impact of Cold Snaps on Child Malnutrition in Nepal and Pakistan**

#### ***3.1 Introduction***

South Asia is facing the dual burden of intensifying climate shocks and persistent child malnutrition, underscoring the need for integrated responses that address both health and environmental challenges (Dong et al. 2018; Burke and Stott 2017; Khadilkar et al. 2024). Household-level factors remain particularly important in shaping nutritional outcomes, and understanding these dynamics can help guide more effective investments and monitoring strategies for vulnerable populations (Wali et al. 2023). Prior research has demonstrated that nutritional status in the region is highly sensitive to climate variability, with extreme weather events directly influencing food security, health, and caregiving capacities (Tiwari et al. 2022; Rahut et al. 2024). Strengthening sanitation infrastructure and prioritizing broader development goals therefore represent critical pathways for reducing this vulnerability (McMahon and Gray 2021; Zakar et al. 2024). Within this broader regional context, Pakistan and Nepal exemplify the complex and multifaceted determinants of child malnutrition. Although both nations suffer from severe air pollution, climate change impacts, and deforestation, the specific nature and primary causes of these problems vary considerably. Both nations have high rates of child stunting and wasting, with Pakistan's rates being slightly higher than those in Nepal (Chowdhury et al. 2023).

South Asia's agricultural economies are particularly vulnerable to extreme weather events, and disruptions to food supply chains threaten regional food security (OECD and Food and Agriculture Organization of the United Nations 2020). One study observed a sharp rise in temperatures within the period of 1979–2021, leading to a 56% increase in areas of South Asia

exposed to extreme heat during the monsoon season and a 66% increase during the pre-monsoon period (Kyaw et al. 2023). As a result, an additional 17 million people are exposed to excessive heat each year, accompanied by an increase of more than six extremely hot days per decade (Kyaw et al. 2023; Aadhar and Mishra 2019).

While heat-related mortality has steadily declined over time, cold-related mortality has remained relatively constant for decades and showed a slight increase in the late 2000s, particularly driven by cardiorespiratory deaths, which rose more than deaths from other causes (Chung et al. 2017; Gao et al. 2024). Extreme temperatures in Southeast Asia broadly pose significant direct threats to human health through multiple pathways, including the heightened risk of child malnutrition (Thiede and Gray 2020; Muttarak 2018).

In Nepal, maternal characteristics such as low educational attainment, limited decision-making power, and poor nutritional status have been strongly associated with severe acute malnutrition among children under five (Hossain et al. 2020). These risks are compounded by poverty, food insecurity, and limited healthcare access, while environmental variability in rainfall and temperature further undermines agricultural productivity and child growth outcomes (Shively 2017).

With a similar per capita gross domestic product and equality index to Nepal (World Bank, 2025), Pakistan also faces a high prevalence of overlapping forms of malnutrition including stunting, wasting, and overweight, previous research noting this is largely driven by socioeconomic inequalities (Naz and Patel 2020; G. M. Arif et al. 2022). Children from poorer households, particularly in rural settings, bear the greatest burden, with gender disparities and unequal access to sanitation and health services worsening these outcomes (Chowdhury et al.

2023). The annual rate of reduction remains only 0.5%, which is low, likely due to ineffective or narrowly focused intervention programs that tend to address one issue at a time versus an multi-sectoral approach (Khaliq et al. 2021; Ali 2021). Moreover, exposure to temperature extremes interacts with these inequities, disproportionately affecting rural populations (Zeng et al. 2022).

In South Asia, heatwaves have been defined using both absolute and relative temperature thresholds (Sharma et al. 2022). Some studies have quantified heatwaves with the Heat Wave Magnitude Index (HWMI), which accounts for both magnitude and duration (Qian et al. 2024; Goyal et al. 2023; Y. Li et al. 2025). The HWMI is calculated as the maximum magnitude of a heatwave in a given year, defined by more than three consecutive days with maximum temperatures exceeding the daily threshold for 1981–2010 (Sharma et al. 2022). However, across the region, countries continue to rely on varying metrics to characterize heatwaves.

Cold weather shocks have been defined as a minimum temperature falling more than one standard deviation below the long-term average (Hongoli and Hahn 2023). Although overall exposure to environmental heat and cold declined between 1990 and 2019, some regions, including South Asia, experienced increases. With projected population growth and more frequent heatwaves, the region is expected to face substantially higher future population exposure (He et al. 2025; Ullah, You, Chen, et al. 2022).

The novelty of this research lies in its dual focus on climatic and household-level determinants of child health. By integrating both minimum and maximum temperature anomalies, the study captures the full spectrum of thermal stressors that may affect children’s growth and development. Examining these climatic factors in conjunction with household-level indicators across two South Asian countries provides a more nuanced understanding of how temperature

variability, particularly cold climate events, contributes to child stunting. Furthermore, this approach identifies key household characteristics, such as access to electricity, improved sanitation, and greater wealth, that can act as protective factors against the negative impacts of climatic stress on child health outcomes.

## **Cold Trends**

Although the risks of extreme heat are increasingly well recognized, a changing climate has also produced complex regional climate interactions (Robeson et al. 2014). In particular, rapid Arctic warming has been linked to unexpected cooling impacts across the mid-latitudes of continental Asia. Recent research has identified key atmospheric drivers linking Arctic amplification to East Asian cold extremes, known popularly as a ‘polar vortex’, illustrating how shifts in polar warming can significantly influence mid-latitude weather systems (Zhuo et al. 2023; Rantanen et al. 2022; Ma et al. 2018). These dynamics were most evident during the 2020–2021 cold spells in East Asia, which were driven by persistent circulation anomalies that extended beyond typical seasonal variability (Dai et al. 2022).

Climate extremes in Pakistan show mixed and regionally variable trends, particularly in the northern areas. While the frequency of summer days has increased, cold nights display inconsistent patterns, and warm nights have generally declined except in the western Pakistan (Khan et al. 2022). These heterogeneous patterns reflect Pakistan’s diverse climatic zones, ranging from extremely cold northern winters to hot southern plains. Future projections for the various sub-regions remain uncertain but suggest intensifying climate extremes that may heighten vulnerabilities (Ali et al. 2021). Recent research documents districts with high health needs frequently overlap with regions of climate stress (S. U. Khan et al. 2023). Evidence further

connects extreme ambient temperatures to adverse birth outcomes, including low birth weight (Hira Fatima et al. 2025) , pointing to potential early-life health risks for children in the region, while other research shows that both hot and cold extremes in the first two years of life undermine child nutritional health (McMahon and Gray 2021).

In Nepal, cold extremes are also a significant concern. Long-term records (1971–2015) show an average of 16 - 18 cold days and 3 - 4 extreme cold days annually, with most stations reporting rising numbers of cold events over recent decades (Shrestha et al. 2023). These cold waves, often accompanied by fog, have been shown to damage crops and undermine agricultural livelihoods (Shrestha et al. 2023; Hamal et al. 2020; Dawadi et al. 2023). Indoor exposure compounds these risks: winter household temperatures in cold regions average just 10.9 °C, more than 6 °C below thermal comfort levels, creating conditions that may endanger health, especially for children (Shahi et al. 2021). Broader climatic variability also shapes winter precipitation trends across Nepal, which influence both cold exposure and food security (Dawadi et al. 2023).

### **Trends in Heat Anomalies**

The frequency and severity of heatwaves and extreme heat events are increasing across Asia, with South Asia experiencing particularly acute human thermal stress (Saeed et al. 2021). Studies have reported that between 1981 and 2019, thermal stress levels rose significantly in South Asia, especially in densely populated areas where vulnerability is compounded by poverty, inadequate infrastructure, and limited adaptive capacity (Ullah, You, Wang, et al. 2022; Kyaw et al. 2023). In Pakistan, projected intensity, duration, and spatial extent of heat extremes will escalate throughout the rest of the current century (F. Khan et al. 2023). Drivers of this warming in various regions of South Asia are primarily driven by reduced cloud cover and increased

outgoing longwave radiation, conditions that enhance solar heating at the surface and intensify regional temperatures (Adhikari and Wang 2025; Dong et al. 2021).

Rising temperatures across South and Southeast Asia pose serious threats to human health, as prolonged exposure to extreme heat undermines survival, productivity, and overall well-being. In regions such as western Nepal, increasing frequency and intensity of climate extremes are straining water resources and elevating health risks in already vulnerable populations. Extreme heat has become a defining regional hazard, intersecting with socioeconomic instability and amplifying existing public health challenges. Mounting evidence indicates that early-life exposure to heat stress contributes to adverse child health outcomes, including impaired growth and higher risks of stunting. Collectively, these findings highlight the urgency of integrating climate resilience into health and development planning across Asia (Behera et al. 2023; Chapagain et al. 2021; Tome et al. 2022; Lin et al. 2022; Ngcamu 2023; McMahon and Gray 2021; Mertens et al. 2023; Rahut et al. 2024).

Selecting Pakistan and Nepal as case studies provides a robust analytical framework for investigating the climate-nutrition nexus due to their contrasting topographical and climatic profiles. While Pakistan offers a critical model for studying the longitudinal effects of acute heat stress and aridity on stunting in low-lying river basins, Nepal provides a necessary counterpoint by highlighting how mountain-dwelling populations navigate the nutritional risks associated with extreme cold snaps and geographic isolation. This comparative approach facilitates a clear evaluation of how distinct infrastructural buffers mitigate environmental shocks across diverse landscapes.

The climate extremes observed in Pakistan and Nepal intersect with existing socioeconomic and health inequalities, emphasizing the need to understand their implications for child health outcomes particularly stunting, which is highly sensitive to both early-life nutrition and environmental stressors. This study examines how exposure to temperature extremes, including both heat and cold anomalies, relates to child nutritional outcomes in Pakistan and Nepal. Specifically, we assess whether such climatic variations are associated with an increased risk of undernutrition and whether household-level factors such as wealth, access to electricity, and availability of safe water moderate these relationships in our region of interest. By comparing two countries with distinct climatic conditions and economic contexts, this research provides a comparative framework for understanding how social and environmental determinants jointly shape child growth outcomes in regions facing a high burden of malnutrition.

### ***3.2 Data and Methods***

#### **Data**

Here I use the 2022 Demographic and Health Survey data from Nepal and 2017-18 in Pakistan, along with temperature data from the Climate Hazards Center InfraRed Temperature with Station data (CHIRTS) five kilometer global dataset. Below we describe the data and methods used.

