How Does Healthcare Quality Moderate the Impact of Drought on Child Nutrition?

Master Thesis Presented to the

Department of Economics at the

Rheinische Friedrich-Wilhelms-Universität Bonn

In Partial Fulfillment of the Requirements for the Degree of

Master of Science (M.Sc.)

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Submitted in September 2025 by:
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Abstract

Life expectancy in Africa is comparatively low due to high child mortality and suboptimal health outcomes, which are particularly sensitive to climate changes. Drought poses a risk factor to the provision of child nutrition in Sub-Saharan Africa, but little is known about how healthcare systems moderate this relationship. To address this gap, this study examines how regional healthcare quality moderates the impact of drought on child growth in Senegal. This study merges high-resolution Standardized Precipitation-Evapotranspiration Index (SPEI) data, geocoded Demographic and Health Surveys (DHS) data, and regional healthcare indicators from Service Provision Assessments (SPA) for 24,857 children from 2012 to 2019. Using fixed-effects models, this study leverages spatio-temporal drought variation to analyze healthcare moderation during two critical windows, in utero and 0–24 months after birth. Results show that early-life drought reduces children's height-for-age z-scores (HAZ) by 0.087 standard deviations, while in-utero effects are not detectable on average except among children from wealthy households. This harm is moderated by healthcare quality in early life, with a 10 percentage point rise in the regional share of private healthcare facilities buffering drought penalty on children's HAZ by 0.054 standard deviations, while an equivalent rise in the share of facilities charging routine fees exacerbates harm by 0.053 standard deviations. Children in poor households are particularly sensitive to droughts. In contrast, middle-income households benefit the most from the private sector and the presence of Integrated Management of Childhood Illness (IMCI)–trained staff. The findings suggest market-driven healthcare could partially offset climate shocks on children's health but exacerbate inequality. The results suggest that building an equitable and resilient healthcare system requires pairing healthcare infrastructure expansion with targeted support for poor households during climate-related shocks.

Keywords: Climate resilience; Child malnutrition; Healthcare quality; Drought impacts

1 Introduction

Global climate extremes, including droughts and heatwaves, impact populations worldwide. These effects are particularly severe for developing countries with rain-fed agriculture, exacerbating global inequality and emphasising the necessity for climate-resilient systems. In Sub-Saharan Africa, recurrent drought undermines child nutrition and raises mortality (Rustad, Rosvold and Buhaug 2020; Wang et al. 2025), making undernutrition a persistent policy concern (Vaillancourt 2016; Brar et al. 2020).

Extensive evidence shows that drought harms health outcomes for children, such as increasing the likelihood of stunting (Le and Nguyen 2021; Wang et al. 2025; Cooper et al. 2019; Headey and Venkat 2024; Dimitrova 2021), operating through agricultural performance, disease infection, and economic mechanisms (Headey and Venkat 2024; Dimitrova 2021). Many studies try to find moderation effects, such as infrastructure and humanitarian aid programs, that can buffer these impacts (Shively 2017; Cooper et al. 2019; Rustad, Rosvold and Buhaug 2020; Gunnsteinsson et al. 2022; Ponnusamy 2022). While some evidence suggests that geographic access to healthcare can buffer against drought-related mortality (Okwaraji et al. 2012; Mullins and White 2020), a significant gap remains in understanding which specific dimensions of healthcare moderate drought's impact on child growth. While many studies assess drought exposure in the period preceding the survey and its interaction with survey-time infrastructure (Shively 2017; Cooper et al. 2019; Rustad, Rosvold and Buhaug 2020; Freudenreich, Aladysheva and Brück 2022; Dimitrova et al. 2023; Wang et al. 2022), scientific consensus holds that the "first 1,000 days" (from conception through the first two years of life) represent the most critical window for a child's growth (Victora et al. 2010; Headey and Venkat 2024).

Therefore, this study asks how drought exposure in utero and in the first 24 months of life affects children's height-for-age z-scores (HAZ) in Senegal, and how healthcare quality moderates these effects. This study will focus on Senegal primarily because it uniquely offers eight years of repeated cross-sectional data from the Demographic and Health Surveys (DHS) and the Service Provision Assessment (SPA), which enables subnational, timing-specific tests of moderation. Meanwhile, Senegal is a Sahelian country facing recurrent droughts (Funk et al. 2012) and persistent undernutrition (Vaillancourt 2016; Brar et al. 2020). In practice, geocoded child anthropometrics from DHS are linked to high-resolution Standardized Precipitation–Evapotranspiration Index (SPEI) drought measures (Gebrechorkos et al. 2023) at the DHS survey cluster level, and to a region–year panel of healthcare indicators constructed from SPA. Empirically, fixed-effects models absorb unobserved heterogeneity at the cluster, birth-season, and survey-year levels; define exposure windows for in utero and the 0–24 months period; and include interactions between drought and the healthcare indicator for each period.

The results show that early-life drought (0–24 months) lowers HAZ by 0.087 standard deviations ($p<0.01$), with no average in-utero effect, apart from a significant penalty observed in children from rich households. Healthcare quality moderates drought effects in the early life stage. A 10-percentage-point increase in the prevalence of private facilities reduces the drought penalty by 0.054 standard deviations. In contrast, a 10-percentage-point increase in the share of facilities

charging routine fees raises the penalty by 0.053 standard deviations. The moderations are unequal, as poor households face the largest losses and gain little from the private sector. In contrast, middle-income households benefit from both private healthcare and Integrated Management of Childhood Illness (IMCI)–trained staff. Children from wealthy households show a significant in-utero drought effect (–0.229, $p<0.01$), and this penalty is further amplified when facilities charge routine fees during pregnancy. In-utero drought effects likely reflect selection bias from mortality among the most vulnerable. Overall, market-driven capacity can buffer shocks, but without financial support, it can widen inequality.

This paper makes some key empirical contributions. This study provides concrete evidence of the moderating effect of healthcare quality on the impact of drought on children's nutrition. Secondly, the analysis employs a time-aligned-to-exposure moderation approach by leveraging Senegal's uniquely 8-wave SPA data. Time-aligned to exposure means measuring healthcare quality in the same region and year as the child's exposure window (in utero; 0–24 months). While prior work often focuses on pre-survey climate exposure, this dataset enables a direct match between healthcare quality and a child's critical "first 1,000 days" window (in utero and 0–24 months). This provides a more precise in time and biologically relevant assessment than is feasible in most African settings, which typically have only one or two waves of SPA data. Third, it shows socioeconomic status heterogeneity in moderation and suggests combining healthcare capacity expansion with targeted financing to safeguard the poor during drought.

The rest of the paper is organized as follows. Section 2 reviews literature on drought's impacts, moderating factors, and methodology. Section 3 introduces Senegal's climate patterns, health system, and other interventions. Section 4 describes data sources, variable construction, and the process of spatial integration. Section 5 details the empirical strategy. Section 6 presents the main results and robustness checks. Section 7 concludes with findings and a discussion of implications for resilient health systems.

2 Literature Review

Drought consistently harms child health, such as raising stunting and lowering HAZ across diverse settings (Le and Nguyen 2021; Wang et al. 2025; Cooper et al. 2019), through interacting channels such as agricultural losses, disease, and economic loss (Headey and Venkat 2024; Dimitrova 2021). A growing literature examines moderation, often through infrastructure or macro-conditions (Shively 2017; Cooper et al. 2019), but direct evidence on healthcare quality as a moderator is limited. Many existing findings focus on the effects of facility access distance on mortality and nutrition rather than quality (Okwaraji et al. 2012; Mullins and White 2020; Rustad, Rosvold and Buhaug 2020; Gunnsteinsson et al. 2022). Methodologically, studies differ in data sources, designs, and in how they define drought and time exposure. Many designs link pre-survey exposure to survey-year moderators. Consequently, it is essential to test whether healthcare quality, time-aligned to exposure, moderates drought during the "first 1,000 days" (in utero and ages 0-24 months).

2.1 Drought's Impact on Child Health

Multi-country research indicates that drought has persistent negative effects on child growth in low- and middle-income countries (Cooper et al. 2019; Le and Nguyen 2021; Dimitrova et al. 2023; Wang et al. 2022; Salvador et al. 2024). Analyses focused on specific nations demonstrate nation-specific results: Ethiopian children exhibit increased stunting during seasonal droughts (Dimitrova 2021), Kyrgyz children show significantly reduced linear growth with each additional drought month during ages 0 to 19 months (Freudenreich, Aladysheva and Brück 2022), and Ivorian under-five mortality increases with the severity of drought (Andriano 2024). In rural Indonesia, women born during above-average rainfall have better adult health, educational attainment, and asset accumulation, supporting the idea that increased precipitation boosts agricultural output and household income, improving infant girls' nutrition during the critical first year with gender-based resource allocation (Maccini and Yang 2009).

In this study's sample, Senegal, drought-related challenges continue to threaten children's nutrition despite the country's relatively strong health system. From 1992 to 2017, Senegal decreased child stunting by 17.9% due to improved maternal health services (Brar et al. 2020); however, drought continues to harm child nutrition (Jampani et al. 2023). During the 2014 drought, impoverished families reduced expenditures on health and education to procure food, thus elevating their children's vulnerability to malnutrition (Nébié, Ba and Giannini 2021).

Stunting is widely understood to originate in the first 1,000 days of life, including in utero and the first 2 years after birth (Victora et al. 2010). Within this window, two strands of evidence emerge. First, in utero drought reduces linear growth and increases neonatal mortality (Abiona 2022; Le and Nguyen 2021; Rocha and Soares 2015; Wang et al. 2025; Rocha and Soares 2015). Second, early-life drought elevates stunting risk (Freudenreich, Aladysheva and Brück 2022; Cooper et al. 2019; Dimitrova 2021; Rustad, Rosvold and Buhaug 2020; Freudenreich, Aladysheva and Brück 2022). However, the definition of "early life" varies across studies. Together, these findings indicate vulnerability across both gestation and infancy while highlighting timing definitions as a key methodological source of estimate variation.

Drought operates through three interconnected pathways. First, water scarcity increases waterborne disease, with diarrheal incidence rising particularly where WASH (water, sanitation, hygiene) infrastructure is inadequate (Dimitrova et al. 2023; Wang et al. 2022; Rocha and Soares 2015). The second and third mechanisms are food security and economic pathways. Drought results in agricultural failure and livestock deaths, significantly impacting food availability and dietary diversity in dependent groups (Cooper et al. 2019; Shively 2017; Dimitrova 2021; Yolchi and Wang 2025). The financial effects extend beyond immediate food availability; drought lowers household income, constraining families' capacity to buy food (Freudenreich, Aladysheva and Brück 2022; Headey and Venkat 2024). Furthermore, income shocks force households to cut expenditures on healthcare and immunizations, exacerbating vulnerability to disease (Mehar, Mittal and Prasad 2016; Headey and Venkat 2024). These results align with previous studies highlighting that climate shocks influence child nutrition through various interconnected pathways (Headey and Venkat 2024; Le and Nguyen 2021).

Drought is also related to miscarriage and child mortality, which can introduce significant selection bias into studies of child nutrition. Severe drought increases infant mortality, particularly in the neonatal period for those exposed in utero (Wang et al. 2025; Andriano 2024; Banerjee and Maharaj 2020). Additionally, drought raises miscarriage and stillbirth rates (Davenport, Dorélien and Grace 2020; Das et al. 2023), creating survivor bias that causes nutrition studies to underestimate actual impacts by examining only live births (Wang et al. 2025; Rocha and Soares 2015). As will be discussed, some of the findings in this study can also be explained by this selective survivor bias.

The impacts of drought vary according to demographic characteristics; yet, trends remain inconsistent for gender. Several studies indicate that boys are more vulnerable to stunting (Dimitrova 2021; Andriano 2024), while others show girls are more vulnerable (Rocha and Soares 2015) or find no significant sex differences (Salvador et al. 2024; Wang et al. 2025). Headey and Venkat (2024) note that despite the inherent vulnerability of male fetuses and infants, son preference and gender norms in various low- and middle-income countries (LMICs) offset this trend by giving boys priority access to nutrition and healthcare during crises, reducing their biological disadvantage. Meanwhile, social and economic disparities are consistent. The impacts of drought are mostly endured by poor households, rural areas, and children of less educated mothers (Cooper et al. 2019; Dimitrova 2021; Ponnusamy 2022).

2.2 Moderating Factors

Drought impacts are well-documented, while protective factors are scarce. Emerging research suggests some buffers but seldom evaluates healthcare quality moderation.

The first type of moderation arises from infrastructure and access to it. Geographical closeness consistently moderates the effects of drought. Children living more than 1.5 hours from healthcare facilities experience mortality rates 2 to 3 times greater during droughts (Okwaraji et al. 2012). In Nepal and Uganda, better road density and facility proximity reduce HAZ sensitivity to rainfall shocks (Shively 2017). Björkman Nyqvist et al. (2023) shows that healthcare access reduces climate-related infant deaths significantly during exposure.

The second type of moderation is institutional buffers. The World Bank's aid program helps children in 16 African nations who are losing weight due to drought (Rustad, Rosvold and Buhaug 2020), while conditional cash transfers mitigate long-term impacts of rainfall shock (Adhvaryu et al. 2024). The quality of governance also moderates the effects of drought (Cooper et al. 2019), and vitamin A supplementation protects children during crises (Gunnsteinsson et al. 2022).

Limited studies focus on healthcare systems. In Sub-Saharan Africa, a high proportion of private facilities is associated with higher child survival, whereas the imposition of fees is associated with poorer outcomes (Simmons, Anthopolos and O'Meara 2021). This study focuses on general conditions rather than healthcare performance during climate shocks, resulting in significant gaps in the understanding of crisis resilience. The limited evidence indicates promising although fragmented trends. Zimbabwe's community health workers maintained child nutrition during the 2015-2016 drought (López-Ejeda et al. 2019). Expanded public health services reduced

temperature-related mortality in Mexico (Cohen and Dechezleprêtre 2022).
These cases illustrate the potential protective role of healthcare, but they remain isolated findings rather than systematic analyses of how healthcare systems shape resilience. To address this gap, this study examines how time-varying healthcare quality moderates the impacts of drought across different developmental windows and population groups.

2.3 Methodology

The common empirical approach employs fixed-effects controlling for time-invariant location characteristics and common temporal shocks (Freudenreich, Aladysheva and Brück 2022; Wang et al. 2022; Cooper et al. 2019; Rustad, Rosvold and Buhaug 2020; Dimitrova 2021; Shively 2017; Le and Nguyen 2021). Interaction terms increasingly test moderation effects, with adaptive capacity factors (governance, trade, agricultural diversity) and sensitivity factors (political stability) identified as key moderators (Cooper et al. 2019; Ponnusamy 2022). Mullins and White (2020) found that access to primary care reduces heat-related mortality by using an interaction term, illustrating a clean blueprint for environmental exposure × healthcare moderation. Therefore, this study will use interaction terms to test the moderation effects.
Different research designs employ different exposure windows. Leading studies model multiple developmental periods simultaneously to avoid omitted timing bias. Maccini and Yang (2009) pioneered this approach by including both birth year and adjacent year rainfall, isolating gestational effects on adult outcomes. On the other hand, many studies include only one exposure period in the empirical model to capture the total effect (Shively 2017; Dimitrova 2021; Freudenreich, Aladysheva and Brück 2022; Le and Nguyen 2021). Other studies separate timing within early childhood and found that infancy is the most sensitive postnatal window (Dimitrova 2021; Freudenreich, Aladysheva and Brück 2022; Shively 2017). Building on them, this study's main model incorporates both in utero and early life exposure windows, while the robustness checks analyse each window individually.
Studies differ in how they define the early life exposure window. A common practice is to proxy early life with the months immediately preceding the interview and then interact this pre-survey drought measure with survey-year moderators (Shively 2017; Cooper et al. 2019; Rustad, Rosvold and Buhaug 2020; Freudenreich, Aladysheva and Brück 2022; Dimitrova et al. 2023; Wang et al. 2022). In effect, many studies treat early life as often the previous 12 to 24 months, rather than the child's first 24 months after birth. Other designs isolate in-utero exposure windows (Le and Nguyen 2021; Andriano 2024), while some combine gestation and infancy (Wang et al. 2025; Rocha and Soares 2015). To align with scientific findings on the critical "first 1,000 days" window, this study uses its rich, repeated cross-sectional data to define and analyze two key exposure periods: the gestational period (in utero) and the first two years of life (0–24 months).
Recent climate research favors the Standardized Precipitation–Evapotranspiration Index (SPEI) drought indicator due to its excellence. Therefore, this study adopts SPEI as the principal drought indicator and standard threshold as well. Most works adopt SPEI values below -1.0 as the standard moderate drought (Freudenreich, Aladysheva and Brück 2022; Rustad, Rosvold and

Buhaug 2020; Dimitrova 2021), though some relax to -0.5 standard deviations or tighten to -1.3 standard deviations for severe events (Cooper et al. 2019; Wang et al. 2025).