This study focuses on Nepal and Pakistan, utilizing the most recent Demographic and Health Surveys (DHS) rounds conducted in 2022 and 2017-2018, respectively. The analysis centers on the child recode file, which provides detailed information on child health outcomes. Specifically, the study uses stunting as the dependent variable, a critical indicator of child malnutrition (de Onis and Branca 2016). We focus on describing the temperature extremes that children who are

between 24-59 months of age experienced, which may have affected their nutritional status, following (Woldesenbet et al. 2023; Dayani and Widyantari 2024; Abdurahman et al. 2016).

The 2022 Nepal Demographic and Health Survey (DHS) employed a fixed cluster size design, selecting 30 households per cluster for a total sample of 14,280 households (New ERA 2023). The 2017–18 Pakistan DHS utilized a comparable two-stage sampling design, encompassing 16,240 households across 561 clusters, with an average of 28 households per cluster (National Institute of Population Studies 2019). From the DHS clusters and households included in this study, a total of 3,955 child observations were analyzed for Nepal and 6,719 for Pakistan.

### ***3.3 Method***

Cold snaps and heatwaves have been defined based on the duration of days in which temperatures fall below or rise above the average temperature for a given region (Oliveira et al. 2022). In this study, to account for spatial heterogeneity, heatwaves and cold snaps will be defined relative to the average temperature patterns specific to each case study country.

Environmental exposures have been determined by aligning temperature increases or decreases with the child's age and the timing of these climatic events, capturing the relevant exposure window up to the child's age at the time of the survey. Using the DHS data, we assessed how cumulative exposure to temperature anomalies may be associated with child stunting risk in different regions. Age stratification was conducted by isolating children into a group of 24–59 months of age. This approach facilitates a more precise analysis of how exposure to climate extremes may influence stunting and outcomes (Alderman and Headey 2018).

In South Asia, heatwaves have been defined using both absolute and relative temperature thresholds (Sharma et al. 2022). Some studies have quantified heatwaves with the Heat Wave Magnitude Index (HWMI), which accounts for both magnitude and duration (Qian et al. 2024; Goyal et al. 2023; Y. Li et al. 2025). The HWMI is calculated as the maximum magnitude of a heatwave in a given year, defined by more than three consecutive days with maximum temperatures exceeding the daily threshold for 1981–2010 (Sharma et al. 2022). However, across the region, countries continue to rely on varying metrics to characterize heatwaves.

Cold weather shocks have been defined as a minimum temperature falling more than one standard deviation below the long-term average (Hongoli and Hahn 2023). With projected population growth and more frequent heatwaves, the region is expected to face substantially higher future population exposure (He et al. 2025; Ullah, You, Chen, et al. 2022; Tuholske et al. 2021).

To capture climate anomalies experienced by children aged 24 to 59 months, we calculated standardized z-scores for both maximum and minimum temperature values. The CHIRTSmax ERA5 daily temperature data (Funk et al. 2019) were spatially linked to each DHS cluster by matching geolocated DHS cluster coordinates with the corresponding grid cells from the CHIRTSmax datasets (Brown et al. 2014). For each cluster, we extracted a 59-month exposure window corresponding to ages 24–59 months to align climatic anomalies with the period of sustained growth following infancy. This window captures cumulative and lagged effects of temperature variability during early childhood, allowing assessment of how prolonged environmental conditions influence health outcomes beyond the initial 24-month postnatal period. We then computed monthly mean anomalies relative to short-term historical averages relevant to the children’s age range and transformed these values into z-scores. This

standardization allowed us to identify periods of unusually high or low temperatures relative to local norms, enabling consistent comparisons across diverse ecological zones (Brown et al. 2014). These temperature z-scores served as continuous indicators of climate extremes, with higher positive values reflecting hotter or drier-than-normal conditions.

### **Model specification**

A multilevel logistic regression model was employed (Gelman and Hill 2006), accounting for the nested structure of children within DHS clusters by including random intercepts. The design allows for the estimation of associations between environmental exposures and child health outcomes, while adjusting for key covariates such as age, sex, electricity access, water source, sanitation, and urban/rural residence (Grace et al. 2020). Temperature anomalies were calculated using the cumulative maximum values within the maximum average temperatures across the clusters as well as using the minimum values within the minimum average temperatures (Brown et al. 2014). We converted all household relevant variables into binary values in order to indicate the presence or absence of factors such as electricity, approved water source, wealth and sanitation.

### ***3.4 Results***

In this paper, we found that cold temperature anomalies play a critical role in understanding child stunting outcomes. While both Pakistan and Nepal experience substantial variability in heat and cold events, Pakistani children appear more sensitive to cold anomalies compared to children in Nepal. Though the single cross-sectional timepoint per country limits causal inference, the cumulative temperature exposure window (24-59 months before survey) captures climate variability across multiple years of children's early lives. Using a specified modeling framework

to assess the effects of extreme maximum and minimum temperature exposure on the probability of stunting, we aimed to determine whether particular climatic conditions are associated with higher prevalence of undernutrition. This approach allowed us to evaluate how deviations at both ends of the temperature spectrum influence child growth outcomes and to identify potential thresholds beyond which climatic stressors may substantially increase health risks.

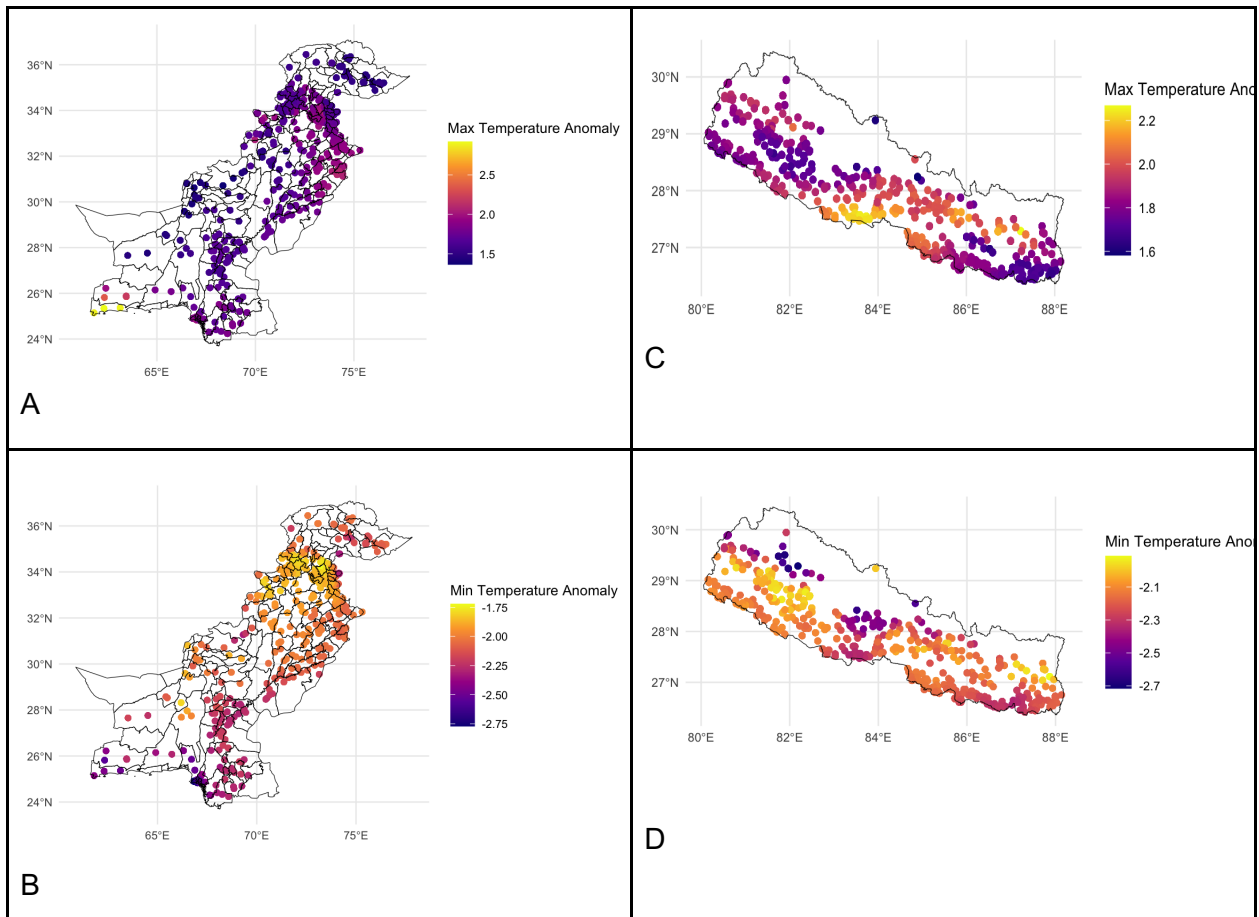


**Figure 3.1** Spatial distribution of temperature anomalies across Pakistan (2012–2017) and Nepal (2017–2022). Panels A and B show maximum and minimum temperature anomalies for Pakistan, while panels C and D show maximum and minimum temperature anomalies for Nepal.

In the period of interest we found that Pakistan experienced positive anomalies in maximum temperature (Figure 1) concentrated in central and northern provinces, whereas minimum temperature anomalies were predominantly negative, with marked cooling across northern

regions. In contrast, Nepal displayed consistent positive anomalies in maximum temperature across most of the country, particularly in the southern and eastern lowlands, while minimum temperature anomalies remained concentrated in the central region of the country, signifying potential cooling. These observations suggest Nepal has colder extremes than Pakistan. These spatially heterogeneous yet temporally consistent patterns underscore the potential divergence between seasonal temperature trends in South Asia, with implications for agricultural systems, public health, and climate adaptation planning (Wang et al. 2018; Aryal et al. 2020).

## Predicted Probabilities of Stunting and Climate Anomalies

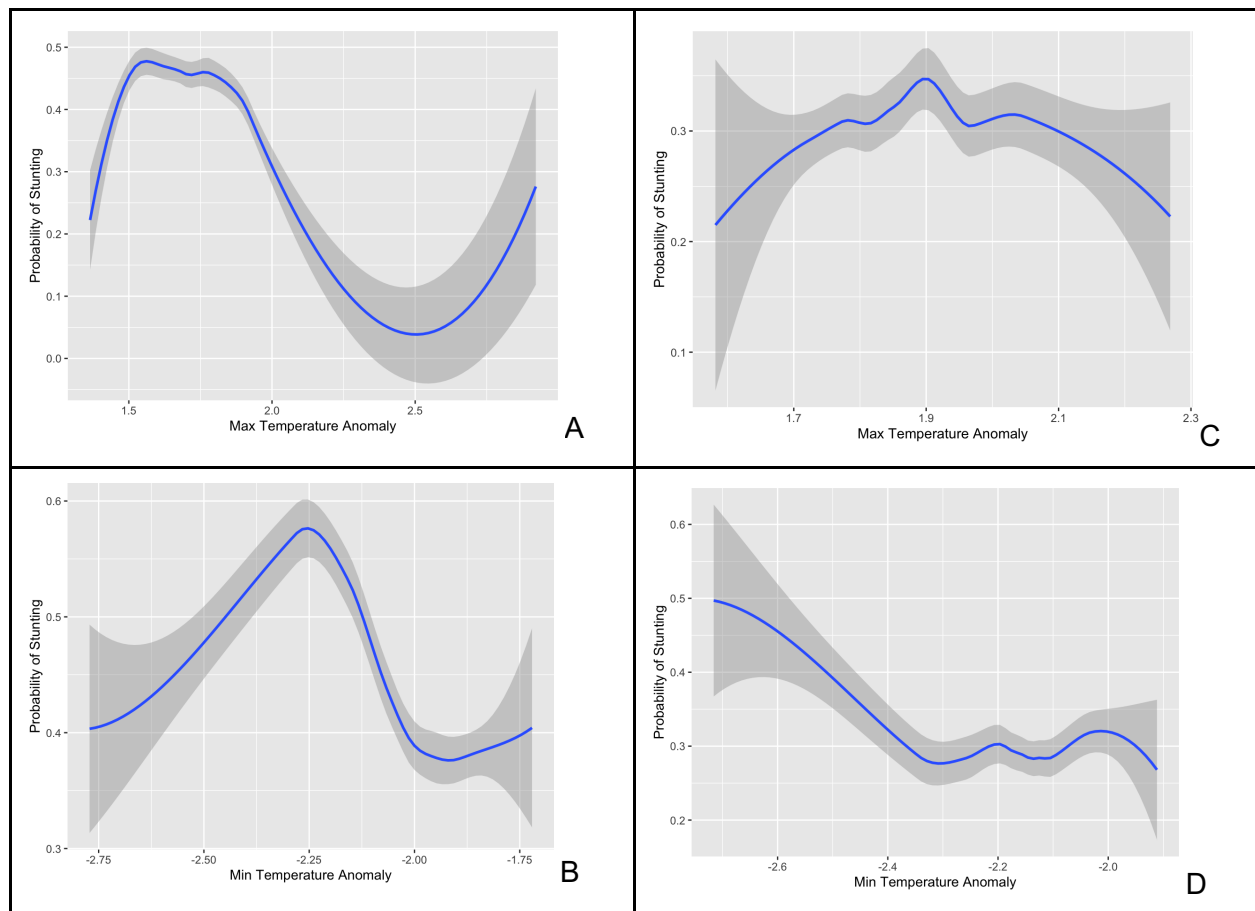


**Figure 3.2** Predicted probabilities of stunting as a function of maximum and minimum temperature anomalies for children ages 24–59 months in Pakistan (Panels A and B) and Nepal (Panels C and D).

In Pakistan, both maximum (Panel A) and minimum (Panel B) temperature anomalies show nonlinear associations with stunting. The probability of stunting is highest at moderate temperature anomalies and declines at both lower and higher extremes of maximum temperature. Similarly, for minimum temperature anomalies, a pronounced peak occurs around  $-2.25$  temperature deviation, suggesting that cold temperature deviations are associated with increased stunting risk, whereas milder or warmer anomalies correspond to reduced risk.

In Nepal, the relationships between temperature anomalies and stunting appear more muted. For maximum temperature anomalies (Panel C), the probability of stunting slightly increases with warmer conditions before leveling off, while for minimum temperature anomalies (Panel D), the probability of stunting declines as temperatures rise, indicating that colder temperature anomalies may heighten stunting vulnerability. Taken together, these results highlight the sensitivity of child growth outcomes to climatic variability, particularly temperature extremes. The observed associations suggest that cold climate events and temperature instability may exacerbate nutritional stress and hinder child development.

| Country  | Indicator                 | Estimate | Std. Error | z value | Pr(> z ) | Significance |
|----------|---------------------------|----------|------------|---------|----------|--------------|
| Nepal    | (Intercept)               | 0.1273   | 0.9414     | 0.135   | 0.8925   |              |
| Nepal    | Electricity access        | -1.1682  | 0.1476     | -7.912  | 2.53E-15 | ***          |
| Nepal    | Drinking water (improved) | 0.4043   | 0.2535     | 1.595   | 0.1108   |              |
| Nepal    | Child Sex                 | 0.1692   | 0.0737     | 2.296   | 0.0217   | *            |
| Nepal    | Child Age                 | -0.144   | 0.0461     | -3.124  | 0.0018   | **           |
| Nepal    | Rural residence           | 0.2349   | 0.0781     | 3.007   | 0.0026   | **           |
| Nepal    | Improved toilet facility  | -0.4341  | 0.1077     | -4.031  | 5.56E-05 | ***          |
| Nepal    | Max temperature anomaly   | 0.2987   | 0.28       | 1.067   | 0.286    |              |
| Nepal    | Min temperature anomaly   | 0.0623   | 0.2892     | 0.215   | 0.8295   |              |
| Nepal    | Wealth (binary)           | -0.4997  | 0.0927     | -5.389  | 7.09E-08 | ***          |
| Pakistan | (Intercept)               | 1.943    | 0.555      | 3.501   | 0.0005   | ***          |
| Pakistan | Electricity access        | 0.1494   | 0.1223     | 1.222   | 0.2216   |              |
| Pakistan | Drinking water (improved) | 0.0092   | 0.1127     | 0.082   | 0.9347   |              |
| Pakistan | Child Age                 | -0.0037  | 0.0026     | -1.421  | 0.1552   |              |
| Pakistan | Child sex                 | -0.1963  | 0.0535     | -3.672  | 0.0002   | ***          |

|          |                          |         |        |         |          |     |
|----------|--------------------------|---------|--------|---------|----------|-----|
| Pakistan | Rural residence          | -0.0313 | 0.0633 | -0.495  | 0.6205   |     |
| Pakistan | Improved toilet facility | -0.2914 | 0.0828 | -3.521  | 0.0004   | *** |
| Pakistan | Max temperature anomaly  | 0.0954  | 0.1783 | 0.535   | 0.5927   |     |
| Pakistan | Min temperature anomaly  | 0.5747  | 0.2265 | 2.537   | 0.0112   | *   |
| Pakistan | Wealth (binary)          | -1.1471 | 0.0677 | -16.939 | 2.00E-16 | *** |

**Table 3.1** Logistic regression estimates of factors associated with child stunting in Nepal (N = 3,955) and Pakistan (N = 6,719). The table reports estimates, standard errors, z-values, p-values, and levels of statistical significance for socioeconomic, demographic, and climate anomaly variables. Significance codes: \*\*\* $p < 0.001$ ; \*\* $p < 0.01$ ;  $p < 0.05$ .

In Nepal, several household- and individual-level predictors were statistically significant. Access to electricity was negatively associated with stunting (estimate =  $-1.17$ ,  $p < 0.001$ ), while improved sanitation (estimate =  $-0.43$ ,  $p < 0.001$ ) and greater household wealth (estimate =  $-0.50$ ,  $p < 0.001$ ) also reduced the odds of stunting (Uddin et al. 2023; Perveen and Amar-Ul-Haque 2023; Qurat-ul-Ann and Mirza 2021). Children residing in rural areas faced higher odds of stunting (estimate =  $0.23$ ,  $p = 0.0026$ ), as did male children (estimate =  $0.17$ ,  $p = 0.0217$ ). Older child age was associated with lower odds of stunting (estimate =  $-0.14$ ,  $p = 0.0018$ ), suggesting a decline in growth faltering after early infancy (Timilsina et al. 2023; Bhusal and Khanal 2025). Temperature anomalies, both maximum (estimate =  $0.30$ ,  $p = 0.286$ ) and minimum (estimate =  $0.06$ ,  $p = 0.8295$ ), were not statistically significant.

In Pakistan, the model similarly revealed significant associations between sanitation, wealth, and child nutrition outcomes. Improved sanitation was linked to a lower likelihood of stunting (estimate =  $-0.29$ ,  $p < 0.001$ ), and household wealth had a strong negative association (estimate =  $-1.15$ ,  $p < 0.001$ ). The minimum temperature anomaly showed a positive and significant relationship with stunting (estimate =  $0.57$ ,  $p = 0.0112$ ), suggesting that climatic conditions may

contribute to nutritional vulnerability. Male children were more likely to be stunted (estimate =  $-0.20$ ,  $p < 0.001$ ), while child age (estimate =  $-0.004$ ,  $p = 0.155$ ) and rural residence (estimate =  $-0.03$ ,  $p = 0.620$ ) were not significant predictors (Soofi et al. 2023).

Overall, results across both countries emphasize the consistent role of household wealth and sanitation as key protective factors against stunting. However, differences in the effects of temperature anomalies indicate that climatic exposure may play a more pronounced role in Pakistan than in Nepal as the effect of extreme heat was stronger in Nepal, underscoring potential differences in vulnerability and adaptive capacity (Giri et al. 2023; Aryal and Chalise 2016). Collectively, these findings suggest that while wealth and climate consistently shape child growth outcomes, the influence of infrastructure access, gender, and age differs across settings, highlighting the importance of context-specific interventions.