The literature reveals two main approaches to measuring drought, distinguished by the chosen time scale of the SPEI. The notation SPEI-k refers to the cumulative water balance over the k months preceding a given month. The first approach utilises long-window SPEI measures to capture persistent drought conditions. After testing multiple SPEI timescales, Cooper et al. (2019) identified SPEI-24 as the most sensitive indicator for predicting child stunting because it effectively captures cumulative drought exposure over the 24 months preceding the interview. Wang et al. (2025) similarly utilises SPEI-24 to cover the duration from pregnancy to the first year of life. Rustad, Rosvold and Buhaug (2020) utilises SPEI-12 to evaluate the preceding year right before the survey. These lengthy timeframes assume that drought affects agricultural cycles and food systems through prolonged environmental stress. The second approach highlights temporal accuracy. Dimitrova (2021) uses SPEI-04 at the end of each season, averaging across seasons from birth to the measurement year to identify recurring seasonal drought trends in lifetime. Most notably, Freudenreich, Aladysheva and Brück (2022) employs monthly SPEI-01 to construct cumulative drought month counts, recognising that child growth responds to accumulated shocks rather than smoothed average conditions. Therefore, to capture the cumulative impact on child growth, this study uses long-timescale drought indices, reflecting the chronic nature of stunting. Exposure is then translated into regression models through three approaches: binary indicators based on single or window-averaged SPEI (Dimitrova 2021; Wang et al. 2025; Rustad, Rosvold and Buhaug 2020; Andriano 2024), continuous SPEI restricted to negative values (Salvador et al. 2024), or cumulative number of drought months (Freudenreich, Aladysheva and Brück 2022; Cooper et al. 2019). This study will employ a standard binary definition and evaluate the marginal effect through a cumulative definition for robustness.

Common controls include child characteristics (sex, birth order), maternal factors (education, age, marital status), and household conditions (wealth, urban residence) (Wang et al. 2025; Simmons, Anthopolos and O'Meara 2021; Cooper et al. 2019; Salvador et al. 2024; Ponnusamy 2022). Infrastructure factors serve as either controls or moderators (Shively 2017; Cooper et al. 2019; Ponnusamy 2022; Simmons, Anthopolos and O'Meara 2021; Salvador et al. 2024).

Limitations persist across this literature. Cross-sectional surveys restrict the longitudinal tracking of the same children and the isolation of specific mechanisms. Moreover, location measurement involves several biases. The GPS displacement of DHS clusters may result in bias, and using survey location as a proxy for birthplace overlooks migration patterns, both of which weaken estimates (Burgert et al. 2013; Wang et al. 2022; Wang et al. 2025). Survivor bias arises when drought increases fetal loss and mortality in infants. Nutrition studies that focus solely on surviving children selectively focus on the more resilient survivors and should be regarded as lower bounds of actual drought impacts (Wang et al. 2025; Rocha and Soares 2015; Ponnusamy 2022). This occurs due to the rare modelling of mortality with nutrition outcomes for living observations in nutrition studies. Most fundamentally, without valid instruments, researchers cannot test the causal mechanisms linking drought with health outcomes.

3 Study Context: Senegal

This section discusses three factors that affect the relationship between drought and nutrition in Senegal: the country's geography and drought patterns, the healthcare system, and organizational interventions.

3.1 Geography, Climate, and Population

Senegal covers an area of 196,722 km^2 and involves three distinct climate zones: the arid Sahel in the north, the semi-arid savanna in the central region, and the humid tropical savanna in the south (Tomalka et al. 2022). The duration and intensity of a single rainy season diminish as one moves northward, resulting in a stated north-south disparity in drought conditions, with northern areas facing more frequent and severe droughts (Singh, Das and Prasad 2025).

Since the 1990s, rainfall patterns have shifted from a uniform distribution to extended dry periods interspersed with intense precipitation events (Fall et al. 2021). Droughts were especially severe in 2011, 2014, and 2018-2019, with the 2018 event resulting in a near doubling of the population facing food insecurity, increasing from 315,000 to 548,000 people (World Food Programme 2018). The majority of rain-fed agriculture, coupled with restricted irrigation, increases vulnerability (Funk et al. 2012).

Figure 1 shows annual drought patterns from 2012-2019 using SPEI-12 values, with values below -1.0 considered as experiencing drought. Consistent with documented patterns, northern and eastern regions consistently show higher drought frequency and severity.

Approximately 25% of Senegal's population is concentrated in the capital, Dakar, which covers only 0.3% of the country's territory, resulting in significant urban-rural disparities in access to services. The northern regions (Saint-Louis, Louga, Matam) experience significant drought, have limited infrastructure, and depend on rain-fed agriculture (Singh, Das and Prasad 2025). This difference in geography affects how the drought affects children's nutrition in different regions.

Agriculture employs 60% of Senegal's population through predominantly small-scale, rain-dependent farming (Fall et al. 2021). Drought contributes to 25% of the variability in child underweight and 31% of income losses in rural households. Families cope by reducing both the quantity and quality of meals, thereby directly raising the risk of stunting (Grossi, Downs and Traska 2021).

Figure 2 maps DHS cluster-level drought exposure from 2012 to 2019. The clusters are concentrated in the western regions and the Senegal River valley, with a sparse eastern coverage. There was widespread drought in 2014, 2018, and 2019 (orange and red clusters), but it was much wetter in 2013 (blue clusters).

3.2 Healthcare System in Senegal

Senegal's maternal health infrastructure is far better than the regional average. The nation achieved a 72% reduction in maternal mortality, decreasing the rate from 553 deaths per 100,000 live births in 2000 to 153 in 2023 (Sy, Sarr and Doucouré 2025; Onambele et al. 2023). This is

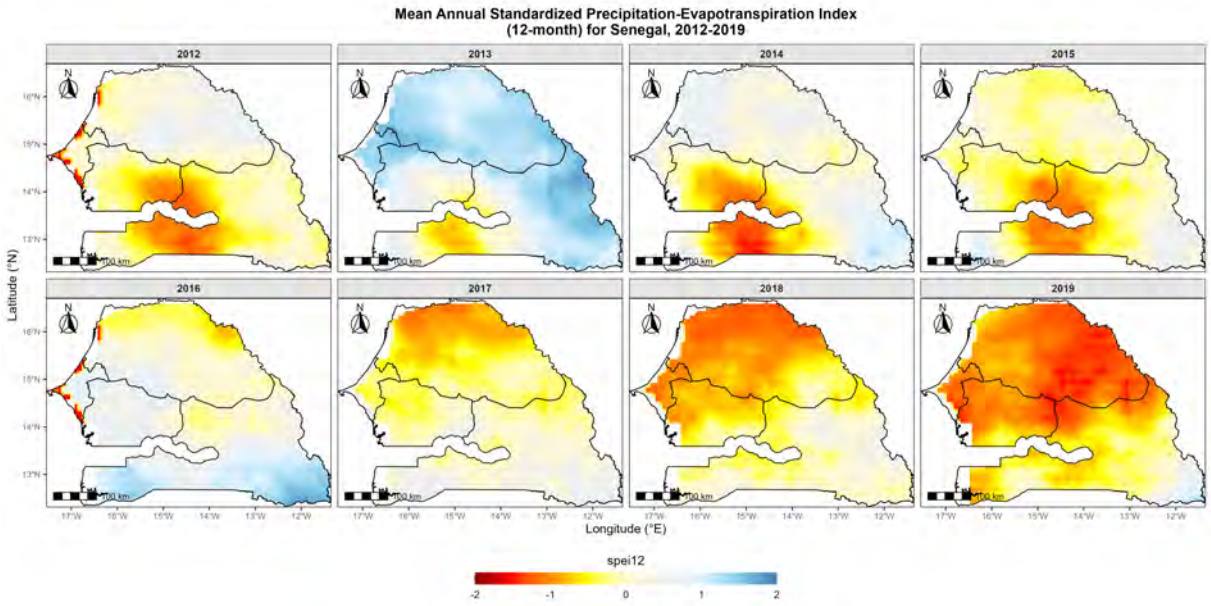
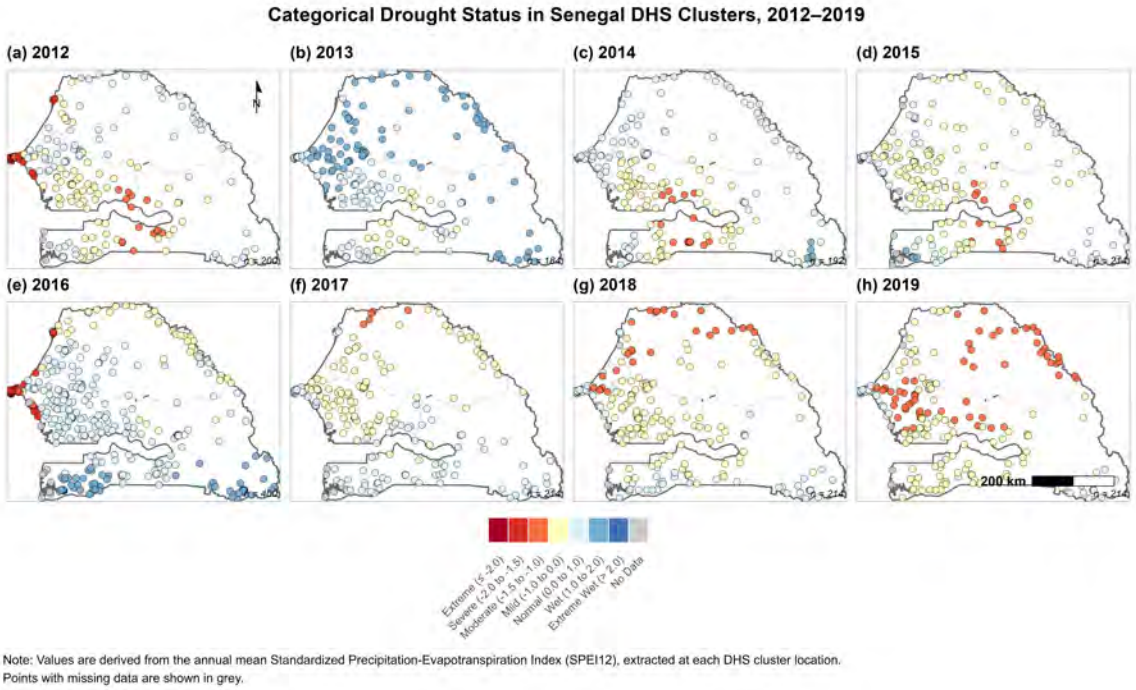


Figure 1: Annual Drought Exposure Across Senegal, 2012–2019.

Data source: CHIRPS–GLEAM, SPEI-12 index.



Note: Values are derived from the annual mean Standardized Precipitation-Evapotranspiration Index (SPEI12), extracted at each DHS cluster location.
Points with missing data are shown in grey.

Figure 2: Annual Drought Exposure across DHS Clusters in Senegal, 2012–2019.

Data source: CHIRPS–GLEAM, SPEI-12 index, DHS Program.

significantly better than the regional averages of 861 deaths per 100,000 in West and Central Africa in 2020 (United Nations Children's Fund (UNICEF) 2025). According to Negash et al. (2025), 97.6% of pregnant women in Senegal have at least one visit for antenatal care, and 74.9% have four or more appointments. This makes Senegal a model for maternal health. However, drought during pregnancy still significantly elevates the risk of low birthweight by 54% in nations with inadequate health systems (Abiona and Ajefu 2023). This study finds that there are no significant in-utero effects on a child's HAZ in Senegal, which may be partly due to the country's superior maternal health.

There are three levels of healthcare: community health posts supply basic care, district health centers give secondary care, and regional and national hospitals give specialized care (Paul et al. 2020). However, resource distribution is significantly uneven. 60% of the population resides in rural areas, yet only 24% of physicians practice in these regions (Honda et al. 2019). The government encounters difficulties in retaining physicians in remote regions, even with the implementation of rural allowances and bonding schemes (Ly, Labonté and Bourgeault 2019).

The private sector is vital but unevenly distributed. While private facilities comprise a small portion of Senegal's healthcare system, they are disproportionately concentrated in the capital. As a result, Dakar has a higher concentration of private health services than any other region (Paul et al. 2020; Barnes et al. 2016). Private clinics maintained crucial services during the COVID-19 pandemic, demonstrating the importance of the private sector (Exemplars in Global Health 2025; Kabwama et al. 2022). The government has engaged private actors in health initiatives (such as the universal health coverage scheme, Couverture Maladie Universelle), recognising that they are important to reaching health goals (Paul et al. 2020).

Since 1999, Senegal has implemented the Integrated Management of Childhood Illness (IMCI), training health workers to diagnose and treat major childhood diseases using integrated protocols (Exemplars in Global Health 2025). In 2013, a policy was enacted to provide some free healthcare for children under five at public facilities. Furthermore, normal childbirth services were made free nationwide as a result of a 2012 initiative (Paul et al. 2020).

3.3 Nutrition Interventions

During drought crises, nutrition surveillance systems identify high-risk areas, enabling rapid deployment of mobile health teams and emergency food supplements before malnutrition spikes. International agencies and NGOs coordinate many emergency responses (Vaillancourt 2016).

In addition to crisis response, international partnerships have enhanced Senegal's ability to deal with undernutrition and strengthen resilience prior to drought events. The World Bank endorsed the Nutrition Enhancement Program, which implemented community-based growth monitoring, counselling, and food supplementation nationwide (Vaillancourt 2016). Interventions successfully reduced the effects of climate shocks on child nutrition (Brar et al. 2020), contributing to Senegal's stunting reduction from 21% to 18% during 2015-2019 despite recurring droughts (Global Nutrition Report 2025; World Bank 2024).

4 Data

This study uniquely links three data sources to investigate the effect of drought exposure on child nutrition, as measured by height-for-age z-scores (HAZ), and to assess whether healthcare quality moderates this relationship in Senegal. Specifically, this study combines repeated cross-sectional data from the Demographic and Health Surveys (DHS) with high-resolution and gridded drought data from the Hydro-JULES global dataset (specifically, the Standardized Precipitation-Evapotranspiration Index, SPEI) and six regional healthcare quality indicators calculated from Service Provision Assessments (SPA). The final dataset covers 24,857 children surveyed between 2012 and 2019 across 400 georeferenced DHS clusters, providing rich spatial and temporal variation.

4.1 Data Sources

The Demographic and Health Surveys (DHS) program provides standardised, nationally representative, and repeated cross-sectional data on population, health, and nutrition. Since its launch in 1984, the program, primarily funded by USAID, has conducted over 400 surveys in more than 90 low- and middle-income countries, making it a cornerstone of global health research.

This study uses Senegal DHS's Children's Recode (KR) data, which contain full records for all children under five born to interviewed women. Each observation includes comprehensive socioeconomic statistics, including child characteristics (anthropometric measurements, sex, birth order, and singleton status), maternal attributes (age at birth and education), and household conditions (wealth quintile, urban/rural residence, and household size).

The finest geographic unit in the DHS is the survey cluster, for which GPS coordinates are provided. While the DHS's standard confidentiality protocol intentionally introduces spatial measurement error by randomly displacing these locations, up to 2 kilometers for urban clusters and up to 5 kilometers for rural clusters, with 1% of rural clusters displaced up to 10 kilometers (Burgert et al. 2013). The cluster level remains the best available and most appropriate spatial resolution for integrating external datasets.

The Standardised Precipitation-Evapotranspiration Index (SPEI) serves as the primary measure of drought exposure in this study. SPEI is a multi-scalar drought index that incorporates both precipitation and potential evapotranspiration to provide a comprehensive assessment of water balance conditions. Gebrechorkos et al. (2023) developed four high-resolution (0.05°) gridded drought records based on the Standardized Precipitation-Evaporation Index (SPEI) for the period 1981–2022. The dataset provides monthly SPEI values across multiple timescales (1 to 48 months) and has been globally validated. It shows excellent agreement with ground-based SPEI estimates as well as with key environmental indicators. Different timescales capture different drought periods: short timescales (1-3 months) reflect agricultural drought and immediate soil moisture conditions, while long timescales (12-48 months) represent hydrological and groundwater drought affecting long-term water resources.

This study utilises the CHIRPS-GLEAM dataset, which combines high-resolution precipitation

(CHIRPS) and potential evapotranspiration (GLEAM). From this, two SPEI metrics are used to capture drought exposure during distinct developmental windows: SPEI-09 for the in utero period and SPEI-24 for the first 24 months of life. This choice of windows aligns with the "first 1,000 days" framework, which identifies the period from conception through age two as critical for a child's development and the key window during which stunting occurs (Black et al. 2013). The choice of these timescales is deliberate. SPEI-09 aligns with the nine-month gestation period, capturing the climate conditions experienced throughout pregnancy. SPEI-24 measures the cumulative water balance during the initial 24 months of a child's life, which is important for finding long-term droughts and how they affect child stunting. This longer window also smooths short-term weather fluctuations while effectively capturing prolonged climate deficits. To assign these measures, in utero exposure is taken as the SPEI-09 value in the child's month of birth. Early-life exposure is the SPEI-24 value in the child's 24th month of life.