### ***3.5 Discussion***

The multilevel modeling approach employed in this study yielded valuable insights into the determinants of child stunting under varying climatic conditions across the DHS survey populations. These results highlight the necessity of jointly considering environmental exposures and household-level characteristics (Figure 3.3) when assessing child nutrition outcomes. These findings suggest that interventions aimed at improving household living conditions including access to reliable infrastructure, adequate sanitation, and economic stability are central to enhancing children's nutritional status and strengthening their resilience to climate stressors. The heightened sensitivity observed in rural and lowland regions indicates that adaptive capacity may be limited and coping mechanisms less robust in areas where poverty and food insecurity are concentrated. Moreover, the nonlinear association identified in Pakistan suggests that both

moderate and extreme heat exposures pose significant health risks. This finding emphasizes that we cannot simply react to acute heat events for instance, by shifting agricultural labor to cooler early morning or late evening hours. Instead, we must prioritize persistent, structural solutions such as the establishment of community cooling centers and the implementation of household-level thermal management. By addressing the full spectrum of heat intensity rather than just the peaks, we can more effectively mitigate the long-term nutritional risks to children.

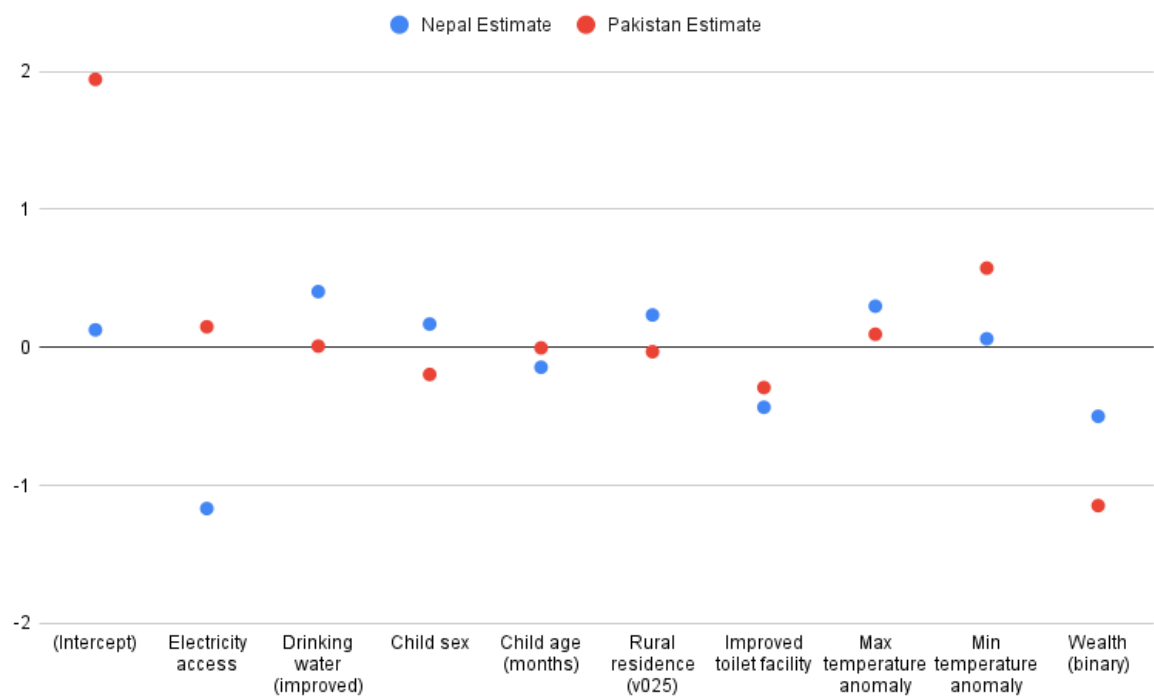


**Figure 3.3 Logistic regression coefficients for child health outcomes in Nepal and Pakistan.** The figure presents estimated log-odds coefficients for household infrastructure, child characteristics, and climate anomaly variables. Positive values indicate higher odds of negative health outcomes, while negative values indicate protective effects.

Household wealth plays a critical role in shaping child nutrition outcomes across South and Southeast Asia. Higher levels of maternal education and household wealth are strongly associated with reduced risks of undernutrition, highlighting the importance of socioeconomic

resources in addressing the burden of malnutrition (Talukder et al. 2025; Prasad et al. 2021).

Policy interventions that directly enhance household economic capacity also demonstrate measurable benefits: conditional cash transfer programs, such as one implemented in the Philippines (Kandpal et al. 2016), have been shown to significantly reduce severe stunting among children, the longer the duration of these programs the more effective they are in mitigating child stunting (Rukiko et al. 2023). Beyond nutritional gains, recent evidence suggests that cash transfers can also lower mortality risks for both adults and children in low- and middle-income settings, reinforcing the broader health benefits of financial support to vulnerable households (Richterman et al. 2023).

Household food insecurity and poor dietary diversity remain critical drivers of stunting and other forms of childhood malnutrition, with particularly high burdens observed in South and Southeast Asia (Azimi and Rahman 2024; Islam et al. 2025). Across low- and middle-income countries, these conditions reflect broader social inequalities shaped by poverty, maternal education, and limited access to nutritious foods that contribute not only to stunting but also to micronutrient deficiencies and impaired child development (Islam et al. 2025; de Paiva et al. 2025).

Gender disparities emerged in the modeling, consistent with research from Pakistan showing that reductions in stunting rates were linked to improvements in socioeconomic status, female-targeted income support, and other health and nutrition investments (Ataullahjan et al. 2025). In South Asia, cultural norms and practices have historically shaped and influenced the health of women and children, with recent dimensions of women's empowerment such as decision-making power and access to resources closely tied to improved child nutrition and reduced stunting (Vir 2016; Raj et al. 2015).

In South Asia, rising heat exposure is projected to dramatically increase cooling demand and worsen indoor discomfort. For instance, in Pakistan, the portion of the country experiencing extremely hot, dry climates may rise from 36.9% to 78.1% by 2080, raising indoor discomfort hours from 423 to 1267 hours (Mehmood et al. 2022). Modeling suggests that the most effective passive strategies include ventilative cooling, reflective or ventilated roofs, window shading, and roof insulation, which can jointly reduce discomfort by up to 320 hours. For those with access to electricity-driven air conditioning, adjusting thermostat setpoints upward (25–26.5 °C) offers an additional significant reduction in cooling energy use (Mehmood et al. 2022). Complementing these building-level strategies, research highlights that changes in cooling degree days and land surface temperature are key factors that inform development outcomes in South Asia, with cooling degree days showing a relationship to development progress and land surface temperature consistently undermining urban livability and productivity. These findings point to the need for integrated interventions, including sustainable cooling technologies, urban greening, and efficient water management, particularly in regions most vulnerable to climate risk (Rana 2025; Gagliano et al. 2012) .

Evidence from diverse geographic contexts suggests that cold temperature anomalies may serve as a protective factor for child growth, offering a contrary view into the patterns I observed in Nepal and Pakistan. In Peru, Nicholas et al. (2021) found that warmer-than-average early-life conditions were linked to lower height-for-age among children under-five, whereas cooler anomalies appeared protective (Nicholas et al. 2021). Broadly studies have concluded that warmer conditions elevate undernutrition risks, implying that relatively cooler conditions can mitigate these effects (Zhu et al. 2024; Grace et al. 2015). Agrarian populations in South Asia are

routinely subjected to seasonal climatic stressors, particularly during the growing season when agricultural labor needs are at their peak (Madan et al. 2018; Hughes et al. 2014). Evidence suggests that these seasonal patterns shape early-life health outcomes in ways that underscore their protective or adverse roles. For instance, one study found that Indian children born during the cooler fall–winter months exhibited more favorable anthropometric outcomes compared to those born in hotter or monsoon seasons (Lokshin and Radyakin 2012). Similarly, it was observed that Peruvian children born during the warm El Niño event of 1997–1998 were shorter and had lower lean body mass relative to children born in cooler, non-El Niño periods (Bayer et al. 2014). Taken together, these studies suggest that in climates where high temperatures exacerbate growth deficits, cold anomalies require further examination in the context of child health as physiological stress, infectious disease exposure, and food system strain all remain relevant.

These findings have direct implications for policy. Climate adaptation and nutrition strategies must be integrated to break the cycle of environmental shocks and poor child health outcomes (Macheka et al. 2022; Tirado et al. 2013). Strengthening primary health systems during high-risk seasons, expanding resilient agricultural practices, and investing in safe water and sanitation systems are critical priorities. Social protection programs including cash transfers, maternal education initiatives, and women’s empowerment efforts can provide households with the resources needed to maintain adequate nutrition during climate shocks (Tenzing 2020). Moreover, national early-warning systems for heat stress (Brimicombe et al. 2024; Lowe et al. 2011) and targeted safety nets for households with young children should be expanded to mitigate the adverse effects of temperature extremes before they result in irreversible growth deficits.

### ***3.6 Conclusion***

This study underscores the interconnectedness of environmental change, social inequities, and child health (Gharpure et al. 2021). Stunting is both a marker of vulnerability and a predictor of lifelong disadvantage, meaning that climate-driven growth faltering has profound implications for human capital, equity, and sustainable development. Addressing it requires not only technical interventions but also governance reforms that prioritize child health in climate adaptation planning. As South Asia experiences increasing exposure to climate extremes, protecting child growth must become a central objective of climate adaptation policy. The findings from this study indicate that targeted, multisectoral strategies integrating poverty reduction, infrastructure improvements, and strengthened health systems can provide a pathway to safeguard children's health and development in a warming world. These results should, however, be interpreted with caution given the context-specific sample and cross-sectional design, which limit causal inference. While the evidence suggests that enhancing household and community infrastructure, expanding access to safe water and reliable electricity, and addressing broader socio-economic disparities could help reduce child stunting, policy and programmatic recommendations remain provisional (Cumming and Cairncross 2016; Byaro et al. 2024; Ramlan et al. 2025). Future research using longitudinal data and more diverse populations is needed to validate these associations and inform effective interventions. Nonetheless, the identified determinants highlight persistent structural inequities that, if addressed through coordinated policy action, could yield substantial progress (Rebouças et al. 2022; Pickett et al. 2022).

## **4.0 The Double Burden of Malnutrition: Child Undernutrition and Maternal Overnutrition in South Asia and Sub-Saharan Africa**

### ***4.1 Introduction***

The coexistence of child undernutrition and maternal overnutrition often referred to as the *double burden of malnutrition* has emerged as a critical public health challenge in many low- and middle-income countries (Tzioumis et al. 2016; Alem et al. 2023; Gebremichael et al. 2025) . Despite decades of progress in reducing childhood stunting and wasting, persistent socioeconomic inequities, food insecurity, and limited access to health services continue to place young children at high nutritional risk (Mane et al. 2025). At the same time, rapid urbanization, shifts in food environments, and increased consumption of energy-dense, nutrient-poor diets have contributed to rising rates of being overweight among women of reproductive age (GBD 2021 Adult BMI Collaborators 2025; Tan et al. 2025; Senekal et al. 2023). This paradoxical overlap reflects profound structural transformations in global food systems and health transitions occurring within the same households and communities (Juul et al. 2025; Venegas Hargous et al. 2023).

The double burden is particularly concerning because it intensifies intergenerational cycles of poor health (Wei et al. 2024; Hu et al. 2023; Panera et al. 2022). Mothers who are overweight

may face metabolic challenges that influence pregnancy outcomes, breastfeeding practices, and the overall nutritional environment in which children grow (Shipp et al. 2024). Meanwhile, children experiencing stunting or chronic undernutrition face long-term consequences including impaired cognitive development, weakened immune systems, and reduced future economic productivity (Lestari et al. 2024; Morales et al. 2023). The simultaneous rise of maternal overnutrition and persistence of child undernutrition reveals a complex, multidimensional problem that demands integrated policy responses that address both poverty-related deprivation and emerging diet-related disease in developing countries (Okyere et al. 2024; Guillaumin and Peleg-Raibstein 2023; Tan et al. 2025).

South Asia and Sub-Saharan Africa are increasingly confronting the double burden of malnutrition, where rising rates of overnutrition coexist with persistent child undernutrition (Biswas et al. 2019; Haque et al. 2021; Hong 2021; Sahiledengle et al. 2024). In South Asia, rapid urbanization, dietary shifts toward inexpensive energy-dense foods, and intergenerational poverty have contributed to growing levels of maternal overweight even as childhood stunting and wasting remain widespread (Riaz and Lodhi 2025; Bansal et al. 2024). However, gaps remain in the literature regarding how these nutrition transitions vary across socio-economic, gendered, and cultural contexts within the region (Daran et al. 2023). In Sub-Saharan Africa, climate variability, recurrent food insecurity, and structural inequalities continue to exacerbate child malnutrition while adult overweight and obesity rise sharply, particularly in urban centers (Daran et al. 2023; W. Wang et al. 2025). Yet empirical research linking household-level nutrition pathways remains limited. Across both regions, social determinants such as wealth, education, and rural–urban residence play a critical role in shaping nutritional risk (Dagher and Linares 2022).

This study investigates the interplay of maternal characteristics and contextual community factors on the co-occurrence of maternal overweight and child undernutrition in four diverse countries, utilizing spatially and temporally explicit Demographic and Health Surveys (DHS) data. A core focus is to determine the influence of wealth quintile and urban/rural residence on this "double burden" of malnutrition. The strategic comparison of South Asian and Sub-Saharan African countries is key, as these regions currently exhibit the world's highest prevalence of this dual burden of persistent child stunting alongside rising maternal obesity often within the same household. This cross-continental analysis provides a robust platform to evaluate how the varying stages of the nutrition transition and distinct climatic stressors such as the Asian monsoon cycles versus the African arid droughts interact with socio-economic variables to drive these divergent nutritional outcomes.

#### *4.2 Methods*

Maternal and child anthropometric indicators were obtained from the latest Demographic and Health Surveys (DHS) for Nepal (2022), Kenya (2022), Burkina Faso (2021), and Pakistan (2018) capturing the most recent health status of households within these case study countries . Maternal nutritional status was assessed using body mass index (BMI), derived from DHS measurements of weight and height (National Institute of Population Studies 2019; New ERA 2023; INSD 2023; Knbs 2022). Weight, recorded in tenths of kilograms, was converted to kilograms, and height, recorded in tenths of centimeters, was converted to meters prior to calculating BMI ( $\text{kg/m}^2$ ). In accordance with World Health Organization (WHO) guidelines, women with a  $\text{BMI} \geq 25 \text{ kg/m}^2$  were classified as overweight

or obese. Child nutritional status was assessed using height-for-age z-scores (HAZ). Following DHS and WHO standards, height for age values were divided by 100 to obtain the standardized HAZ metric, and children with HAZ < -2 SD were categorized as stunted. Observations flagged by DHS as implausible or missing were excluded from the observed sample. Mother-child dyads were linked within each survey using household and line number identifiers; when household dyad-level linkage was not available, data were merged using cluster identifiers consistent with DHS structure.

| <b>Countries</b>                | <b>Burkina Faso</b>                 | <b>Kenya</b>                        | <b>Nepal</b>                        | <b>Pakistan</b>                  |
|---------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|----------------------------------|
|                                 | Mean (SD) /<br>Median [Min,<br>Max] | Mean (SD) /<br>Median [Min,<br>Max] | Mean (SD) /<br>Median [Min,<br>Max] | Mean (SD) / Median<br>[Min, Max] |
| Sample size (n)                 | 2,130                               | 13,437                              | 2,164                               | 8,746                            |
| Maternal<br>Characteristics     |                                     |                                     |                                     |                                  |
| <b>Maternal age<br/>(years)</b> |                                     |                                     |                                     |                                  |
| Mean (SD)                       | 29.8 (7.13)                         | 28.8 (6.74)                         | 26.5 (5.46)                         | 28.4 (6.14)                      |
| Median [Min,<br>Max]            | 29.0 [16, 49]                       | 28.0 [15, 49]                       | 26.0 [15, 49]                       | 28.0 [16, 49]                    |
| <b>Age category</b>             |                                     |                                     |                                     |                                  |
| 13–19 years                     | 118 (5.5%)                          | 863 (6.4%)                          | 149 (6.9%)                          | 445 (5.1%)                       |
| 20–35 years                     | 1,515 (71.1%)                       | 10,148                              | 1,877 (86.7%)                       | 7,091 (81.1%)                    |

|                                                |                       |                       |                       |                      |
|------------------------------------------------|-----------------------|-----------------------|-----------------------|----------------------|
|                                                |                       | (75.5%)               |                       |                      |
| 36–49 years                                    | 497 (23.3%)           | 2,426 (18.1%)         | 138 (6.4%)            | 1,210 (13.8%)        |
| <b>Body Mass Index (BMI, kg/m<sup>2</sup>)</b> |                       |                       |                       |                      |
| Mean (SD)                                      | 23.20 (4.64)          | 24.20 (5.52)          | 22.40 (4.18)          | 24.90 (5.25)         |
| Median [Min, Max]                              | 22.40 [12.30, 100.00] | 23.10 [14.10, 100.00] | 21.60 [13.90, 100.00] | 24.20 [14.40, 48.80] |
| <b>Overweight/obese mother (BMI ≥25)</b>       | 566 (26.6%)           | 4,860 (36.2%)         | 487 (22.5%)           | 4,087 (46.7%)        |
| <b>Highest education level</b>                 |                       |                       |                       |                      |
| Mean (SD)                                      | 0.557 (0.856)         | 1.55 (0.910)          | 1.29 (0.823)          | 0.958 (1.12)         |
| Median [Min, Max]                              | 0 [0, 3]              | 2 [0, 3]              | 1 [0, 3]              | 0 [0, 3]             |
| <b>Child Characteristics</b>                   |                       |                       |                       |                      |
| Stunted (HAZ < -2 SD)                          | 417 (19.6%)           | 2,230 (16.6%)         | 559 (25.8%)           | 3,247 (37.1%)        |
| <b>Household Characteristics</b>               |                       |                       |                       |                      |
| <b>Household size</b>                          |                       |                       |                       |                      |
| Mean (SD)                                      | 8.28 (4.40)           | 5.92 (2.70)           | 5.74 (2.45)           | 10.6 (5.55)          |
| Median [Min, Max]                              | 7 [2, 34]             | 5 [2, 21]             | 5 [2, 22]             | 9 [2, 40]            |
| <b>Electricity access</b>                      | 541 (25.4%)           | 6,786 (50.5%)         | 1899 (87.7%)          | 7,945 (90.9%)        |
| <b>Wealth quintile</b>                         |                       |                       |                       |                      |
| Poorest                                        | 410 (19.3%)           | 2,931 (21.8%)         | 691 (31.9%)           | 1,864 (21.3%)        |
| Poorer                                         | 404 (19.0%)           | 2,711 (20.2%)         | 447 (20.7%)           | 2,109 (24.1%)        |
| Middle                                         | 427 (20.0%)           | 2,865 (21.3%)         | 430 (19.9%)           | 1,728 (19.8%)        |
| Richer                                         | 344 (16.2%)           | 2,776 (20.7%)         | 347 (16.0%)           | 1,598 (18.3%)        |
| Richest                                        | 545 (25.6%)           | 2,154 (16.0%)         | 249 (11.5%)           | 1,447 (16.5%)        |
| <b>Region</b>                                  |                       |                       |                       |                      |
| Urban                                          | 752 (35.3%)           | 4,777 (35.6%)         | 1,108 (51.2%)         | 3,754 (42.9%)        |
| Rural                                          | 1,378 (64.7%)         | 8,660 (64.4%)         | 1,056 (48.8%)         | 4,992 (57.1%)        |

| Dyad classification |               |               |               |               |
|---------------------|---------------|---------------|---------------|---------------|
| Neither condition   | 1,244 (58.4%) | 7,008 (52.2%) | 1,206 (55.7%) | 2,807 (32.1%) |
| Stunting-only       | 311 (14.6%)   | 1,569 (11.7%) | 471 (21.8%)   | 1,852 (21.2%) |
| Overweight-only     | 460 (21.6%)   | 4,199 (31.2%) | 398 (18.4%)   | 2,692 (30.8%) |
| Double burden       | 104 (4.9%)    | 661 (4.9%)    | 88 (4.1%)     | 1,395 (16.0%) |

**Table 4.1** Descriptive statistics summarizing maternal, child, and household characteristics across the analytic samples of the four case countries.

## Outcome Variables

### Child Nutritional Status

Child stunting was assessed using height-for-age z-scores (HAZ) based on the 2009 WHO Child Growth Standards (WHO 2009b). Children with  $HAZ < -2$  standard deviations from the reference median were classified as stunted. Child anthropometric measurements were collected by trained DHS field staff following standardized protocols and using calibrated equipment.

### Maternal Nutritional Status

Maternal BMI was calculated as weight in kilograms divided by height in meters squared ( $\text{kg/m}^2$ ). Overweight and obesity were defined according to WHO cutoffs ( $BMI \geq 25 \text{ kg/m}^2$ ) (WHO 2025b). Maternal anthropometric data were measured using calibrated weighing scales (accurate to 100 g) and height boards (accurate to 0.1 cm).