Service Provision Assessments (SPA) is a comprehensive assessment of quality of care provision measured in health facilities across a country. SPA have been conducted by The Demographic and Health Surveys (DHS) Program and supported by United States Agency for International Development (USAID) since 1997 thus allowing examination of trends in certain countries. The SPA assesses the availability and Quality of Care (QoC) for healthcare services, focusing on antenatal care (ANC), family planning (FP), maternity care, and sick child services.

Drawing on the framework of Simmons, Anthopolos and O'Meara (2021), this study extracts the same six indicators to measure healthcare quality and cost. These indicators are generated at the regional-year level, as this is the best resolution at which a panel dataset can be constructed from the SPA surveys. Each indicator is computed as a facility-weighted proportion, producing robust, time-varying measures of the local health environment.

4.2 Sample

Senegal was selected as the setting for this study due to the unique combination of data availability and high climatic relevance. The primary advantage is the valuable availability of annual, repeated cross-sectional data from both the Demographic and Health Surveys (DHS) and the Service Provision Assessment (SPA) for the period 2012–2019 (Agence Nationale de la Statistique et de la Démographie (ANSD) [Senegal] and ICF International 2012–2019). This continuous flow of data from Senegal is remarkably unique. Many Sub-Saharan African nations possess only one or two waves of the Service Provision Assessment (SPA) survey, making it very difficult to track temporal changes. Senegal's multi-wave data enable the development of a time-varying panel of healthcare quality indicators. This enables time-aligned-to-exposure matching of the healthcare context to each child's distinct drought exposure period (in utero; 0–24 months).

The initial dataset contained 400 DHS clusters and 59235 raw observations. The final sample consists only of observations having complete records for essential variables. This excluded observations with missing anthropometric measurements, incomplete or out-of-range birth dates, younger than 3 months, and those falling outside the data coverage period. This process resulted in a final analytical sample of 24,857 children.

4.3 Variable Definitions

The outcome is height-for-age z-scores (HAZ), measured and calculated using the WHO 2006 growth standards, which compare each child's height to the median of a healthy reference population of the same age and sex in the DHS survey (WHO Multicentre Growth Reference Study Group 2006). Lower values indicate potential undernutrition. Following standard practice in the nutrition literature, this process excludes observations with biologically implausible HAZ values outside the range [-6, 6], which is likely due to measurement or recording errors. This continuous measure of height captures the cumulative impact of chronic nutritional deficiency, making it particularly suitable for studying long-term drought effect on children's nutrition.

Treatments are defined as two primary drought exposure variables based on distinct growing windows for each child i, born in time y and living in cluster c. First, *in utero drought* ($\text{Drought}^{\text{InUtero}}_{ic,y-9m}$) is a binary indicator equal to 1 if the SPEI-09 value, capturing conditions over the nine months preceding a child's birth time y, falls below –1. Second, *early-life drought* ($\text{Drought}^{\text{EarlyLife}}_{ic,y}$) is a binary indicator equal to 1 if the SPEI-24 value, capturing conditions over the 24 months following birth, falls below –1.

There are six healthcare quality indicators ($\text{HealthQuality}_{k,ry}$) at the region-year level: (1) the proportion of facilities under private ownership in the given region; (2) the proportion of facilities with at least one doctor in the given region; (3) the proportion of facilities with child health providers trained in Integrated Management of Childhood Illness (IMCI) protocols in the given region; (4) the proportion of facilities charging fees for routine consultations in the given region; (5) the proportion of facilities charging fees for childhood immunizations in the given region; and (6) the proportion of facilities charging fees for regular birth deliveries in the given region. Control Variables ($\mathbf{X}_{ict}$) are included at the child, maternal, and household levels. Child characteristics comprise age in months at interview, sex, birth order, and singleton birth status. Maternal characteristics include the mother's age at birth and educational attainment. Household characteristics include wealth quintile from the DHS-provided asset-based index, an urban/rural residence indicator, and household size.

4.4 Spatial Data Integration

This study calculated region-by-year health system quality indicators by aggregating facility-level metrics from the SPA surveys. The child-level DHS data were combined with these indicators to reflect two exposure periods. First, indicators were matched by region and second year of life to measure early life healthcare. Second, birth time and region were used to match indicators to capture gestational circumstances. Due to DHS migration history restrictions, this study proxies birthplace with survey cluster location, as is common in the literature.

To calculate individual drought exposure, a multi-step process was implemented for linking geocoded DHS cluster locations with gridded monthly climate data from two SPEI accumulation indices: SPEI-09 and SPEI-24. The SPEI data, originally covering all of Africa at 0.05° resolution, was subset to the Senegal region. Then extract the entire record of climate information

of each cluster for the research period. The spatial matching process employed a progressive search strategy to maximize coverage while maintaining data quality. For each of the 400 DHS clusters, the process first attempted to extract SPEI values at the nearest grid point. Due to missing values concentrated in the northern boundary region—where Senegal borders Mauritania and the Sahara Desert—data gaps were not randomly distributed but correlated with arid zones that experience more extreme and persistent drought conditions. Therefore, when this yielded insufficient data (less than 50% coverage), the buffering search expanded to average values within 5km and then 10km radius buffers. This approach successfully matched all 400 clusters with climate data: 347 clusters (86.8%) through nearest-point extraction, 7 clusters (1.8%) using 5km buffers, and 46 clusters (11.5%) using 10km buffers.

Later, child-specific drought exposures were calculated using SPEI values at critical developmental time points. For in utero exposure, SPEI-09 values were used at the child's birth month, which reflect cumulative climate conditions over the nine months preceding birth. For early childhood exposure, SPEI-24 values were extracted at 24 months of age (or at the interview date for younger children), representing cumulative conditions over the 24 months from birth to age two. A binary moderate drought experience is defined as 1 if the SPEI value falls below -1.

4.5 Descriptive Statistics

This analysis exploits a multi-level data structure that spans three nested levels of observation. At the individual-child level, the outcome is the height-for-age z-score (HAZ), and additional covariates are included to capture each child's demographics, maternal characteristics, and household context. The drought exposure based on SPEI is measured for each child at the DHS cluster level. At the regional level, six healthcare-quality indicators from the SPA, which vary by region and year, are used to test for moderation effects.

Table 1 provides summary statistics for the analysis sample containing 24,857 children. The mean height-for-age z-score (HAZ) of -1.019 indicates considerable stunting within the sample. Drought indicators are binary variables (1 = exposed to moderate drought, SPEI < -1), with 15.7% of individuals exposed in utero and 18.7% during early life. Child characteristics indicate a balanced gender distribution, with 49.7% female participants and an average age of around 25 months at the time of the interview. Maternal education level is categorized as follows: 1 = none, 2 = primary, 3 = secondary, 4 = higher secondary, and 5 = other. The average level of education is low. The wealth quintile ranges from 1 (poorest) to 5 (richest), with a mean of 2.37, suggesting a poorer sample. Urban residence constitutes 29.6% of the sample, reflecting population distribution.

Figure 3 shows that each colored line denotes a region in Senegal, monitoring variations in six healthcare quality metrics from 2012 to 2019. The main patterns observed are the low availability of private facilities (4.8% at 24 months of age), the limited presence of doctors (8.4%), and the prevalence of routine fee charging (92.7%). The sample size decreases to 23,473 for assessing healthcare quality during the gestational year, due to data availability constraints.

Table 1: Descriptive Statistics

Variable	N	Mean	SD	Min	Max
Outcome Variable					
Height-for-Age Z-score	24,857	-1.019	1.267	-5.890	5.900
Treatment Variables					
In Utero Drought (Moderate)	24,857	0.157	0.364	0.000	1.000
Early Life Drought (Moderate)	24,857	0.187	0.390	0.000	1.000
Child Characteristics					
Child Age (months)	24,857	25.080	15.733	3.000	59.000
Female Child	24,857	0.497	0.500	0.000	1.000
Birth Order	24,857	3.601	2.328	1.000	14.000
Singleton Birth	24,857	0.964	0.186	0.000	1.000
Maternal Characteristics					
Mother's Age at Birth	24,857	27.555	6.753	14.000	49.000
Mother's Education Level	24,857	1.466	0.743	1.000	5.000
Household Characteristics					
Household Size	24,857	15.107	8.724	2.000	90.000
Wealth Quintile (1-5)	24,857	2.369	1.263	1.000	5.000
Urban Residence	24,857	0.296	0.456	0.000	1.000
Healthcare Quality (24 months)					
Prop. Private Facilities	24,857	0.048	0.081	0.000	0.946
Prop. Facilities with Doctor	24,857	0.084	0.068	0.000	0.500
Prop. Staff IMCI Trained	24,857	0.047	0.035	0.000	0.152
Prop. Charging Routine Fees	24,857	0.927	0.067	0.609	1.000
Prop. Charging Vaccine Fees	24,857	0.021	0.055	0.000	1.000
Prop. Charging Delivery Fees	24,857	0.516	0.303	0.000	1.000
Healthcare Quality (Birth Year)					
Prop. Private Facilities	23,473	0.057	0.120	0.000	0.946
Prop. Facilities with Doctor	23,473	0.084	0.062	0.000	0.500
Prop. Staff IMCI Trained	23,473	0.040	0.031	0.000	0.152
Prop. Charging Routine Fees	23,473	0.924	0.075	0.609	1.000
Prop. Charging Vaccine Fees	23,473	0.109	0.234	0.000	1.000
Prop. Charging Delivery Fees	23,473	0.565	0.318	0.000	1.000

Notes: Descriptive statistics for the analysis sample.

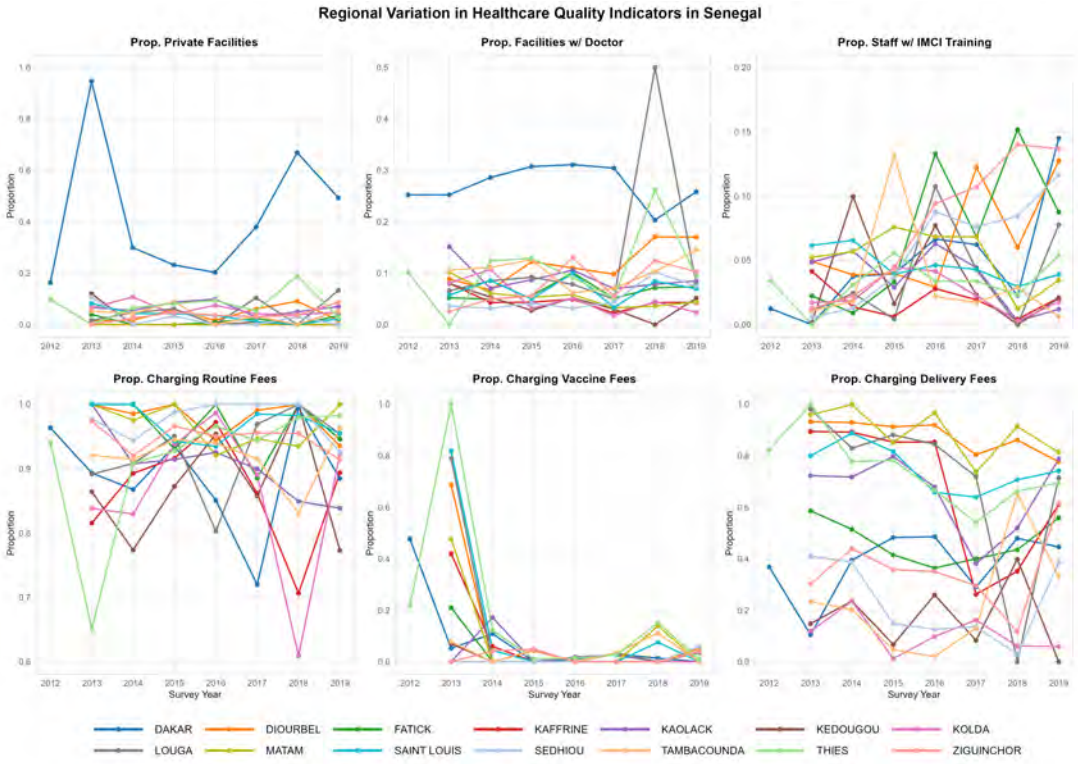


Figure 3: Regional Variation in Healthcare Quality Indicators in Senegal.
Data source: SPA Survey.

5 Empirical Strategy

This study examines healthcare moderation through disease and economic pathways. During drought, unsafe water consumption increases waterborne illness while reduced agricultural income constrains healthcare expenditure (Mehar, Mittal and Prasad 2016). Capturing these mechanisms requires measuring healthcare quality time-aligned to exposure, because illness risks rise immediately when water becomes scarce or unsafe and hygiene deteriorates.

Senegal's unique combination of repeated DHS and SPA surveys enables this time-aligned measurement. Since survey-year healthcare (typically 1–3 years later) may reflect drought-induced changes like investments, migration, or infrastructure expansion, aligning healthcare with exposure minimizes spatiotemporal mismeasurement. Moreover, effect modifiers should be measured before or during exposure, not afterwards, ensuring causal interpretation. Therefore, Model 3a uses gestational healthcare to test the moderation of in utero drought, while Model 3b uses second-year healthcare for early-life drought (0-24 months). This temporal precision ensures interaction coefficients identify actual moderation effects.

5.1 Model Specifications

In order to estimate the impact of drought exposure on child linear growth, empirical analysis begins with a baseline specification that captures the direct effects of drought in early life and in utero. Following Shah and Steinberg (2017), two drought exposure windows will be combined. Model 1 provides clean estimates of baseline drought effects. All models control for a rich set of

covariates while absorbing unobserved heterogeneity through three sets of fixed effects. Cluster fixed effects control for time-invariant geographic characteristics, such as soil quality, location, climate, and historical development. Birth season fixed effects account for seasonal patterns in agricultural and climate cycles, disease burden, and food availability that affect children born in different months. Survey year fixed effects control for temporal shocks and policy changes affecting all children surveyed in a given year, such as healthcare policies, national nutrition programs, and macroeconomic conditions that impact food prices. This approach ensures that drought impacts are not confounded with temporal trends; however, survey year fixed effects may absorb variation from recently exposed, younger children whose drought experience overlaps with the survey timing. Robustness test 7 therefore excludes survey year fixed effects to verify that results are not sensitive to this choice.

Model 2 extends the baseline by controlling for regional healthcare quality. By incorporating early life healthcare indicators, this model examines whether areas with improved health infrastructure are linked to the effects of drought on children's HAZ.

Finally, Models 3a and 3b introduce interaction terms between drought exposure and healthcare quality to assess the moderation effects. Model 3a interacts in-utero drought with gestational health quality, while Model 3b interacts the early life (0-24 months) drought with health indicators at the second year of life. Since drought variation provides quasi-random shocks, the interaction coefficients δ_k can identify the moderating effects of healthcare quality on drought impacts.

Model 1: Baseline Drought Effects

$$HAZ_{icryt} = \alpha + \beta_1 \, Drought_{ic,y-9m}^{\text{InUtero}} + \beta_2 \, Drought_{ic,y}^{\text{EarlyLife}} + \theta \mathbf{X}'_{icyt} + \mu_c + \lambda_s + \tau_t + \varepsilon_{icryt} \quad (1)$$

Model 2: Drought Effects with Healthcare Quality Controls

$$\begin{aligned} \text{HAZ}_{icryt} = \alpha + \beta_1 \, Drought_{ic,y-9m}^{\text{InUtero}} + \beta_2 \, Drought_{ic,y}^{\text{EarlyLife}} + \gamma_k \, HealthQuality_{k,r,y+2} \\ + \theta \, \mathbf{X}'_{icyt} + \mu_c + \lambda_s + \tau_t + \varepsilon_{icryt} \end{aligned} \quad (2)$$

Model 3a: Gestational Period Moderation

$$\begin{aligned} HAZ_{icryt} = \alpha + \beta_1 \, Drought_{ic,y-9m}^{\text{InUtero}} + \beta_2 \, Drought_{ic,y}^{\text{EarlyLife}} + \gamma_k \, HealthQuality_{k,ry} \\ + \delta_k \left(Drought_{ic,y-9m}^{\text{InUtero}} \times HealthQuality_{k,ry} \right) + \mathbf{X}'_{icyt} \, \theta + \mu_c + \lambda_s + \tau_t + \varepsilon_{icrt} \end{aligned} \quad (3)$$

Model 3b: Early-Life Period Moderation

$$HAZ_{icryt} = \alpha + \beta_1 Drought^{\text{InUtero}}_{ic,y-9m} + \beta_2 Drought^{\text{EarlyLife}}_{ic,y} + \gamma_k HealthQuality_{k,r,y+2} + \delta_k \left(Drought^{\text{EarlyLife}}_{ic,y} \times HealthQuality_{k,r,y+2} \right) + \mathbf{X}'_{icyt}\theta + \mu_c + \lambda_s + \tau_t + \varepsilon_{icrt} \quad (4)$$

To clarify notations used in the empirical specifications, HAZ_{icryt} denotes the height-for-age z-score (HAZ) of child i in cluster c, region r, born in time y, and observed in survey year t. The key explanatory variables are $Drought^{\text{InUtero}}_{ic,y-9m}$, the moderate drought indicator for child i during the nine-month in utero period, and $Drought^{\text{EarlyLife}}_{ic,y}$, the drought exposure experienced during the 24 months after birth time y.

Models 2 and 3 incorporate regional healthcare quality indicators to examine both direct effects and moderating relationships. These indicators are denoted as $HealthQuality_{k,r,y}$ for indicator k in region r in birth year y (for in utero exposure), and $HealthQuality_{k,r,y+2}$ for the healthcare quality when the child is 2 years old (for early-life period). To test whether healthcare quality can moderate drought's adverse effects, two sets of interaction terms are used. First, Model 3a interacts in utero drought exposure with gestational healthcare quality: $Drought^{\text{InUtero}}_{ic,y-9m} \times HealthQuality_{k,r,y}$. This tests whether exposure-aligned healthcare quality during pregnancy can buffer prenatal shocks. Second, Model 3b interacts early-life drought exposure with second-year healthcare quality: $Drought^{\text{EarlyLife}}_{ic,y} \times HealthQuality_{k,r,y+2}$. This specification examines whether healthcare quality available when the child is 2 years old can help children recover from drought shocks experienced during the first two years of life.

All models control for a vector of covariates $\mathbf{X}'_{icyt}$ for the child's age, birth order, singleton status, mother's age at birth and education level, household size, wealth quintile, and urban residence. To account for unobserved heterogeneity, the model also includes cluster fixed effects μ_c, birth-season fixed effects λ_s, and survey–year fixed effects τ_t. The disturbance ε_{icrt} is clustered at the DHS cluster level.

5.2 Robustness Checks

Robustness tests are employed to address three key methodological challenges. Firstly, alternative SPEI thresholds are assessed to validate drought measurements. Binary variables are then replaced with categorical variables, and monthly exposure based on SPEI-01 can be calculated to capture cumulative effects. Second, to alleviate potential endogeneity, controls for nutritional aid programs (including Plumpy'doz supplementation, maternal iron, and infant vitamin A) are employed despite sample limitations, and total effects models are estimated to isolate each exposure window. Third, studies are conducted across wealth categories, gender, and urban-rural residence to assess heterogeneity.

Robustness Test 1: Controlling Aid Programs

Due to data restrictions of 8,038 observations, nutritional supplementation is only used for robustness tests. These controls include Plumpy'doz (ready-to-use supplementary food), maternal

iron supplementation throughout pregnancy, and 6-month infant vitamin A supplementation. Including aid programs addresses two competing mechanisms: if aid successfully targets drought areas, controlling for it should reveal larger underlying drought damages; if both aid and healthcare target similar populations, multicollinearity could reduce the healthcare moderation effect.

Robustness Test 2: Drought Intensity Categories

In this test, the binary moderate drought indicator is substituted with a categorical definition (none/moderate/severe) to examine dose-response relationships. The binary specification may hide important nonlinearities if severe drought causes qualitatively different coping mechanisms or overwhelms healthcare buffers.

Robustness Test 3: Total Effects Models

This test estimates separate models for in utero and early-life drought to identify total effects for each exposure period without controlling for the other. This addresses two concerns: first, it enables comparison with existing literature that typically examines only one exposure window; second, it avoids potential over-controlling if in utero drought affects early-life vulnerability (a mediating pathway). The main specification includes both exposure windows simultaneously to prevent omitted variable bias and isolate the independent effect of each period. In contrast, this robustness test runs separate models to capture each period's total effect.

Robustness Test 4: Alternative Thresholds for Drought Definitions

This test varies the definition of drought by employing SPEI thresholds of -0.8 (mild), -1.0 (moderate), -1.2 (moderate+), and -1.5 (severe) to evaluate sensitivity and allow comparisons across different cutoffs. Evaluating different thresholds determines whether health effects follow a linear dose-response relationship or exhibit threshold effects.

Robustness Test 5: Cumulative Monthly Exposure and Marginal Effects

This test replaces binary indicators with continuous measures counting months of drought exposure using SPEI-01, following Freudenreich, Aladysheva and Brück (2022). While SPEI-09 and SPEI-24 capture persistent drought (affecting 18.7% and 15.7% of children for early-life and in utero periods, respectively), averaging SPEI-01 values over 24 months never reaches -1 even for children experiencing 14 drought months (mean = -0.67). This averaging masks substantial variation: 82.6% of children experienced at least one drought month, with 19.2% facing more than 6 months in the early-life period. Therefore, counting experienced drought months is better than averaging SPEI-01 over 24 months. Using monthly counts from SPEI-01 preserves the variation, allowing tests of whether health impacts accumulate linearly with each additional month of drought.

Robustness Test 6: Heterogeneity by Wealth, Gender and Residence

This test employs regression models based on household wealth terciles, child gender, and rural/urban residency to identify vulnerable groups. Evaluate if socioeconomic status affects healthcare moderation and drought impacts across groups.

Robustness Test 7: Excluding Survey Year Fixed Effects

Since early-life drought exposure (0-24 months) may overlap with survey timing for younger children, survey-year fixed effects could potentially over-control for recent drought impacts. This

test excludes survey year fixed effects while retaining cluster and birth season fixed effects to compare those two approaches.

6 Results

6.1 Main Regression Results

Table 2 presents the estimated effects of moderate drought exposure from Models 1 and 2. Early-life drought (0–24 months) has a consistently negative and highly significant influence on children's HAZ, with coefficients ranging from −0.083 to −0.089. A moderate drought in the first 24 months of life reduces HAZ by 0.087 standard deviations in the Table 2 model (1). In contrast, in utero drought exposure exhibits no significant coefficients close to zero (−0.001 to −0.003), indicating no evidence of long-term impacts on linear growth. This null finding could result from maternal buffering during pregnancy, which protects the fetuses from moderate drought. Another explanation is selective survival, where only the most resilient fetuses or newborns survive under the drought. Alternatively, the possibility exists that in utero effects manifest through pathways not captured in later HAZ measurements.

Analysis of healthcare quality indicators reveals that the proportion of facilities with doctors shows the most significant positive correlation with HAZ (0.425, $p < 0.01$ in Model 2). The introduction of routine and delivery fees are positively correlated with HAZ (0.281, $p < 0.10$ and 0.200, $p < 0.01$), likely reflecting the quality of services. Charging vaccine fees is negatively associated with HAZ (−0.405, $p < 0.05$ in Model 2). Private facilities show positive but non-significant main effects (0.192 in Model 2).

Socioeconomic characteristics demonstrate significant and logical associations with HAZ. Children from wealthy families exhibit higher HAZ, with each wealth quintile associated with significantly higher values. Maternal education shows a positive correlation; children of mothers with primary, secondary, or higher education exhibit significantly higher HAZ than those with no education. Female children exhibit superior outcomes relative to males, and singleton births show significantly higher HAZ compared to multiple births. Birth order and child age are negatively correlated with HAZ. Later-born children in bigger families are associated with lower HAZ. The age of the mother at childbirth positively correlates with children's HAZ, while household size has a modest negative link, and urban residence has no significant effect on HAZ.

Table 3 reports whether healthcare quality during gestation moderates in utero drought impacts. None of the six healthcare quality indicators shows significant moderating effects, consistent with the null main effect of in utero drought.

Table 4 reveals significant healthcare moderation of early-life drought impacts, as measured at the child's 24th month. Private facility share provides protection. The interaction coefficient of 0.536 ($p < 0.10$) indicates that a 10 percentage-point increase in private facilities reduces drought damage on HAZ by 0.054 standard deviations. Conversely, the prevalence of routine fees worsens the impact of drought ($\beta = -0.526$, $p < 0.10$), meaning a 10 percentage-point increase in the prevalence of facilities imposing routine fees intensifies drought penalties by 0.053

Table 2: Models 1 & 2: Drought Effects

	Dependent variable: Height-for-age Z-score (HAZ)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treatment Variables							
In Utero Drought (Moderate)	-0.001	-0.001	-0.001	-0.001	-0.003	-0.003	-0.001
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Early Life Drought (Moderate)	-0.087***	-0.084***	-0.088***	-0.087***	-0.084***	-0.089***	-0.083***
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Healthcare Quality Indicators (24th Month)							
Prop. Private Facilities		0.192					
		(0.144)					
Prop. Facilities with Doctor			0.425***				
			(0.164)				
Prop. Staff IMCI Trained				-0.052			
				(0.290)			
Prop. Charging Routine Fees					0.281*		
					(0.156)		
Prop. Charging Vaccine Fees						-0.405**	
						(0.185)	
Prop. Charging Delivery Fees							0.200***
							(0.046)
Child Characteristics							
Child Age (months)	-0.009***	-0.009***	-0.009***	-0.009***	-0.009***	-0.009***	-0.009***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Female Child	0.120***	0.120***	0.120***	0.120***	0.120***	0.120***	0.121***
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
Birth Order	-0.021***	-0.020***	-0.020***	-0.021***	-0.021***	-0.021***	-0.021***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Singleton Birth	0.776***	0.775***	0.777***	0.776***	0.775***	0.777***	0.779***
	(0.056)	(0.056)	(0.056)	(0.056)	(0.056)	(0.056)	(0.056)
Maternal Characteristics							
Mother's Age at Birth	0.013***	0.013***	0.012***	0.013***	0.013***	0.013***	0.013***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Mother Edu: Primary	0.088***	0.087***	0.087***	0.088***	0.088***	0.088***	0.093***
	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)
Mother Edu: Secondary	0.123***	0.123***	0.123***	0.123***	0.123***	0.123***	0.133***
	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)
Mother Edu: Higher	0.293***	0.289***	0.290***	0.293***	0.296***	0.292***	0.308***
	(0.070)	(0.070)	(0.070)	(0.070)	(0.070)	(0.070)	(0.070)
Mother Edu: Other	0.070	0.003	0.105*	0.069	0.038	0.065	0.067
	(0.054)	(0.074)	(0.056)	(0.055)	(0.058)	(0.055)	(0.055)
Household Characteristics							
Wealth: 2nd Quintile	0.168***	0.167***	0.166***	0.168***	0.166***	0.168***	0.160***
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.024)	(0.023)
Wealth: 3rd Quintile	0.355***	0.353***	0.351***	0.355***	0.353***	0.357***	0.338***
	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.029)
Wealth: 4th Quintile	0.515***	0.509***	0.503***	0.515***	0.513***	0.518***	0.488***
	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)
Wealth: Richest Quintile	0.741***	0.729***	0.720***	0.741***	0.742***	0.747***	0.710***
	(0.047)	(0.047)	(0.046)	(0.047)	(0.047)	(0.047)	(0.047)
Urban Residence	0.040	0.039	0.038	0.040	0.043	0.041	0.048
	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)
Household Size	-0.003**	-0.003**	-0.003**	-0.003**	-0.003***	-0.003***	-0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Fixed Effects							
Cluster	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics							
Observations	24,857	24,857	24,857	24,857	24,857	24,857	24,857
R^2	0.111	0.111	0.112	0.111	0.112	0.112	0.112
Within R^2	0.061	0.061	0.062	0.061	0.061	0.062	0.063

Notes: The dependent variable is Height-for-age z-score (HAZ). Model (1) shows the baseline specification without healthcare quality. Models (2)–(7) separately add healthcare quality indicators measured at 24 months. Reference categories: male child, non-singleton birth, no maternal education, poorest wealth quintile, rural residence. All models include cluster, survey year, and birth season fixed effects. Standard errors clustered at DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

Table 3: Model 3a: Gestational Healthcare as Moderator

	Dependent variable: Height-for-age Z-score (HAZ)					
	(1)	(2)	(3)	(4)	(5)	(6)
Main Variables						
In Utero Drought	0.019	0.060	0.034	0.291	0.012	0.003
	(0.029)	(0.042)	(0.044)	(0.318)	(0.027)	(0.055)
Early Life Drought	-0.093***	-0.095***	-0.095***	-0.096***	-0.096***	-0.090***
	(0.026)	(0.025)	(0.026)	(0.026)	(0.026)	(0.025)
Healthcare Quality Indicators (Birth Year)						
Prop. Private Facilities	0.098					
	(0.093)					
Prop. Facilities with Doctor		0.230				
		(0.231)				
Prop. Staff IMCI Trained			-0.328			
			(0.378)			
Prop. Charging Routine Fees				-0.165		
				(0.143)		
Prop. Charging Vaccine Fees					0.183***	
					(0.043)	
Prop. Charging Delivery Fees						0.184***
						(0.051)
In Utero × Healthcare Quality						
In Utero × Private Facilities	-0.240					
	(0.285)					
In Utero × Doctor Availability		-0.606				
		(0.380)				
In Utero × IMCI Trained			-0.645			
			(0.772)			
In Utero × Routine Fees				-0.309		
				(0.346)		
In Utero × Vaccine Fees					0.110	
					(0.172)	
In Utero × Delivery Fees						0.008
						(0.088)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
Cluster	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics						
Observations	23,473	23,473	23,473	23,473	23,473	23,473
R^2	0.114	0.114	0.114	0.114	0.114	0.115
Within R^2	0.062	0.062	0.062	0.062	0.062	0.063

Notes: Testing whether healthcare quality at gestation moderates in utero drought effects. The dependent variable is Height-for-age z-score (HAZ). Each column represents a different healthcare quality indicator and its interaction with in utero drought: (1) private facilities, (2) doctor availability, (3) IMCI training, (4) routine fees, (5) vaccine fees, (6) delivery fees. All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at the DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

Table 4: Model 3b: Early life Healthcare as Moderator

	Dependent variable: Height-for-age Z-score (HAZ)					
	(1)	(2)	(3)	(4)	(5)	(6)
Main Variables						
In Utero Drought	-0.001	-0.001	-0.001	-0.004	-0.002	-0.000
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Early Life Drought	-0.110***	-0.109***	-0.087**	0.401	-0.085***	-0.112**
	(0.029)	(0.039)	(0.042)	(0.289)	(0.026)	(0.045)
Healthcare Quality Indicators (24th Month)						
Prop. Private Facilities	0.126					
	(0.152)					
Prop. Facilities with Doctor		0.363*				
		(0.192)				
Prop. Staff IMCI Trained			-0.052			
			(0.314)			
Prop. Charging Routine Fees				0.407**		
				(0.182)		
Prop. Charging Vaccine Fees					-0.375**	
					(0.191)	
Prop. Charging Delivery Fees						0.190***
						(0.047)
Early Life × Healthcare Quality						
Early Life × Private Facilities	0.536*					
	(0.278)					
Early Life × Doctor Availability		0.222				
		(0.306)				
Early Life × IMCI Trained			0.002			
			(0.647)			
Early Life × Routine Fees				-0.526*		
				(0.311)		
Early Life × Vaccine Fees					-0.200	
					(0.448)	
Early Life × Delivery Fees						0.057
						(0.081)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
Cluster	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics						
Observations	24,857	24,857	24,857	24,857	24,857	24,857
R^2	0.112	0.112	0.111	0.112	0.112	0.113
Within R^2	0.062	0.062	0.061	0.062	0.062	0.063

Notes: Testing whether healthcare quality at 24 months old can moderate early life drought effects. The dependent variable is Height-for-age z-score (HAZ). Each column represents a different healthcare quality indicator measured at 24 months and its interaction with early life drought: (1) private facilities, (2) doctor availability, (3) IMCI training, (4) routine fees, (5) vaccine fees, (6) delivery fees. All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at the DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

standard deviations. This different pattern suggests that private facilities with better resources buffer drought effects, but fee requirements burden households during drought.

Overall, healthcare characteristics show heterogeneous moderation effects. Higher private facility rates may protect children from drought. However, charging routine fees worsens drought damage by introducing financial hurdles during crises. This reveals a significant policy paradox: market-based approaches that enhance the accessibility of health systems can exacerbate inequality during crises. Private healthcare's strengths must be combined with financial tools, such as subsidies, to ensure access for vulnerable populations during climatic shocks.

6.2 Robustness Checks Results

Robustness 1 addresses concerns regarding potential confounding from humanitarian aid programs. The sample size consists of 8,038 observations, which is limited by the availability of data, particularly for Plumpy'Doz supplementation, which is only available from 2017 to 2019. Table 5 reveals that controlling for aid programs largely amplifies drought effects. Early-life drought effects increase significantly from -0.087 to -0.194 ($p < 0.01$), whereas in utero effects shift from null to a positive value, yet remain statistically insignificant (0.038, $p > 0.10$). This amplification suggests that aid programs may obscure the actual detrimental impacts of drought in the aid-receiving sample. Aid control patterns are consistent with targeted interventions and reverse causation. Plumpy'doz supplementation shows a negative correlation with HAZ (-0.235, not significant), suggesting the program's focus on malnourished children. The inclusion of vitamin A in the diet has a negative association with growth (-0.062, $p < 0.05$), indicating that individuals at risk were effectively treated. Iron supplementation during pregnancy shows significant favorable effects (0.279, $p < 0.01$), possibly reflecting both its preventive benefits and the potential for selection bias.