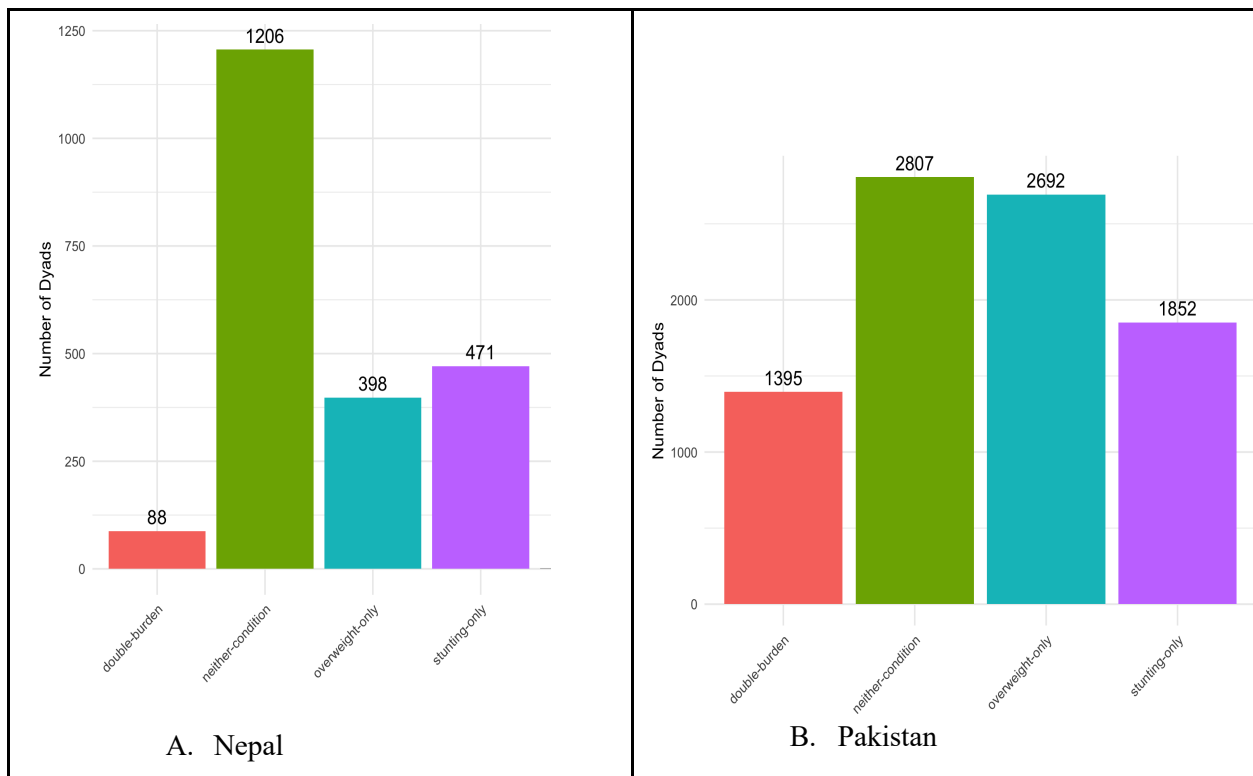
### Double Burden of Malnutrition Classification

Mother–child pairs were categorized into four mutually exclusive groups (Table 1) to capture the co-occurrence of child undernutrition and maternal overnutrition (Félix-Beltrán et al. 2021):

1. **Stunting-only:** Stunted child ( $HAZ < -2$ ) with a non-overweight mother ( $BMI < 25 \text{ kg/m}^2$ )
2. **Overweight-only:** Non–stunted child ( $HAZ \geq -2$ ) with an overweight or obese mother ( $BMI \geq 25 \text{ kg/m}^2$ )

3. **Double burden:** Stunted child ( $HAZ < -2$ ) with an overweight or obese mother ( $BMI \geq 25 \text{ kg/m}^2$ )
4. **Neither condition:** Non-stunted child ( $HAZ \geq -2$ ) with a non-overweight mother ( $BMI < 25 \text{ kg/m}^2$ )

### 4.3 Results



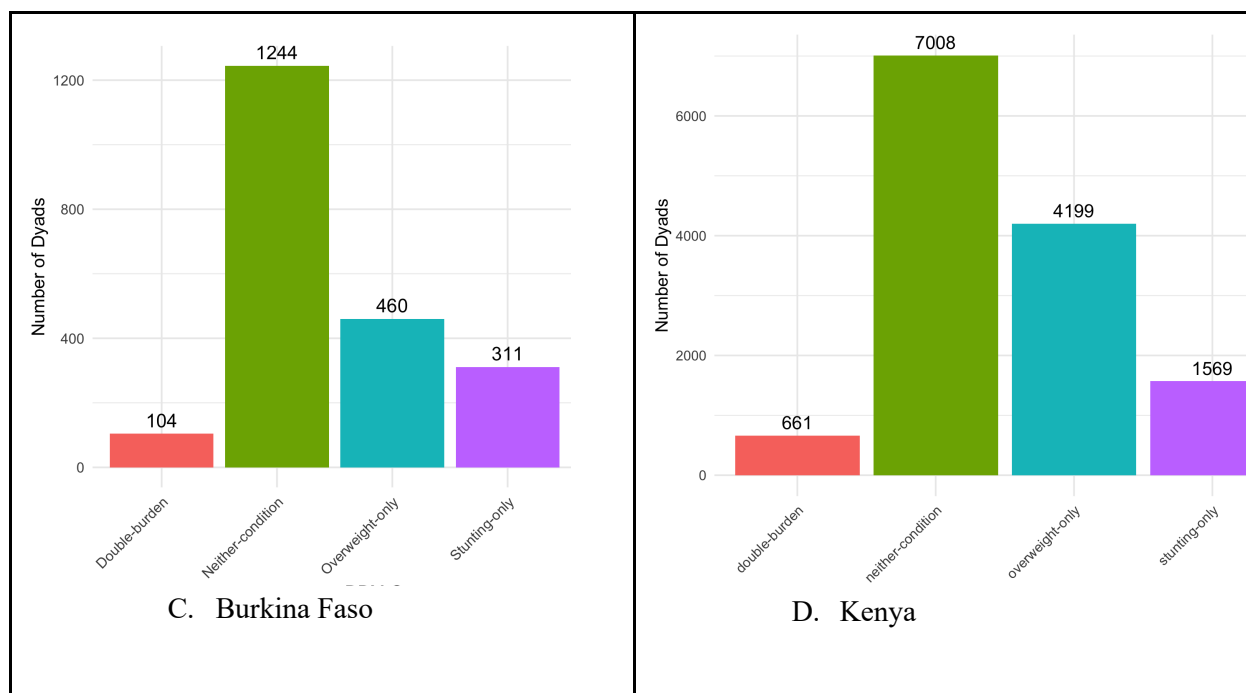


**Figure 4.1 Distribution of mother–child dyad nutritional status across four countries.**

The figure shows the percentage distribution of mother–child dyads classified into four groups: neither maternal overweight nor child stunting, maternal overweight only, child stunting only, and the double burden of malnutrition (co-occurrence of maternal overweight and child stunting) in Nepal (A), Pakistan (B), Burkina Faso (C), and Kenya (D). Sample sizes are shown for each category within the country.

Across all four countries in Figure 1, the majority of mother–child dyads fell into the *neither-condition* category, although the distribution of nutritional phenotypes varied substantially. In Nepal, over half of dyads had neither maternal overweight nor child stunting (55.8%), while stunting-only dyads (21.8%) were slightly more prevalent than overweight-only dyads (18.4%); the double burden of malnutrition (4.1%). In Pakistan, a more polarized pattern was observed, with similar proportions of neither-condition (32.1%) and overweight-only dyads (30.8%), alongside a notably high prevalence of double-burden dyads (16.0%), the highest among the four case study countries. In Burkina Faso, the distribution was dominated by neither-condition dyads (58.7%), with overweight-only (21.7%) and stunting-only (14.7%) dyads occurring less frequently, and a low prevalence of double burden (4.9%). In Kenya, over half of dyads were classified as neither-condition (52.2%), while overweight-only dyads constituted nearly one-third

(31.2%); stunting-only (11.7%) and double-burden dyads (4.9%) less common. Overall, overweight-only dyads were more prevalent than stunting-only dyads in Pakistan and Kenya, whereas the double burden of malnutrition remained relatively rare in Nepal, Burkina Faso, and Kenya but was substantial in Pakistan.

| Variable / Category        | Nepal aOR (95% CI), p          | Pakistan aOR (95% CI), p     | Kenya aOR (95% CI), p          | Burkina Faso aOR (95% CI), p |
|----------------------------|--------------------------------|------------------------------|--------------------------------|------------------------------|
| Child stunting:<br>Stunted | 0.74 (0.56–0.99),<br>0.043*    | 0.82 (0.62–1.07),<br>0.145   | 0.73 (0.61–0.87),<br><0.001*** | 0.99 (0.09–11.0),<br>0.994   |
| Wealth: Poorer             | 1.45 (0.99–2.12),<br>0.059     | 1.19 (0.96–1.47),<br>0.109   | 1.34 (1.14–1.57),<br><0.001*** | 1.02 (0.01–64.9),<br>0.994   |
| Wealth: Middle             | 2.13 (1.46–3.11),<br><0.001*** | 1.37 (1.07–1.76),<br>0.012*  | 1.54 (1.29–1.84),<br><0.001*** | 1.34 (0.02–68.9),<br>0.886   |
| Wealth: Richer             | 3.30 (2.22–4.89),<br><0.001*** | 1.47 (1.13–1.92),<br>0.005** | 1.75 (1.41–2.17),<br><0.001*** | 1.64 (0.03–86.2),<br>0.818   |
| Wealth: Richest            | 6.44 (4.07–10.2),<br><0.001*** | 1.59 (1.17–2.16),<br>0.003** | 2.29 (1.78–2.95),<br><0.001*** | 3.12 (0.06–164.3),<br>0.664  |
| Maternal age: 20–35        | 1.90 (1.07–3.36),<br>0.028*    | 0.98 (0.76–1.25),<br>0.852   | 0.95 (0.78–1.15),<br>0.585     | 1.21 (0.02–98.6),<br>0.93    |
| Maternal age: 36–49        | 3.51 (1.73–7.10),<br><0.001*** | 1.00 (0.75–1.32),<br>0.989   | 1.09 (0.88–1.35),<br>0.44      | 1.21 (0.02–104.3),<br>0.935  |
| Maternal education         | 1.19 (1.01–1.40),<br>0.036*    | 1.01 (0.94–1.08),<br>0.876   | 1.08 (1.01–1.15),<br>0.021*    | 1.06 (0.37–3.05),<br>0.908   |

|                       |                            |                                |                                |                            |
|-----------------------|----------------------------|--------------------------------|--------------------------------|----------------------------|
| Household electricity | 1.05 (0.98–1.13),<br>0.165 | 1.18 (0.86–1.61),<br>0.305     | 1.14 (0.99–1.33),<br>0.074     | 0.83 (0.03–21.4),<br>0.912 |
| Residence: Rural      | 0.93 (0.70–1.23),<br>0.615 | 0.44 (0.34–0.58),<br><0.001*** | 0.74 (0.63–0.87),<br><0.001*** | 0.37 (0.01–9.59),<br>0.551 |
| Cluster variance (SD) | 0.50 (0.71)                | 1.69 (1.30)                    | 0.89 (0.94)                    | 31.67 (5.63)               |
| ICC                   | 0.13                       | 0.34                           | 0.21                           | 1                          |
| N (clusters)          | 464                        | 552                            | 1570                           | 432                        |