Table 6 and Table 7 show that the healthcare moderation effects lose significance when controlling for aid programs, while the drought harms increase. This pattern reveals geographic and socioeconomic disparities. Private facilities are concentrated in urban with affluent households, whereas aid programs primarily focus on historically underdeveloped, drought-prone regions with inadequate healthcare infrastructure. When the analysis focuses on the aid-receiving sample, it is inherently more vulnerable than the complete sample. In this context, the measured impact of drought appears more severe, and the protective effect of healthcare becomes less evident. This reveals a buffering gap, as the most drought-vulnerable populations are isolated from market-based and well-equipped health systems and rely heavily on humanitarian aid. Therefore, the results from the main analysis should be considered as a lower bound of actual effects.

Figure 4 from Robustness 2 examines the dose–response relationship by splitting moderate ($-1.5 \leq \text{SPEI} < -1$) and severe ($\text{SPEI} < -1.5$) drought categories. The baseline models from Table 8 confirm that the main effects of healthcare quality remain consistent with the main analysis. Early-life drought exhibits a monotonic pathway: moderate drought reduces HAZ by 0.085 standard deviations ($p < 0.01$), whereas severe drought exacerbates the reduction to 0.111 standard deviations. However, this estimate lacks statistical significance due to the smaller

sample size. This linear relationship confirms that postnatal growth faltering intensifies with drought severity.

In contrast, in utero exposure demonstrates a complex pattern. Moderate drought shows a slight positive correlation with HAZ (0.030, $p > 0.10$), whereas severe drought has negative impacts (-0.038 SD, $p > 0.10$). This inverted-U pattern likely reflects the presence of two mechanisms in Senegal. First, survivor bias suggests that moderate drought results in selective fetal mortality among the most vulnerable, thereby producing a strongly selected cohort. Robustness test 6 supports this interpretation, as the significant in utero drought effect appears only among richer households (–0.229, p<0.01). Second, Senegal's robust maternal health infrastructure may be capable of safeguarding fetal development during moderate shocks. However, severe drought undermines both mechanisms. Selection becomes less effective, and even strong maternal care and resilient survivors cannot adequately offset extreme deprivation, leading to negative average outcomes. This interpretation aligns with Wang et al. (2025), who document higher infant mortality during severe and prolonged droughts.

Table 9 examines gestational healthcare moderators for in-utero drought. The positive interaction between severe in utero drought and delivery fees (0.172, $p < 0.10$) likely reflects a proxy function rather than genuine protection. Prenatal and neonatal care is usually better at facilities that charge delivery fees. Delivery fees consistently show unexpected positive correlations across specifications because they serve as proxies for healthcare quality and resource availability, rather than as barriers. Table 10 shows considerable protective effects for early-life drought that increase with severity. Private facilities significantly buffer moderate early-life drought impacts (interaction: 0.496, $p < 0.10$), with a 10 percentage-point increase in private share improving drought-exposed children's HAZ by 0.496 standard deviations. For severe drought, the interaction magnitude more than doubles (1.089), though it loses statistical significance, likely due to the limited number of severe drought observations. Delivery fees exhibit a significant positive interaction with severe early-life drought (0.568, $p < 0.05$). Still, this service is not directly related to children after birth, indicating that better-resourced facilities gain increased importance as environmental stress escalates.

Robustness 3 addresses potential over-controlling concern by estimating the total effect of each drought period separately. Table 11 compares total effects (each drought period analysed separately) with the combined specification. The remarkable stability of the coefficients validates the main approach: early-life drought shows virtually identical effects whether estimated alone (-0.0871, $p < 0.01$) or with in utero control (-0.0870, $p < 0.01$). In utero drought remains insignificant in both the single (-0.002) and combined (-0.001) specifications. This independence suggests that the two exposure periods operate through distinct biological pathways rather than early-life drought mediating in utero effects. Healthcare quality indicators maintain consistent associations with HAZ regardless of specification.

Table 12 and Table 13 show consistent results with main analysis. For early-life drought, private facilities maintain strong protective effects (0.537, p < 0.10), nearly identical to specifications that control for in-utero exposure (0.536 in main analysis). The routine fee interaction remains

significantly negative (–0.525, p < 0.10), confirming that fee-based barriers harm drought-exposed children regardless of specification.

Robustness 4 varies the SPEI threshold for defining drought from mild (-0.8) to moderate (-1.0) to moderate plus (-1.2), and severe (-1.5), revealing crucial insights about measurement sensitivity, non-linear relationship, and potential survivor bias. Table 14 exhibits two clear patterns. For early-life drought, effects intensify from mild to moderate thresholds: -0.074 ($p < 0.01$) at SPEI < -0.8, -0.087 ($p < 0.01$) at SPEI < -1.0, peaking at -0.150 ($p < 0.01$) for SPEI < -1.2. However, at the severe threshold (SPEI < -1.5), the effect diminishes to -0.101, which is not statistically significant. This pattern may reflect selective mortality or the reduced sample size at extreme values.

Figure 5 vividly illustrates the striking divergence between in-utero and early-life drought impacts across thresholds. In utero effects are typically null across thresholds, showing negative outcomes only at extreme severity levels. This pattern reflects two mechanisms in Senegal: maternal health systems buffer against mild stress, while moderate stress promotes positive selection through fetal loss; however, severe drought overwhelms both mechanisms. At extreme thresholds, comprehensive prenatal care and selection are insufficient to fully mitigate risks, resulting in observable harm even in resilient pregnancies. This interpretation explains the in utero effects observed in Senegal across drought levels.

Robustness 5 employs continuous drought exposure measures (in months of drought) by counting SPEI-01 rather than using binary indicators. This test uses the 1-month SPEI to capture short-term fluctuations because monthly counts better capture cumulative nutritional stress and provide enhanced statistical power to detect marginal effects and healthcare moderation. The distribution in Figure 6 and Figure 7 reveals distinct exposure patterns: for early-life drought, nearly 30% of children experience zero months, but exposed children show substantial variation (1-15 months). Close to half of the observations have zero in utero exposure, with the remaining children showing peaks at 2 and 4 months, reflecting seasonal conception patterns due to gestational timing.

Table 15 demonstrates that each additional month of early-life drought reduces HAZ by 0.024 standard deviations (p < 0.01). Conversely, marginal in-utero drought shows almost null effect (0.007, p > 0.10), reinforcing that prenatal impacts remain null regardless of measurement approach. Healthcare quality maintains consistent patterns. Table 16 tests gestational healthcare moderation of in-utero drought months. All interactions remain non-significant, like the main analysis. Table 17 reveals the same protective effects for early-life drought. Private facilities show the stronger moderation (interaction: 0.081, p < 0.05), meaning each additional drought month causes 0.008 standard deviations less harm in areas with 10% more private facilities.

Robustness 6 shows complex vulnerability patterns that vary by demographics and exposure time. Table 18 and Table 19 reveal that early-life drought causes consistent harm across most groups (-0.075 to -0.119 SD), with poor children suffering the most (-0.119, $p < 0.01$) and girls more affected than boys (-0.115 vs. -0.074, both $p < 0.05$). Remarkably, in utero drought only harms wealthy children significantly (-0.229, p<0.01; interaction: -0.220, p<0.01). Table 19 formally tests these group differences through interaction models. The in-utero × rich interaction (–0.22,

p < 0.01) confirms that wealthy households uniquely suffer from prenatal drought. Protective mechanisms related to wealth may account for the noted difference. Impoverished populations may exhibit greater survivor bias, as drought conditions can lead to selective fetal loss, resulting in the survival of the most resilient individuals in the analysis. Wealthy families with better resources and healthcare access may have lower fetal mortality rates, which could lead to more births of vulnerable fetuses. Girls are more sensitive to drought in utero (interaction: -0.085, p<0.05). This pattern likely reflects two mechanisms. First, biological vulnerability leads to higher male fetal loss during drought, resulting in positive selection among surviving boys. Second, the remaining gender difference may emerge postnatally when drought-stressed male newborns receive preferential care and resources after birth. During early life (0-24 months), drought harms all groups with no significant differential effect.

Table 20 examines the moderation of gestational healthcare, indicating that routine fees have a negative interaction with in utero drought for wealthy households (-2.281, p<0.05). This suggests that affluent households may reduce prenatal care in response to economic constraints resulting from drought. Table 21 shows notable heterogeneity in early life moderation. Private sector offers significant drought protection for middle-income households (0.979, p<0.01) and urban residents (0.665, p<0.10). Additionally, IMCI-trained staff offer significant support to middle-income families (1.971, p<0.10). However, poor households receive no benefit from either private facilities (-0.444, insignificant) or IMCI-trained staff significantly, despite facing the largest drought penalties. This pattern indicates that vulnerable and underprivileged populations are unable to access market-based and public healthcare during the crisis.

Robustness Test 7 excludes survey year fixed effects while retaining cluster and birth season fixed effects. The core findings remain stable. Table 22 shows that drought coefficients remain stable, changing only slightly in the baseline models—from -0.087 ($p < 0.01$) in the main analysis to -0.073 ($p < 0.01$). Table 23 examines the moderation of gestational healthcare, indicating a similar pattern to the main analysis, with no significant moderation effects. Table 24 highlights differences in early-life moderation. Notably, the protective effect of private facilities actually strengthens (0.638, $p < 0.05$ versus 0.536, $p < 0.10$ in the main analysis), suggesting that the main specification provides conservative estimates. The routine fees interaction loses significance, although the direction remains negative.

7 Discussion and Conclusion

Climate vulnerability in Senegal varies by demographic subgroups and developmental stage. Early life drought (0–24 months) results in a reduction of HAZ by 0.087 standard deviations on average, which exacerbates to 0.119 standard deviations in the poor households. In utero effects are null and non-significant on average, unlike other large-scale studies, such as Le and Nguyen (2021), which finds that in utero drought reduces HAZ by 0.03 standard deviations across 55 low and middle-income countries (1990–2018). Those results may be explained by two factors: Senegal's relatively strong maternal health infrastructure could be protecting fetal

development. Alternatively, droughts may be causing a selective bias in favour of the most resilient fetuses and infants, resulting in a sample of survivors that is, on average, more resilient. In this study, only children from wealthier households exhibit significant growth penalties from in utero drought (–0.229), likely because better resources reduce miscarriage and infant mortality, thereby revealing effects that remain hidden among poorer households due to the selective survival of children.

Healthcare infrastructure demonstrates protective capacity. A 10 percentage point increase in private facility share reduces drought penalties by 0.054 standard deviations during early life, consistent with Simmons, Anthopolos and O'Meara (2021), who find positive associations of private facilities on child survival. However, facilities charging routine fees worsen harm by 0.053 standard deviations, highlighting service quality-affordability issues during climatic shocks. Nevertheless, this protection is unequal. Poor households, which suffer the most from drought, benefit minimally from the expansion of private healthcare. Middle-income households obtain significant protection from private facilities and IMCI-trained staff. Children from affluent families have a notable in-utero drought effect (–0.229, $p<0.01$), which is exacerbated when facilities impose routine fees throughout pregnancy. These differences show how market-based and public health systems exacerbate inequality in climate shocks. Public interventions, such as IMCI training and aids, show potential, but their non-random deployment requires rigorous evaluation. The findings also reveal a complex gender dynamic. A critical direction for future research is to capture sex-differentiated fetal and neonatal mortality and family resource allocation in response to climate shocks.

These findings demonstrate the importance of fair, accessible health systems that can adapt to climate change. Begin with drought-specific financial policies, such as indexed insurance, fee waivers, and private provider emergency vouchers. Second, increase nutritional aid for drought-affected communities and promote gender equity. Third, subsidies should target low-income households, drought-prone areas, and extreme weather occurrences.

The strength of this study is its integration of geocoded climatic, health, and demographic data, accompanied by comprehensive robustness checks. The primary empirical contribution is to offer a nuanced understanding of how different dimensions of healthcare quality moderate the effect of drought on child nutrition. These findings highlight critical research and policy priorities. Future research should incorporate mortality and malnutrition data to reveal selection effects, while policy experiments, such as targeted fee waivers during droughts, are necessary to validate causal pathways. Ultimately, establishing equitable climate resilience necessitates more considerate institutions; it involves a profound comprehension of household interactions with health systems during crises, ensuring that essential services are accessible to all children.

References

Abiona, Olukorede. 2022. "Malnutrition pathway for the impact of in utero drought shock on child growth indicators in rural households". *Environment and Development Economics* 27 (1): 20–39.

Abiona, Olukorede and Joseph B Ajefu. 2023. "The impact of timing of in utero drought shocks on birth outcomes in rural households: evidence from Sierra Leone". *Journal of Population Economics* 36 (3): 1333–1362.

Adhvaryu, Achyuta, Teresa Molina, Anant Nyshadham and Jorge Tamayo. 2024. "Helping children catch up: Early life shocks and the progresa experiment". *The Economic Journal* 134 (657): 1–22.

Agence Nationale de la Statistique et de la Démographie (ANSD) [Senegal] and ICF International. 2012–2019. *Senegal Continuous Demographic and Health Survey (DHS) Children's Recode and Service Provision Assessment (SPA) Surveys [Datasets].* IPUMS Demographic and Health Surveys (IPUMS DHS), IPUMS and ICF [Distributors]. http://idhsdata.org.

Andriano, Liliana. 2024. "Agricultural droughts and under-five mortality in Côte d'Ivoire: Differential impacts across social and demographic groups". *Population and Environment* 46 (4): 28.

Banerjee, Rakesh and Riddhi Maharaj. 2020. "Heat, infant mortality, and adaptation: Evidence from India". *Journal of Development Economics* 143:102378.

Barnes, Andrew Carmona, Arsène Kpangon, Pamela Riley and Erin Mohebbi. 2016. *Senegal private health sector assessment: selected health products and services.* SHOPS Plus Project. https://shopsplusproject.org/sites/default/files/resources/Senegal%20Private%20Health%20Sector%20Assessment_Selected%20Products%20and%20Services.pdf.

Björkman Nyqvist, Martina, Tillmann von Carnap, Andrea Guariso and Jakob Svensson. 2023. "Weather shocks, child mortality, and adaptation: experimental evidence from Uganda". *medRxiv,* 2023–04.

Black, Robert E, Cesar G Victora, Susan P Walker, Zulfiqar A Bhutta, Parul Christian, Mercedes De Onis, Majid Ezzati, Sally Grantham-McGregor, Joanne Katz, Reynaldo Martorell et al. 2013. "Maternal and child undernutrition and overweight in low-income and middle-income countries". *The Lancet* 382 (9890): 427–451.

Brar, Samanpreet, Nadia Akseer, Mohamadou Sall, Kaitlin Conway, Ibrahima Diouf, Karl Everett, Muhammad Islam, Papa Ibrahima Sylmang Sène, Hana Tasic, Jannah Wigle et al. 2020. "Drivers of stunting reduction in Senegal: a country case study". *The American Journal of Clinical Nutrition* 112:860S–874S.

Burgert, Clara R., Josh Colston, Thea Roy and Blake Zachary. 2013. *Geographic Displacement Procedure and Georeferenced Data Release Policy for the Demographic and Health Surveys,* DHS Spatial Analysis Reports 7. Calverton, Maryland, USA: ICF International. Accessed 29 August 2025. https://dhsprogram.com/pubs/pdf/SAR7/SAR7.pdf.

Cohen, François and Antoine Dechezleprêtre. 2022. "Mortality, temperature, and public health provision: evidence from Mexico". *American Economic Journal: Economic Policy* 14 (2): 161–192.

Cooper, Matthew W, Molly E Brown, Stefan Hochrainer-Stigler, Georg Pflug, Ian McCallum, Steffen Fritz, Julie Silva and Alexander Zvoleff. 2019. "Mapping the effects of drought on child stunting". *Proceedings of the National Academy of Sciences* 116 (35): 17219–17224.

Das, Susmita, Sharoardy Sagar, Srizan Chowdhury, Konok Akter, Muhammad Zahirul Haq and Syed Manzoor Ahmed Hanifi. 2023. "The risk of miscarriage is associated with ambient temperature: evidence from coastal Bangladesh". *Frontiers in Public Health* 11:1238275.

Davenport, Frank, Audrey Dorélien and Kathryn Grace. 2020. "Investigating the linkages between pregnancy outcomes and climate in sub-Saharan Africa". *Population and Environment* 41 (4): 397–421.

Dimitrova, Anna. 2021. "Seasonal droughts and the risk of childhood undernutrition in Ethiopia". *World Development* 141:105417.

Dimitrova, Anna, Alexander Gershunov, Morgan C Levy and Tarik Benmarhnia. 2023. "Uncovering social and environmental factors that increase the burden of climate-sensitive diarrheal infections on children". *Proceedings of the National Academy of Sciences* 120 (3): e2119409120.

Exemplars in Global Health. 2025. "What Did Senegal Do?" Accessed 31 July 2025. https://www.exemplars.health/topics/under-five-mortality/senegal/what-did-senegal-do.

Fall, Cheikh Modou Noreyni, Christophe Lavaysse, Hervé Kerdiles, Mamadou Simina Dramé, Philippe Roudier and Amadou Thierno Gaye. 2021. "Performance of dry and wet spells combined with remote sensing indicators for crop yield prediction in Senegal". *Climate Risk Management* 33:100331.

Freudenreich, Hanna, Anastasia Aladysheva and Tilman Brück. 2022. "Weather shocks across seasons and child health: Evidence from a panel study in the Kyrgyz Republic". *World Development* 155:105801.

Funk, Christopher C., Jim Rowland, Alkhalil Adoum, Gary Eilerts, James Verdin and Libby White. 2012. *A Climate Trend Analysis of Senegal,* Fact Sheet 2012-3123. Reston, VA: U.S. Geological Survey. https://doi.org/10.3133/fs20123123.

Gebrechorkos, Solomon H, Jian Peng, Ellen Dyer, Diego G Miralles, Sergio M Vicente-Serrano, Chris Funk, Hylke E Beck, Dagmawi T Asfaw, Michael B Singer and Simon J Dadson. 2023. "Global high-resolution drought indices for 1981–2022". *Earth System Science Data Discussions* 2023:1–28.

Global Nutrition Report. 2025. "Nutrition Profile: Senegal". Accessed 31 July 2025. https://globalnutritionreport.org/resources/nutrition-profiles/africa/western-africa/senegal/.

Grossi, A., S. Downs and S. Traska. 2021. *Climate Impacts on Nutrition in Senegal: Literature Review.* New York: International Research Institute for Climate and Society, Earth Institute, Columbia University. https://iri.columbia.edu/wp-content/uploads/2021/05/Literature-Review_Climate-Impacts-on-Nutrition-in-Senegal_final_Sd_AG_clean2.pdf.

Gunnsteinsson, Snaebjorn, Teresa Molina, Achyuta Adhvaryu, Parul Christian, Alain Labrique, Jonathan Sugimoto, Abu Ahmed Shamim and Keith P West Jr. 2022. "Protecting infants from natural disasters: The case of vitamin A supplementation and a tornado in Bangladesh". *Journal of Development Economics* 158:102914.

Headey, Derek and Aishwarya Venkat. 2024. *Extreme weather and undernutrition: A critical but constructive review of the literature.* IFPRI Discussion Paper 2236. Washington, DC: International Food Policy Research Institute (IFPRI).

Honda, Ayako, Nicolas Krucien, Mandy Ryan, Ibrahima Ska Ndella Diouf, Malick Salla, Mari Nagai and Noriko Fujita. 2019. "For more than money: willingness of health professionals to stay in remote Senegal". *Human resources for health* 17 (1): 28.

Jampani, Mahesh, Mame Henriette Astou Sambou, Niranga Alahacoon and Giriraj Amarnath. 2023. "Distribution of drought events and their impact on child malnutrition in Senegal". In *International Water Management Institute Conference Papers.* Abstract only. https://cgspace.cgiar.org/items/7b071cb8-ac93-4cd4-9438-d34a74372c82.

Kabwama, Steven N, Suzanne N Kiwanuka, Mala Ali Mapatano, Olufunmilayo I Fawole, Ibrahima Seck, Alice Namale, Rawlance Ndejjo, Susan Kizito, Fred Monje, Marc Bosonkie et al. 2022. "Private sector engagement in the COVID-19 response: experiences and lessons from the Democratic Republic of Congo, Nigeria, Senegal and Uganda". *Globalization and health* 18 (1): 60.

Le, Kien and My Nguyen. 2021. "In-utero exposure to rainfall variability and early childhood health". *World Development* 144:105485.

López-Ejeda, Noemí, Pilar Charle Cuellar, Antonio Vargas and Saul Guerrero. 2019. "Can community health workers manage uncomplicated severe acute malnutrition? A review of operational experiences in delivering severe acute malnutrition treatment through community health platforms". *Maternal & child nutrition* 15 (2): e12719.

Ly, Birama Apho, Ronald Labonté and Ivy Lynn Bourgeault. 2019. “The beliefs of Senegal’s physicians toward the use of telemedicine”. *Pan African Medical Journal* 34: 97.

Maccini, Sharon and Dean Yang. 2009. “Under the weather: Health, schooling, and economic consequences of early-life rainfall”. *American economic review* 99 (3): 1006–1026.

Mehar, Mamta, Surabhi Mittal and Narayan Prasad. 2016. “Farmers coping strategies for climate shock: Is it differentiated by gender?” *Journal of Rural Studies* 44:123–131.

Mullins, Jamie T and Corey White. 2020. “Can access to health care mitigate the effects of temperature on mortality?” *Journal of Public Economics* 191:104259.

Nébié, Elisabeth Kago Ilboudo, Diaba Ba and Alessandra Giannini. 2021. “Food security and climate shocks in Senegal: Who and where are the most vulnerable households?” *Global Food Security* 29:100513.

Negash, Habtu Kifle, Ashebir Mamay Gebru, Mihret Getnet, Mihret Melese, Berihun Agegn Mengistie, Desalegn Anmut Bitew, Tilahun Nega Godana, Yosef Belay Bizuneh, Amare Belete Getahun, Mikias Mered Tilahun et al. 2025. “Antenatal care visits and associated factors in Senegal: a multilevel poisson regression analysis of the 2023 DHS survey”. *Frontiers in Global Women’s Health* 6:1524361.

Okwaraji, Yemisrach B, Simon Cousens, Yemane Berhane, Kim Mulholland and Karen Edmond. 2012. “Effect of geographical access to health facilities on child mortality in rural Ethiopia: a community based cross sectional study”. *Plos one* 7 (3): e33564.

Onambele, Luc, Sara Guillen-Aguinaga, Laura Guillen-Aguinaga, Wilfrido Ortega-Leon, Rocio Montejo, Rosa Alas-Brun, Enrique Aguinaga-Ontoso, Ines Aguinaga-Ontoso and Francisco Guillen-Grima. 2023. “Trends, projections, and regional disparities of maternal mortality in Africa (1990–2030): an ARIMA forecasting approach”. *Epidemiologia* 4 (3): 322–351.

Paul, Elisabeth, Youssoupha Ndiaye, Farba L Sall, Fabienne Fecher and Denis Porignon. 2020. “An assessment of the core capacities of the Senegalese health system to deliver Universal Health Coverage”. *Health Policy OPEN* 1:100012.

Ponnusamy, Sundar. 2022. “Rainfall shocks, child mortality, and water infrastructure”. *Health Economics* 31 (7): 1317–1338.

Rocha, Rudi and Rodrigo R Soares. 2015. “Water scarcity and birth outcomes in the Brazilian semiarid”. *Journal of development economics* 112:72–91.

Rustad, Siri Aas, Elisabeth Lio Rosvold and Halvard Buhaug. 2020. “Development aid, drought, and coping capacity”. *The Journal of Development Studies* 56 (8): 1578–1593.

Salvador, Coral, Raquel Nieto, Thandi Kapwata, Caradee Y Wright, Chris Reason, Luis Gimeno and Ana M Vicedo-Cabrera. 2024. "Analyzing the effects of drought at different time scales on cause-specific mortality in South Africa". *Environmental Research Letters* 19 (5): 054022.

Shah, Manisha and Bryce Millett Steinberg. 2017. "Drought of opportunities: Contemporaneous and long-term impacts of rainfall shocks on human capital". *Journal of Political Economy* 125 (2): 527–561.

Shively, Gerald E. 2017. "Infrastructure mitigates the sensitivity of child growth to local agriculture and rainfall in Nepal and Uganda". *Proceedings of the National Academy of Sciences* 114 (5): 903–908.

Simmons, Ryan A, Rebecca Anthopolos and Wendy Prudhomme O'Meara. 2021. "Effect of health systems context on infant and child mortality in sub-Saharan Africa from 1995 to 2015, a longitudinal cohort analysis". *Scientific Reports* 11 (1): 16263.

Singh, Gurjeet, Narendra N Das and PV Vara Prasad. 2025. "Geospatial monitoring and analysis of agricultural drought to identify hotspots and risk assessment for Senegal". *Geography and Sustainability* 6 (1): 100248.

Sy, Ibrahima, Samba Cor Sarr and Amadou Doucouré. 2025. "Strengthening health systems and accountability: Senegal's path to success in reproductive, maternal, newborn, and child health". *The Lancet* 405 (10488): 1445–1448.

Tomalka, Julia, Stefan Lange, Stephanie Gleixner and Christoph Gornott. 2022. *Climate Risk Profile: Senegal.* Climate Risk Profiles for Sub-Saharan Africa Series. Potsdam, Germany: Potsdam Institute for Climate Impact Research (PIK), July. https://publications.pik-potsdam.de/pubman/item/item_27253_1.

United Nations Children's Fund (UNICEF). 2025. "Maternal Mortality: UNICEF Data". Accessed 16 August 2025. https://data.unicef.org/topic/maternal-health/maternal-mortality/.

Vaillancourt, Denise. 2016. *A Decade of World Bank Support to Senegal's Nutrition Program.* Technical report. The World Bank Group.

Victora, Cesar Gomes, Mercedes De Onis, Pedro Curi Hallal, Monika Blössner and Roger Shrimpton. 2010. "Worldwide timing of growth faltering: revisiting implications for interventions". *Pediatrics* 125 (3): e473–e480.

Wang, Pin, Ernest Asare, Virginia E Pitzer, Robert Dubrow and Kai Chen. 2022. "Associations between long-term drought and diarrhea among children under five in low-and middle-income countries". *Nature Communications* 13 (1): 3661.

Wang, Pin, Tormod Rogne, Joshua L Warren, Ernest O Asare, Robert A Akum, N'datchoh E Toure, Joseph S Ross and Kai Chen. 2025. "Long-term drought and risk of infant mortality in Africa: A cross-sectional study". *PLoS medicine* 22 (1): e1004516.

WHO Multicentre Growth Reference Study Group. 2006. "WHO Child Growth Standards based on length/height, weight and age". *Acta Paediatrica* 450:76–85. Supplement, https://doi.org/10.1111/j.1651-2227.2006.tb02378.x.

World Bank. 2024. "Combining Childhood Education and Nutrition to Cultivate Bright Futures in Senegal", 9 April 2024. Accessed 31 July 2025. https://www.worldbank.org/en/results/2024/04/09/combining-childhood-education-and-nutrition-to-cultivate-bright-futures-in-senegal.

World Food Programme. 2018. *Annual Country Report – Senegal, SN01, 2018.* https://www.wfp.org/publications/annual-country-reports-senegal. Country Brief (January 2018) embedded in Annual Report; Accessed July 31, 2025.

Yolchi, Jamshid and Huaiyu Wang. 2025. "The impact of climate change on household dietary diversity in Afghanistan". *Climate Risk Management* 47:100687.

A Appendix: Robustness Checks

A.1 Robustness 1: Aid-related Controls

Table 5: Robustness 1: Aid-Related Controls (Models 1 & 2)

	Height-for-age Z-score (HAZ)						
	Baseline	Private Facilities	Doctor Availability	IMCI Training	Routine Fees	Vaccine Fees	Delivery Fees
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Main Variables							
In Utero Drought (Moderate)	0.038	0.039	0.035	0.041	0.036	0.039	0.038
	(0.038)	(0.038)	(0.038)	(0.038)	(0.038)	(0.039)	(0.038)
Early Life Drought (Moderate)	-0.194***	-0.199***	-0.184***	-0.180***	-0.189***	-0.194***	-0.193***
	(0.044)	(0.045)	(0.044)	(0.044)	(0.045)	(0.044)	(0.045)
Aid Controls							
Plumpy'doz Supplement	-0.235	-0.236	-0.236	-0.234	-0.234	-0.235	-0.235
	(0.150)	(0.150)	(0.150)	(0.151)	(0.149)	(0.150)	(0.150)
Iron During Pregnancy	0.279***	0.280***	0.276***	0.273***	0.279***	0.279***	0.279***
	(0.067)	(0.067)	(0.068)	(0.068)	(0.067)	(0.067)	(0.067)
Vitamin A (6 months)	-0.062**	-0.062**	-0.060**	-0.063**	-0.063**	-0.062**	-0.062**
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)
Healthcare Quality		-0.100	0.475*	1.267**	0.208	0.202	0.012
		(0.220)	(0.252)	(0.608)	(0.241)	(0.480)	(0.077)
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects							
Cluster	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics							
Observations	8,038	8,038	8,038	8,038	8,038	8,038	8,038
R^2	0.202	0.202	0.203	0.203	0.202	0.202	0.202
Within R^2	0.109	0.109	0.109	0.110	0.109	0.109	0.109

Notes: Robustness 1 check examining drought effects on child HAZ with aid-related controls included. Model (1) shows baseline effects with aid controls only. Models (2)-(7) separately add healthcare quality indicators measured during the early 24-month period: (2) proportion of private facilities, (3) proportion with doctor availability, (4) proportion with IMCI-trained staff, (5) proportion charging routine fees, (6) proportion charging vaccine fees, (7) proportion charging delivery fees. Early life drought shows consistent negative effects ranging from -0.180 to -0.199 ($p<0.01$) across specifications. In utero drought effects remain insignificant (0.035-0.041). Among aid controls, iron supplementation during pregnancy shows positive effects (0.273-0.280, $p<0.01$), while vitamin A shows negative associations (-0.060 to -0.063, $p<0.05$). Plumpy'doz supplement shows no significant effect. Healthcare quality indicators show mixed results: doctor availability (0.475, $p<0.10$) and IMCI training (1.267, $p<0.05$) show positive associations, while fee-related indicators show no significant effects. Sample restricted to observations with complete aid and healthcare quality data (N=8,038). All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at DHS cluster level in parentheses. $^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$.

Table 6: Robustness 1: Gestational Healthcare as Moderator with Aid Controls

	Height-for-age Z-score (HAZ)					
	Private Facilities (1)	Doctor Availability (2)	IMCI Training (3)	Routine Fees (4)	Vaccine Fees (5)	Delivery Fees (6)
Main Variables						
In Utero Drought (Moderate)	0.013	0.057	-0.013	0.337	0.022	0.118*
	(0.047)	(0.058)	(0.067)	(0.416)	(0.040)	(0.067)
Early Life Drought (Moderate)	-0.196***	-0.199***	-0.198***	-0.196***	-0.193***	-0.190***
	(0.045)	(0.045)	(0.045)	(0.045)	(0.044)	(0.044)
Aid Controls						
Plumpy'doz Supplement	-0.235	-0.237	-0.232	-0.237	-0.235	-0.238
	(0.149)	(0.150)	(0.150)	(0.150)	(0.150)	(0.151)
Iron During Pregnancy	0.280***	0.281***	0.281***	0.278***	0.279***	0.278***
	(0.067)	(0.068)	(0.067)	(0.067)	(0.067)	(0.067)
Vitamin A (6 months)	-0.062**	-0.063**	-0.062**	-0.061**	-0.062**	-0.061**
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)
Healthcare Quality	-0.189	-0.239	-0.351	-0.035	0.006	0.121
	(0.308)	(0.350)	(0.592)	(0.285)	(0.857)	(0.078)
In Utero × Healthcare Quality	0.519	-0.143	1.093	-0.324	0.923	-0.164
	(0.556)	(0.468)	(1.091)	(0.455)	(1.212)	(0.115)
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
Cluster	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics						
Observations	8,038	8,038	8,038	8,038	8,038	8,038
R^2	0.202	0.202	0.202	0.202	0.202	0.203
Within R^2	0.109	0.109	0.109	0.109	0.109	0.109

Notes: Robustness 1 check examining whether healthcare quality at birth year moderates in utero drought effects on child HAZ, with aid-related controls included. Each column tests a different healthcare quality indicator and its interaction with in utero drought: (1) private facilities, (2) doctor availability, (3) IMCI training, (4) routine fees, (5) vaccine fees, (6) delivery fees. Early life drought shows consistent negative effects across all specifications (-0.190 to -0.199, p<0.01). In utero drought main effects vary by specification, with only model (6) showing marginal significance (0.118, p<0.10). Among aid controls, iron supplementation during pregnancy shows consistent positive effects (0.278-0.281, p<0.01), while vitamin A shows negative effects (-0.061 to -0.063, p<0.05). Plumpy'doz supplement shows no significant effects. Healthcare quality main effects are not significant across any specification. Interaction terms between in utero drought and healthcare quality indicators show no significant moderation effects. Sample restricted to observations with complete aid and birth year healthcare quality data (N=8,038). All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