**Table 4.2:** Adjusted odds ratios (aOR) for factors associated with overweight mothers: Results from multilevel logistic regression models in Burkina Faso (n=2,130) , Kenya (n=13,437), Pakistan (n= 8,746), and Nepal (n = 2,164). Mothers under 20 years old and the poorest wealth quintile served as the reference groups for this analysis.

### **Child nutritional status and maternal overweight**

Across countries seen in Table 4.2, child stunting status showed heterogeneous associations with maternal overweight. In Nepal, mothers of stunted children had significantly lower odds of being overweight compared with mothers of non-stunted children (aOR = 0.74; 95% CI: 0.56–0.99; p = 0.043). A similar inverse association was observed in Kenya (aOR = 0.73; 95% CI: 0.61–0.87; p < 0.001). In Pakistan and Burkina Faso, child stunting was not significantly associated with maternal overweight.

### **Household wealth and maternal overweight**

Strong positive associations between household wealth and maternal overweight were observed in Nepal, Pakistan, and Kenya. In Nepal, the odds of maternal overweight increased monotonically across wealth quintiles, with mothers in the richest households having substantially higher odds of being overweight (aOR = 6.44; 95% CI: 4.07–10.2; p < 0.001) compared with those in the poorest households. In Kenya, similar but less pronounced gradients were observed, with significantly higher odds of maternal overweight across all wealth quintiles, including the richest households (aOR = 2.29; 95% CI: 1.78–2.95; p < 0.001).

In Pakistan, maternal overweight was also positively associated with wealth, with significant associations observed among mothers in the middle (aOR = 1.37; 95% CI: 1.07–1.76;  $p = 0.012$ ), richer (aOR = 1.47; 95% CI: 1.13–1.92;  $p = 0.005$ ), and richest wealth quintiles (aOR = 1.59; 95% CI: 1.17–2.16;  $p = 0.003$ ). In contrast, no statistically significant associations between wealth and maternal overweight were observed in Burkina Faso, although estimates were imprecise.

### **Maternal age and education**

Maternal age was significantly associated with maternal overweight in Nepal only. Mothers aged 20–35 years had higher odds of being overweight compared with younger mothers (aOR = 1.90; 95% CI: 1.07–3.36;  $p = 0.028$ ), with even higher odds observed among mothers aged 36–49 years (aOR = 3.51; 95% CI: 1.73–7.10;  $p < 0.001$ ). No significant associations between maternal age and overweight were observed in Pakistan, Kenya, or Burkina Faso. Higher maternal education was associated with increased odds of maternal overweight in Nepal (aOR = 1.19; 95% CI: 1.01–1.40;  $p = 0.036$ ) and Kenya (aOR = 1.08; 95% CI: 1.01–1.15;  $p = 0.021$ ), while no significant associations were found in Pakistan or Burkina Faso.

### **Household characteristics and place of residence**

Household electricity was not significantly associated with maternal overweight in any of the four countries. Rural residence was associated with significantly lower odds of maternal overweight in Pakistan (aOR = 0.44; 95% CI: 0.34–0.58;  $p < 0.001$ ) and Kenya (aOR = 0.74; 95% CI: 0.63–0.87;  $p < 0.001$ ), while no statistically significant associations were observed in Nepal or Burkina Faso.

### **Random effects**

Between-cluster variability in maternal overweight was observed across all countries, with intraclass correlation coefficients (ICC) of 0.13 in Nepal, 0.34 in Pakistan, 0.21 in Kenya, and 1.00 in Burkina Faso, indicating varying levels of community-level clustering.

#### ***4.4 Discussion***

The patterns observed across the four case-study countries highlight the complex socio-economic and public health dynamics underlying maternal overweight in South Asia and Sub-Saharan Africa. Although each context presents distinct demographic and economic profiles, shared themes emerge in the results. The roles of wealth, maternal age, education, and rural versus urban residency underscore the growing double burden of malnutrition.

Our results show a consistent pattern of the strong association between higher household wealth and increased odds of maternal overweight in Nepal, Pakistan, and Kenya. The disparity is especially steep in Nepal, where mothers in the richest households are more than six times more likely to be overweight compared to those in the poorest households. Rapid economic changes may promote dietary shifts toward more energy-dense foods, which, combined with increasingly sedentary lifestyles, heightens the risk of overweight. This is because the cost of processed, energy-dense foods has decreased significantly, while the cost of fruits and vegetables has risen.(Choudhury et al. 2025; Pries et al. 2019; Downs et al. 2022). In Kenya and Pakistan, similar but more moderate wealth effects indicate that economic resources increase access within precarious health landscapes(Popkin and Ng 2022; Popkin et al. 2012). These countries have access to significant levels of processed foods, while also needing to do reduced physical labor within urbanized lifestyles (Schirley et al. 2015). The relationship between wealth and nutrition largely does not appear in Burkina Faso, likely due to different stages of nutritional transition or limited variability in wealth-related lifestyle behaviors. The strong wealth gradient across

multiple contexts reinforces the need for public health interventions that consider how economic development shapes nutritional outcomes and health inequities.

An important pattern identified is the link between child stunting and maternal overweight. Specifically, in both Nepal and Kenya, the likelihood of a mother being overweight is significantly lower in households where children are stunted. This reflects the well-documented intra-household nutritional disparities in which children continue to experience chronic undernutrition even as their caretakers become overweight (Blankenship et al. 2020; Sahiledengle et al. 2023). Such coexistence of maternal overweight and child stunting often within the same household points to structural food insecurity, dietary monotony, and poor-quality diets are often the result of limited time, financial constraints, and restricted access to healthy foods. In many low-resource settings, families rely on inexpensive, energy-dense but nutrient-poor processed foods, which can contribute to maternal obesity, while the same structural barriers, food insecurity, inadequate dietary diversity, and constrained access to nutritious options continue to place children at risk of undernutrition. (Lukwa et al. 2025; Stone et al. 2025). These findings align with the broader narrative of the double burden of malnutrition, where improvements in food quality often benefit adults (Carvajal-Aldaz et al. 2022). Pakistan and Burkina Faso do not show significant associations, which may indicate differing household food dynamics, higher quality diets or context-specific determinants of child undernutrition.

Maternal age is a key determinant of maternal obesity, particularly in Nepal, where older women (36–49 years) have a more than threefold increased likelihood of being overweight. This pattern suggests age-related metabolic changes compounded by cumulative lifestyle exposures and possibly declining physical activity as seen in other countries (Nglazi and Ataguba 2022; Manoussi et al. 2025; Shen et al. 2024). In contrast, maternal age effects are absent in Pakistan,

Kenya, and Burkina Faso, pointing to variation in age-patterned lifestyles or differing population health trajectories across settings. The findings from Nepal underscore the need for adopting life-course approaches, focusing on various time-points in the lives of both children and their mothers, for effective obesity prevention. (Mannino et al. 2023).

Education also plays an important role in maternal obesity, showing positive and significant associations with maternal overweight in Nepal and Kenya. Higher educational attainment may shift dietary behaviors by increasing disposable income or adopting more modern, less active lifestyles. Conversely, in Pakistan and Burkina Faso, maternal education shows no significant effect, suggesting a weaker relationship between schooling and nutritional behaviors or differing cultural norms around food, gender roles, and body size.

The results for rural residency further illustrate the interplay between built environment and nutrition. Mothers living in rural communities in Pakistan and Kenya have significantly lower odds of being overweight, reflecting persistent urban–rural divides in access to processed foods, transportation, and lifestyle patterns which have been observed in other regions (Neuman et al. 2013; Khudri et al. 2025). Urban areas, often characterized by more sedentary occupations and greater exposure to Westernized diets, appear to intensify overweight risk. These findings reinforce the need for targeted programming that recognizes how obesogenic environments manifest differently across rural–urban landscapes (Choudhury et al. 2025).

Finally, the substantial variation in cluster-level random effects, particularly in Burkina Faso, suggests strong geographic or contextual heterogeneity in the determinants of maternal overweight. High intraclass correlation coefficient values in Pakistan and Kenya similarly highlight that community-level factors such as food environments, cultural norms, healthcare

access, and regional economic disparities play an important role.

#### ***4.5 Conclusion***

The persistent and complex nature of the double burden of malnutrition is underscored by this study, which highlights the varied socio-economic factors affecting overweight mothers in households also experiencing child malnutrition. The coexistence of maternal overweight and child stunting reflects deep structural challenges shaped by both wealth disparities and uneven geographic development. Rising household wealth is associated with increased exposure to energy-dense diets and sedentary lifestyles, while enduring poverty limits children's nutritional intake and overall well-being. Further research is required to fully understand these patterns.

The findings signal urban–rural differences. Mothers residing in rural areas particularly in Pakistan and Kenya appear less likely to be overweight, potentially due to greater engagement in physically demanding work, limited access to processed foods, and stronger reliance on traditional diets. In contrast, urban environments may foster obesogenic conditions that heighten maternal overweight risk. Greater attention to maternal health is essential, as maternal nutritional status shapes the long-term trajectories of both obesity and child malnutrition observed globally (Forgie et al. 2020; Papathakis et al. 2016; Thornburg and Valent 2024).