Table 7: Robustness 1: Early-Life Healthcare as Moderator with Aid Controls

	Height-for-age Z-score (HAZ)					
	Private Facilities (1)	Doctor Availability (2)	IMCI Training (3)	Routine Fees (4)	Vaccine Fees (5)	Delivery Fees (6)
Main Variables						
In Utero Drought (Moderate)	0.039	0.035	0.041	0.036	0.038	0.038
	(0.038)	(0.038)	(0.038)	(0.038)	(0.039)	(0.038)
Early Life Drought (Moderate)	-0.188***	-0.157**	-0.169**	-0.217	-0.181***	-0.176**
	(0.053)	(0.063)	(0.069)	(0.379)	(0.049)	(0.079)
Aid Controls						
Plumpy'doz Supplement	-0.236	-0.235	-0.235	-0.234	-0.234	-0.235
	(0.150)	(0.151)	(0.151)	(0.150)	(0.150)	(0.150)
Iron During Pregnancy	0.280***	0.276***	0.273***	0.279***	0.280***	0.280***
	(0.068)	(0.068)	(0.068)	(0.067)	(0.067)	(0.067)
Vitamin A (6 months)	-0.062**	-0.060**	-0.063**	-0.063**	-0.062**	-0.062**
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)
Healthcare Quality	-0.079	0.579**	1.324**	0.199	0.349	0.025
	(0.237)	(0.288)	(0.663)	(0.288)	(0.507)	(0.092)
Early Life × Healthcare Quality	-0.241	-0.310	-0.222	0.030	-0.681	-0.039
	(0.633)	(0.535)	(1.077)	(0.416)	(1.135)	(0.161)
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
Cluster	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics						
Observations	8,038	8,038	8,038	8,038	8,038	8,038
R^2	0.202	0.203	0.203	0.202	0.202	0.202
Within R^2	0.109	0.109	0.110	0.109	0.109	0.109

Notes: Robustness 1 check examining whether healthcare quality during early 24 months can moderate early life drought effects on child HAZ, with aid-related controls included. Each column tests a different healthcare quality indicator measured at 24 months and its interaction with early life drought: (1) private facilities, (2) doctor availability, (3) IMCI training, (4) routine fees, (5) vaccine fees, (6) delivery fees. In utero drought shows no significant effects across specifications (0.035-0.041). Early life drought main effects vary by specification, ranging from -0.157 ($p<0.05$) with doctor availability to -0.217 (n.s.) with routine fees. Among aid controls, iron supplementation during pregnancy shows consistent positive effects (0.273-0.280, $p<0.01$), while vitamin A shows negative effects (-0.060 to -0.063, $p<0.05$). Plumpy'doz supplement shows no significant effects. For healthcare quality main effects, doctor availability (0.579, $p<0.05$) and IMCI training (1.324, $p<0.05$) show significant positive associations with HAZ, while fee-related indicators show no significant effects. None of the interaction terms between early life drought and healthcare quality reach statistical significance. Sample restricted to observations with complete aid and 24-month healthcare quality data (N=8,038). All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at DHS cluster level in parentheses. $^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$.

A.2 Robustness 2: Categorical Drought Measures

Table 8: Robustness 2: Categorical Drought Measures (Models 1 & 2)

	Height-for-age Z-score (HAZ)						
	Baseline	Private Facilities	Doctor Availability	IMCI Training	Routine Fees	Vaccine Fees	Delivery Fees
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Drought Exposure							
In Utero: Moderate Drought	0.030	0.030	0.029	0.030	0.027	0.027	0.031
	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)
In Utero: Severe Drought	-0.038	-0.039	-0.038	-0.038	-0.040	-0.038	-0.040
	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)
Early Life: Moderate Drought	-0.085***	-0.081***	-0.086***	-0.085***	-0.081***	-0.087***	-0.080***
	(0.025)	(0.025)	(0.024)	(0.025)	(0.025)	(0.025)	(0.025)
Early Life: Severe Drought	-0.111	-0.110	-0.114	-0.112	-0.109	-0.109	-0.115
	(0.074)	(0.074)	(0.073)	(0.074)	(0.074)	(0.074)	(0.073)
Healthcare Quality		0.201	0.425**	-0.057	0.280*	-0.397**	0.202***
		(0.144)	(0.164)	(0.290)	(0.156)	(0.184)	(0.046)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects							
Cluster	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics							
Observations	24,857	24,857	24,857	24,857	24,857	24,857	24,857
R^2	0.111	0.112	0.112	0.111	0.112	0.112	0.113
Within R^2	0.061	0.062	0.062	0.061	0.062	0.062	0.063

Notes: Examines categorical drought effects on child HAZ, distinguishing between moderate and severe drought exposure. Reference category is no drought (SPEI ≥ -1). Moderate drought defined as -1.5 ≤ SPEI < -1; severe drought as SPEI < -1.5. Model (1) shows baseline effects. Models (2)-(7) separately add healthcare quality indicators measured during the early 24-month period: (2) proportion of private facilities, (3) proportion with doctor availability, (4) proportion with IMCI-trained staff, (5) proportion charging routine fees, (6) proportion charging vaccine fees, (7) proportion charging delivery fees. Early life moderate drought shows consistent negative effects (-0.080 to -0.087, p<0.01), while severe drought effects are larger but not statistically significant (-0.109 to -0.115). In utero drought shows no significant effects for either moderate (0.027-0.031) or severe (-0.038 to -0.040) exposure. Among healthcare quality indicators: doctor availability shows positive association (0.425, p<0.05), routine fees marginally positive (0.280, p<0.10), delivery fees positive (0.202, p<0.01), while vaccine fees show negative association (-0.397, p<0.05). Sample includes 24,857 observations. All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

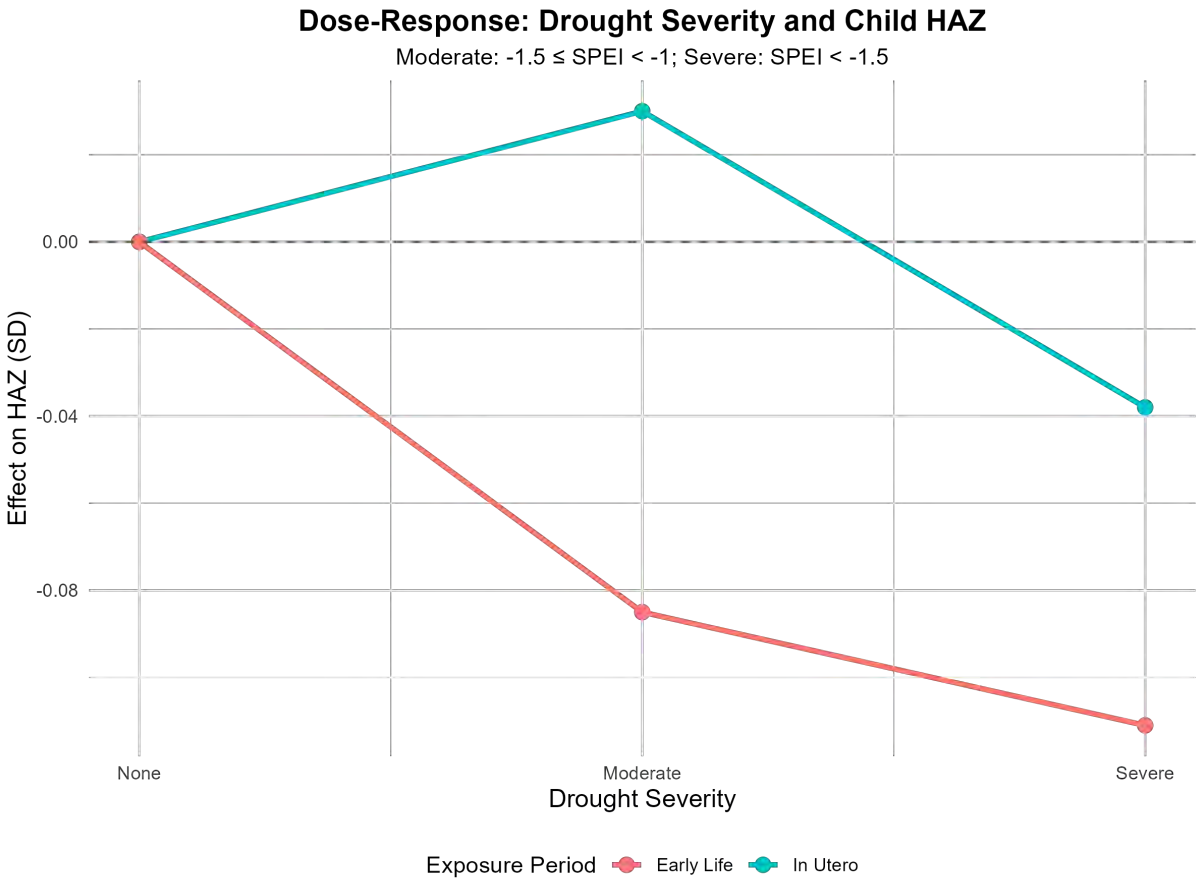


Figure 4: Robustness 2: Categorical Drought Dose-Response Plot

Table 9: Robustness 2: Categorical Drought (Model 3a - Gestational Healthcare)

	Height-for-age Z-score (HAZ)					
	Private Facilities (1)	Doctor Availability (2)	IMCI Training (3)	Routine Fees (4)	Vaccine Fees (5)	Delivery Fees (6)
Drought Exposure						
In Utero: Moderate Drought	0.046	0.094*	0.059	0.200	0.045	0.091
	(0.037)	(0.053)	(0.051)	(0.390)	(0.036)	(0.070)
In Utero: Severe Drought	-0.020	0.001	-0.016	0.415	-0.030	-0.138**
	(0.040)	(0.058)	(0.064)	(0.460)	(0.037)	(0.067)
Early Life: Moderate Drought	-0.089***	-0.090***	-0.091***	-0.092***	-0.090***	-0.086***
	(0.026)	(0.025)	(0.026)	(0.026)	(0.026)	(0.025)
Early Life: Severe Drought	-0.133*	-0.131*	-0.133*	-0.134*	-0.146*	-0.119
	(0.078)	(0.078)	(0.079)	(0.078)	(0.078)	(0.077)
Healthcare Quality	0.091	0.226	-0.349	-0.175	0.187***	0.183***
	(0.093)	(0.234)	(0.378)	(0.144)	(0.043)	(0.051)
In Utero Moderate × Healthcare Quality	-0.169	-0.705	-0.564	-0.175	0.088	-0.093
	(0.377)	(0.539)	(0.954)	(0.424)	(0.210)	(0.116)
In Utero Severe × Healthcare Quality	-0.263	-0.374	-0.383	-0.487	0.102	0.172*
	(0.368)	(0.462)	(1.068)	(0.496)	(0.311)	(0.104)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
Cluster	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics						
Observations	23,473	23,473	23,473	23,473	23,473	23,473
R^2	0.114	0.114	0.114	0.114	0.115	0.115
Within R^2	0.062	0.062	0.062	0.062	0.063	0.063

Notes: Examines whether healthcare quality at birth year moderates in utero drought effects by severity category. Reference category is no drought (SPEI ≥ -1). Moderate drought defined as -1.5 ≤ SPEI < -1; severe drought as SPEI < -1.5. Each column tests a different healthcare quality indicator at birth year and its interactions with both moderate and severe in utero drought: (1) private facilities, (2) doctor availability, (3) IMCI training, (4) routine fees, (5) vaccine fees, (6) delivery fees. Early life moderate drought shows consistent negative effects (-0.086 to -0.092, p<0.01), while severe drought shows larger negative effects (-0.119 to -0.146, p<0.10). In utero drought main effects vary: moderate drought marginally significant with doctor availability (0.094, p<0.10), severe drought negative and significant with delivery fees (-0.138, p<0.05). Healthcare quality main effects significant only for vaccine fees (0.187, p<0.01) and delivery fees (0.183, p<0.01). Interaction terms largely insignificant except severe drought × delivery fees (0.172, p<0.10). Sample restricted to observations with birth year healthcare quality data (N=23,473). All models include controls for child characteristics and household demographics. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

Table 10: Robustness 2: Categorical Drought (Model 3b - Early-Life Healthcare)

	Height-for-age Z-score (HAZ)					
	Private Facilities (1)	Doctor Availability (2)	IMCI Training (3)	Routine Fees (4)	Vaccine Fees (5)	Delivery Fees (6)
Drought Exposure						
In Utero: Moderate Drought	0.029	0.029	0.030	0.027	0.028	0.030
	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)
In Utero: Severe Drought	-0.038	-0.036	-0.037	-0.041	-0.035	-0.040
	(0.033)	(0.032)	(0.032)	(0.033)	(0.033)	(0.032)
Early Life: Moderate Drought	-0.106***	-0.100**	-0.091**	0.401	-0.082***	-0.075
	(0.029)	(0.039)	(0.042)	(0.302)	(0.027)	(0.047)
Early Life: Severe Drought	-0.152	-0.229	-0.014	0.455	-0.158**	-0.419***
	(0.096)	(0.145)	(0.135)	(0.901)	(0.076)	(0.134)
Healthcare Quality	0.136	0.374*	-0.051	0.407**	-0.379**	0.189***
	(0.152)	(0.192)	(0.314)	(0.182)	(0.190)	(0.047)
Early Life Moderate × Healthcare Quality	0.496*	0.153	0.123	-0.524	-0.357	-0.013
	(0.274)	(0.307)	(0.644)	(0.325)	(0.479)	(0.085)
Early Life Severe × Healthcare Quality	1.089	1.390	-2.430	-0.613	1.774	0.568**
	(1.459)	(1.556)	(2.425)	(0.973)	(1.373)	(0.228)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
Cluster	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics						
Observations	24,857	24,857	24,857	24,857	24,857	24,857
R^2	0.112	0.112	0.112	0.112	0.112	0.113
Within R^2	0.062	0.062	0.061	0.062	0.062	0.063

Notes: Examines whether healthcare quality during the early 24 months can moderate early life drought effects by severity category. Reference category is no drought (SPEI ≥ -1). Moderate drought defined as -1.5 ≤ SPEI < -1; severe drought as SPEI < -1.5. Each column tests a different healthcare quality indicator at 24 months and its interactions with both moderate and severe early life drought: (1) private facilities, (2) doctor availability, (3) IMCI training, (4) routine fees, (5) vaccine fees, (6) delivery fees. In utero drought shows no significant effects for either moderate (0.027-0.030) or severe (-0.035 to -0.041) categories. Early life moderate drought main effects vary considerably by specification, from negative and significant (-0.106, p<0.01 for private facilities) to positive but insignificant (0.401 for routine fees). Early life severe drought shows mixed effects, significant only with vaccine fees (-0.158, p<0.05) and delivery fees (-0.419, p<0.01). Healthcare quality main effects show doctor availability positive (0.374, p<0.10), routine fees positive (0.407, p<0.05), vaccine fees negative (-0.379, p<0.05), and delivery fees positive (0.189, p<0.01). For interaction effects, moderate drought × private facilities shows positive moderation (0.496, p<0.10), while severe drought × delivery fees shows significant positive moderation (0.568, p<0.05), suggesting some protective effects of private healthcare quality during the critical early life period. Charging delivery fees could be considered as a proxy of good healthcare quality. Sample includes 24,857 observations. All models include controls for child characteristics and household demographics. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

A.3 Robustness 3: Total Effects Models

Table 11: Robustness 3: Total Effect Models (Models 1 & 2 Comparison)

	Height-for-age Z-score (HAZ)						
	Baseline	Private Facilities	Doctor Availability	IMCI Training	Routine Fees	Vaccine Fees	Delivery Fees
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: In Utero Only (Total Effects)							
In Utero Drought (Moderate)	-0.002	-0.003	-0.003	-0.002	-0.005	-0.004	-0.002
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Healthcare Quality		0.245*	0.414**	-0.011	0.317**	-0.379**	0.204***
		(0.142)	(0.167)	(0.292)	(0.156)	(0.182)	(0.046)
Observations	24,857	24,857	24,857	24,857	24,857	24,857	24,857
R^2	0.111	0.111	0.111	0.111	0.111	0.111	0.112
Within R^2	0.061	0.061	0.061	0.061	0.061	0.061	0.062
Panel B: Early Life Only (Total Effects)							
Early Life Drought (Moderate)	-0.087***	-0.084***	-0.088***	-0.087***	-0.084***	-0.089***	-0.083***
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Healthcare Quality		0.192	0.425**	-0.052	0.280*	-0.404**	0.200***
		(0.144)	(0.164)	(0.290)	(0.156)	(0.185)	(0.046)
Observations	24,857	24,857	24,857	24,857	24,857	24,857	24,857
R^2	0.111	0.111	0.112	0.111	0.112	0.112	0.113
Within R^2	0.061	0.061	0.062	0.061	0.061	0.062	0.063
Panel C: Combined Model (Both Drought Periods)							
In Utero Drought (Moderate)	-0.001	0.000	-0.001	-0.001	-0.003	-0.002	-0.001
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Early Life Drought (Moderate)	-0.087***	-0.084***	-0.088***	-0.087***	-0.084***	-0.089***	-0.083***
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Healthcare Quality		0.192	0.425**	-0.052	0.280*	-0.404**	0.200***
		(0.144)	(0.164)	(0.290)	(0.156)	(0.185)	(0.046)
Observations	24,857	24,857	24,857	24,857	24,857	24,857	24,857
R^2	0.111	0.111	0.112	0.111	0.112	0.112	0.113
Within R^2	0.061	0.061	0.062	0.061	0.061	0.062	0.063