## 5.0 Conclusion

### *5.1 Summary of Research*

This dissertation examined the multifaceted determinants of child malnutrition across South Asia and Sub-Saharan Africa, with particular emphasis on the roles of climate variability, household infrastructure, and the emerging double burden of malnutrition. Four interrelated case studies were presented utilizing Demographic and Health Survey (DHS) data from Burkina Faso, Kenya, Nepal, and Pakistan. The research contributes novel insights into how environmental stressors and socioeconomic transitions shape child nutritional outcomes in low- and middle-income countries.

The findings reveal both universal patterns and important context-specific variations in the determinants of child malnutrition. Chapter 2 demonstrated that temperature extremes, particularly heat and cold anomalies are associated with child stunting in Burkina Faso and Kenya, with the impact of household infrastructure varying substantially between countries. In Burkina Faso, electricity access and urban residence emerged as significant protective factors, while in Kenya, improved water and sanitation infrastructure showed stronger associations with reduced stunting risk. Notably, this study provided the first empirical evidence that cold temperature anomalies may paradoxically be associated with reduced stunting in certain contexts, with effects appearing more pronounced in warmer regions.

Chapter 3 extended this climate-nutrition analysis to South Asia, examining temperature anomalies and child stunting in Nepal and Pakistan. These countries have pronounced cold and hot seasons as well as significant variation in climate regimes, resulting in a much greater range of temperature anomalies than in Burkina Faso and Kenya. The results revealed that while cold

temperature anomalies were significantly associated with increased stunting risk in Pakistan, the associations in Nepal were weaker and less consistent. These findings underscore the importance of considering local climatic baselines and seasonal variations when assessing climate-related health risks. Across both countries, household wealth and sanitation access consistently emerged as strong protective factors, suggesting that socioeconomic conditions mediate the relationship between climate exposure and child health outcomes.

Chapter 4 shifted focus to the double burden of malnutrition, examining the coexistence of child undernutrition and maternal overnutrition across all four study countries. The analysis of 26,568 mother-child dyads revealed striking heterogeneity in the prevalence and determinants of this phenomenon. Child stunting showed inverse associations with maternal overweight in Nepal and Kenya, suggesting that in these contexts, households experiencing child undernutrition may face different constraints than those experiencing maternal overnutrition. In contrast, no such associations were observed in Pakistan or Burkina Faso, indicating that the double burden manifests differently depending on the stage of nutrition transition and local food environments. Strong positive wealth gradients in maternal overweight emerged in Nepal, Kenya, and Pakistan, with the richest households showing substantially higher odds of maternal overweight, a pattern that was absent in Burkina Faso, where overall prevalence of maternal overweight remained very low.

## ***5.2 Theoretical and Methodological Contributions***

This dissertation makes several important theoretical contributions to understanding malnutrition in transitioning economies. First, this research demonstrates that child nutritional status is significantly and uniquely determined by climate variability, particularly temperature extremes.

Unlike the more conspicuous threats of floods or droughts, thermal anomalies—such as acute heatwaves and unseasonable cold snaps function as silent stressors. These extremes disrupt local food systems and increase the physiological metabolic demands on developing bodies, silently eroding household resilience and exacerbating the risk of stunting in climate-vulnerable settings. By integrating high-resolution climate data (CHIRTS) (Funk et al. 2019) with nationally representative health surveys, this research provides empirical evidence that both heat and cold anomalies can influence stunting risk, though the direction and magnitude of effects vary considerably by context. This finding challenges simplified assumptions about climate-health relationships and highlights the need for nuanced, location-specific assessments (S. Wang et al. 2025; Redicker et al. 2025).

Second, the dissertation contributes to theories of nutrition transition (Popkin and Ng 2022) by documenting how the double burden of malnutrition emerges differently across socioeconomic gradients and geographic contexts. The strong wealth gradients observed in Nepal, Kenya, and Pakistan where maternal overweight increases sharply with household wealth while child stunting persists suggest that these countries are at intermediate stages of nutrition transition. In contrast, Burkina Faso appears to remain at an earlier stage, where undernutrition predominates across all socioeconomic strata and maternal overweight remains rare even among the wealthy. This heterogeneity underscores that nutrition transitions do not follow uniform trajectories and that policy responses should be tailored to local contexts.

Third, the research demonstrates the critical importance of household infrastructure—including electricity, water, and sanitation—as mediators of both climate-related and socioeconomic determinants of child health. The finding that different types of infrastructure provide varying degrees of protection across countries suggests that infrastructure development strategies should

be evidence-based and context-appropriate rather than following one-size-fits-all approaches. Similar results have been found by previous research (Shively 2017).

### ***5.3 Practical Implications***

This research provides a roadmap for policymakers and healthcare providers to navigate the complex nexus between climate variability and public health in Africa and Asia. A primary insight from this work is the necessity of expanding the climate adaptation narrative beyond heat-centric models to include resilience against cold temperature anomalies. In tropical, humid regions, cold snaps pose significant physiological risks that may be overlooked in current National Adaptation Plans (Ebi and Prats 2015; Kowalczyk and Dorevitch 2024; WHO 2025a). By integrating both heat and cold related protocols into existing disaster risk reduction frameworks, governments can prioritize winterization efforts such as improved household insulation and energy access to mitigate the metabolic stressors that drive chronic malnutrition during cold or hot extremes. In tropical climates, the distinction between winterization and heat protection dissolves into a unified, year-round strategy focused on blocking external thermal gain while strictly managing internal humidity levels (Givoni 1994; Penner 2024; Ouedraogo et al. 2022).

Furthermore, the evidence suggests that household-level infrastructure serves as a primary buffer against environmental shocks. Access to reliable electricity, improved water sources, and modern sanitation systems are not merely development goals; they are critical public health interventions that protect children from the stunting and wasting typically associated with temperature extremes. This insight should fundamentally shift resource allocation away from siloed, sector-specific projects toward integrated infrastructure development. Reframing investments in rural

electrification and universal water access as high-impact climate adaptation strategies allows policymakers to strengthen the built environment, thereby reducing the disease-based and physiological pathways through which climate shocks harm vulnerable populations.

Effective policy should also address the "urban paradox" and the rising "Double Burden" of malnutrition and overnutrition. As seen in Burkina Faso, rapid urbanization often erodes the traditional urban advantage as infrastructure fails to keep pace with population growth, leading to increased vulnerability in high-density informal settlements (Santosh and Kane 2025). Future interventions should account for urban heat islands while simultaneously addressing the dual challenge of child stunting and maternal overnutrition. Resource allocation should target nutrient-dense food systems in urban centers to counteract the dietary shifts brought about by globalization, ensuring that development goals focus on the quality of nutrition rather than just caloric quantity (Leroy et al. 2025; Grevulo-Minofu et al. 2025).

Finally, the integration of high-resolution climate data with standard health surveys offers a powerful tool for proactive intervention. By developing sub-national early warning systems that monitor temperature Z-scores in real-time, healthcare providers can identify high-risk periods before physiological impacts manifest as permanent growth deficits (Machefer et al. 2025; Majdoubi et al. 2026). This data-driven approach allows for the targeted distribution of nutritional supplements and health screenings exactly when and where they are needed most. Moving from a reactive model of emergency aid to a proactive model of place-based resilience building.

#### ***5.4 Future Research Directions***

The multilevel modeling framework and the DHS data employed in this dissertation holds considerable promise for investigating other critical health outcomes shaped by environmental variability and geographic clustering. One particularly urgent application involves examining relationships between temperature anomalies and regional violence or conflict (Bollfrass and Shaver 2015; Heo et al. 2025; Belli et al. 2025). Emerging evidence suggests that extreme heat may exacerbate social tensions and contribute to civil unrest, particularly in resource-scarce settings where temperature extremes strain agricultural production and livelihoods (Robinson 2025; Fatima et al. 2022). The pathways linking temperature to violence have been shown to operate across multiple scales from individual physiological responses to heat stress, to household economic shocks (Zhou et al. 2022; Tattersall et al. 2012; Mueller et al. 2014; Thiede and Gray 2017), to community resource competition, to regional patterns of displacement.

Multi-level models that nest individuals within households, households within communities, and communities within regions could disentangle these nested effects while accounting for spatial clustering. Additionally, investigating temperature-violence relationships alongside HIV prevalence could reveal important synergies, as conflict-affected populations often experience disrupted healthcare access and increased transmission risk (Nikitin et al. 2024; Logie et al. 2025). Temperature anomalies may indirectly influence HIV rates through conflict-related pathways or potentially through direct effects on healthcare-seeking patterns (Buczkowska et al. 2025). Longitudinal multilevel models linking high-resolution climate data with geocoded health and conflict data could illuminate whether temperature shocks predict subsequent increases in violence and HIV incidence.

Beyond violence and infectious disease, multilevel modeling approaches could substantially advance understanding of how environmental variables contribute to obesity in low- and middle-income countries (Muhammad et al. 2025). While this dissertation documented strong socioeconomic gradients in maternal overweight, the role of broader environmental contexts including built environments, ambient temperature, and air pollution impacts on maternal obesity remains underexplored. Temperature anomalies may influence obesity through multiple mechanisms: extreme heat may reduce physical activity and climate-related agricultural disruptions may shift populations toward processed foods (Muhammad et al. 2025).

A common limitation across all chapters stems from inherent constraints in survey-based research (Grace et al. 2020), including potential recall bias in self-reported data, challenges in reaching remote or marginalized populations, and systematic non-response patterns that may affect representativeness. These limitations are not unique to this dissertation but reflect broader methodological challenges facing population health research in low- and middle-income countries. Despite these constraints, DHS data remain among the most rigorous and comprehensive sources of population health information available in these settings, employing standardized protocols, rigorous quality control, and nationally representative sampling designs . Moving forward, continued and expanded funding for DHS and similar survey platforms is essential not merely for sustaining existing data collection efforts, but for extending reach to underserved populations including conflict-affected areas, informal urban settlements, and remote rural communities. Enhanced coverage of hard-to-reach populations would improve the representativeness of findings, enable more precise estimation of health disparities, and strengthen the evidence base for targeted interventions.

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