Notes: Examines total effects of drought exposure with healthcare quality indicators measured at 24 months. Panel A excludes early life drought to estimate total effect of in utero exposure. Panel B excludes in utero drought to estimate total effect of early life exposure. Panel C includes both drought periods simultaneously for comparison. Model (1) shows baseline effects without healthcare quality. Models (2)-(7) separately add healthcare quality indicators: (2) proportion of private facilities, (3) proportion with doctor availability, (4) proportion with IMCI-trained staff, (5) proportion charging routine fees, (6) proportion charging vaccine fees, (7) proportion charging delivery fees. In Panel A, in utero drought shows no significant total effects (-0.002 to -0.005). In Panel B, early life drought shows consistent negative total effects (-0.083 to -0.089, p<0.01). Panel C confirms early life drought dominates when both periods included. Healthcare quality effects consistent across panels: doctor availability positive (0.414-0.425, p<0.05), routine fees marginally positive (0.280-0.317, p<0.10-0.05), delivery fees positive (0.200-0.204, p<0.01), while vaccine fees negative (-0.379 to -0.404, p<0.05). Sample includes 24,857 observations. All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

Table 12: Robustness 3: Total Effects (Model 3a - Gestational Healthcare)

	Height-for-age Z-score (HAZ)					
	Private Facilities (1)	Doctor Availability (2)	IMCI Training (3)	Routine Fees (4)	Vaccine Fees (5)	Delivery Fees (6)
Main Variable						
In Utero Drought (Moderate)	0.015	0.055	0.033	0.267	0.010	-0.004
	(0.029)	(0.042)	(0.043)	(0.316)	(0.027)	(0.055)
Healthcare Quality	0.118	0.232	-0.264	-0.145	0.183***	0.188***
	(0.091)	(0.232)	(0.378)	(0.144)	(0.043)	(0.051)
In Utero × Healthcare Quality	-0.220	-0.586	-0.706	-0.285	0.076	0.015
	(0.281)	(0.380)	(0.764)	(0.344)	(0.173)	(0.088)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
Cluster	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics						
Observations	23,473	23,473	23,473	23,473	23,473	23,473
R^2	0.113	0.113	0.113	0.113	0.114	0.114
Within R^2	0.061	0.061	0.061	0.061	0.062	0.062

Notes: Examines whether healthcare quality at birth year moderates in utero drought effects, excluding early life drought to isolate total effects. Each column tests a different healthcare quality indicator at birth year and its interaction with in utero drought: (1) private facilities, (2) doctor availability, (3) IMCI training, (4) routine fees, (5) vaccine fees, (6) delivery fees. In utero drought main effects vary by specification, ranging from -0.004 (delivery fees) to 0.267 (routine fees), none statistically significant. Healthcare quality main effects significant only for vaccine fees (0.183, $p<0.01$) and delivery fees (0.188, $p<0.01$). None of the interaction terms reach statistical significance, with coefficients ranging from negative (IMCI: -0.706, doctor: -0.586) to near zero (delivery: 0.015), suggesting healthcare quality at birth does not significantly moderate in utero drought's total effects. Sample restricted to observations with birth year healthcare quality data (N=23,473). All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at DHS cluster level in parentheses. $^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$.

Table 13: Robustness 3: Total Effects (Model 3b - Early-Life Healthcare)

	Height-for-age Z-score (HAZ)					
	Private Facilities (1)	Doctor Availability (2)	IMCI Training (3)	Routine Fees (4)	Vaccine Fees (5)	Delivery Fees (6)
Main Variable						
Early Life Drought (Moderate)	-0.110***	-0.109***	-0.087**	0.400	-0.085***	-0.112**
	(0.029)	(0.039)	(0.042)	(0.288)	(0.026)	(0.045)
Healthcare Quality	0.126	0.363*	-0.052	0.405**	-0.374*	0.190***
	(0.152)	(0.192)	(0.313)	(0.181)	(0.191)	(0.047)
Early Life × Healthcare Quality	0.537*	0.223	0.002	-0.525*	-0.202	0.058
	(0.278)	(0.306)	(0.648)	(0.311)	(0.448)	(0.081)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
Cluster	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics						
Observations	24,857	24,857	24,857	24,857	24,857	24,857
R^2	0.112	0.112	0.111	0.112	0.112	0.113
Within R^2	0.062	0.062	0.061	0.062	0.062	0.063

Notes: Examines whether healthcare quality during the early 24 months can moderate early life drought effects, excluding in utero drought to isolate total effects. Each column tests a different healthcare quality indicator at 24 months and its interaction with early life drought: (1) private facilities, (2) doctor availability, (3) IMCI training, (4) routine fees, (5) vaccine fees, (6) delivery fees. Early life drought main effects vary by specification, ranging from -0.112 ($p<0.05$) with delivery fees to 0.400 (n.s.) with routine fees, with most showing significant negative effects. Healthcare quality main effects show doctor availability positive (0.363, $p<0.10$), routine fees positive (0.405, $p<0.05$), delivery fees positive (0.190, $p<0.01$), and vaccine fees negative (-0.374, $p<0.10$). Interaction terms reveal heterogeneous moderation effects: private facilities show significant positive moderation (0.537, $p<0.10$), suggesting protective effects, while routine fees show significant negative interaction (-0.525, $p<0.10$), indicating potential exacerbation. Other interactions are not significant. Sample includes 24,857 observations. All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at the DHS cluster level in parentheses. $^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$.

A.4 Robustness 4: Alternative Thresholds for Drought Definitions

Table 14: Robustness 4: Alternative Thresholds for Drought Definitions (Models 1)

	Height-for-age Z-score (HAZ)			
	SPEI < -0.8 (Less Strict) (1)	SPEI < -1.0 (Main Spec) (2)	SPEI < -1.2 (More Strict) (3)	SPEI < -1.5 (Most Strict) (4)
Drought Exposure				
In Utero Drought	-0.005	-0.001	0.004	-0.039
	(0.023)	(0.025)	(0.026)	(0.032)
Early Life Drought	-0.074***	-0.087***	-0.150***	-0.101
	(0.022)	(0.024)	(0.036)	(0.074)
Controls	Yes	Yes	Yes	Yes
Fixed Effects				
Cluster	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes
Fit Statistics				
Observations	24,857	24,857	24,857	24,857
R^2	0.111	0.111	0.111	0.111
Within R^2	0.061	0.061	0.061	0.061

Notes: Examines sensitivity of drought effects to different SPEI threshold definitions. Each column uses a different SPEI cutoff to define drought exposure: (1) SPEI < -0.8 captures less strict drought conditions with more exposed children, (2) SPEI < -1.0 represents the main specification used throughout the analysis, (3) SPEI < -1.2 uses a more restrictive definition, and (4) SPEI < -1.5 captures only severe drought conditions with fewer exposed children. In utero drought shows no significant effects across any threshold, with coefficients ranging from -0.039 to 0.004. The –1.2 threshold may reflect selective survival. Early life drought shows consistent negative effects across thresholds, with magnitude increasing from -0.074 (p<0.01) at the less strict threshold to -0.150 (p<0.01) at SPEI < -1.2, then diminishing to -0.101 (n.s.) at the most restrictive threshold, likely due to reduced statistical power from fewer drought-exposed observations. The consistency of early life effects across less strict to moderately strict thresholds (-0.074 to -0.150, all p<0.01) confirms the robustness of the main findings. The inverted U-shape pattern (effects strongest at -1.2) suggests a trade-off between drought severity and sample size. All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

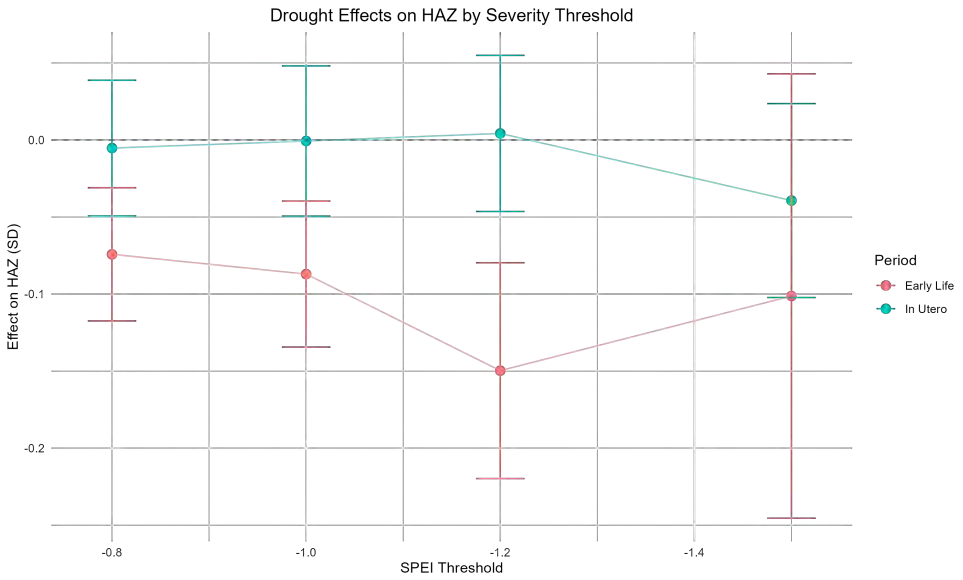


Figure 5: Robustness 4: Drought Effects by SPEI Threshold

A.5 Robustness 5: Marginal Effects Models

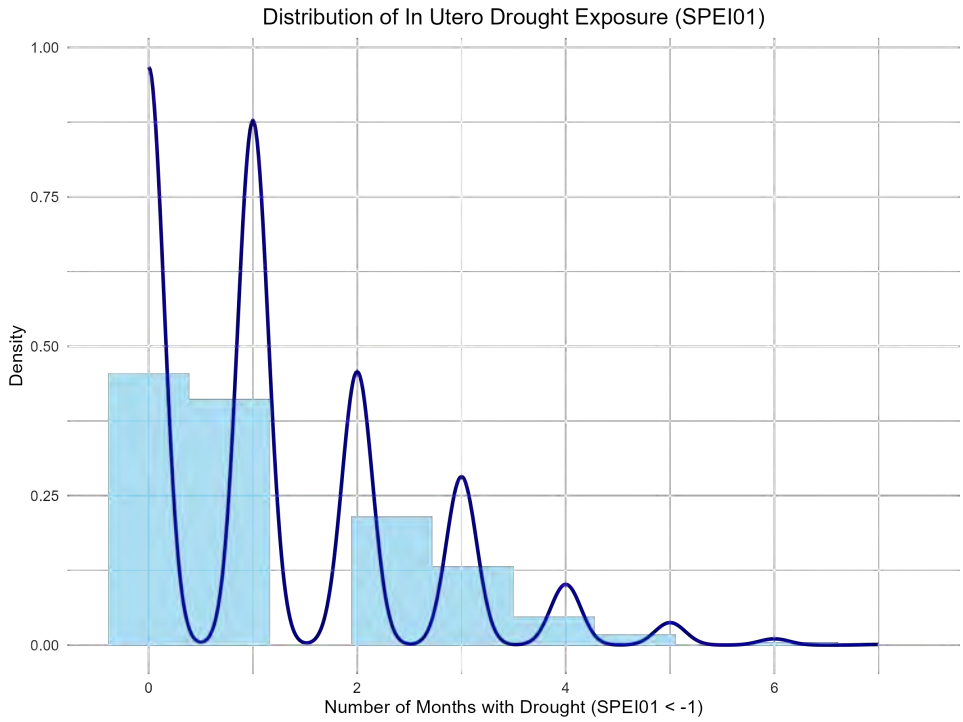


Figure 6: Robustness 5: Distribution of In Utero Drought Exposure Months.

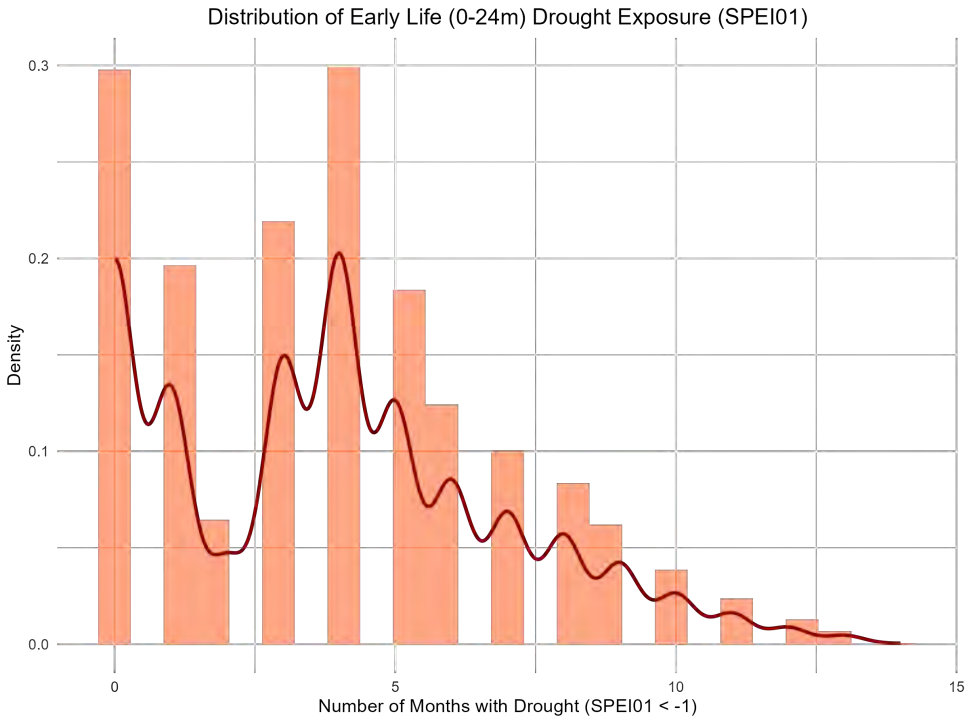


Figure 7: Robustness 5: Distribution of Early Life Drought Exposure Months.

Table 15: Robustness 5: Marginal Effects of Cumulative Drought (Models 1 & 2)

	Height-for-age Z-score (HAZ)						
	Baseline	Private Facilities	Doctor Availability	IMCI Training	Routine Fees	Vaccine Fees	Delivery Fees
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Drought Exposure (Months)							
In Utero Drought	0.007	0.013	0.011	0.013	0.013	0.013	0.012
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Early Life Drought	-0.024***	-0.021***	-0.022***	-0.021***	-0.021***	-0.021***	-0.020***
	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Healthcare Quality		0.215	0.379***	0.430	0.270*	-0.012	0.163***
		(0.140)	(0.143)	(0.275)	(0.155)	(0.260)	(0.045)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects							
Cluster	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics							
Observations	27,186	25,762	25,762	25,762	25,762	25,762	25,762
R^2	0.109	0.111	0.111	0.111	0.111	0.111	0.112
Within R^2	0.059	0.058	0.059	0.058	0.058	0.058	0.059

Notes: Examines drought effects using continuous exposure measure (number of months with SPEI01 < -1) rather than binary indicator. Model (1) shows baseline effects. Models (2)-(7) separately add healthcare quality indicators measured at 24 months: (2) proportion of private facilities, (3) proportion with doctor availability, (4) proportion with IMCI-trained staff, (5) proportion charging routine fees, (6) proportion charging vaccine fees, (7) proportion charging delivery fees. In utero drought exposure (0-9 months possible) shows no significant effects (0.007-0.013 per month). Early life drought exposure (0-24 months possible) shows consistent negative effects of approximately -0.020 to -0.024 HAZ points per month of exposure ($p<0.01$), implying marginal effects. Healthcare quality indicators show similar patterns to main specification: doctor availability (0.379, $p<0.01$), routine fees (0.270, $p<0.10$), and delivery fees (0.163, $p<0.01$) show positive associations. The consistency of results using continuous exposure measure confirms robustness of main findings using binary drought indicator. Sample sizes differ between baseline (N=27,186) and models with healthcare quality (N=25,762) due to data availability. All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at DHS cluster level in parentheses. $^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$.

Table 16: Robustness 5: Marginal Effects (Model 3a - Gestational Healthcare)

	Height-for-age Z-score (HAZ)					
	Private Facilities (1)	Doctor Availability (2)	IMCI Training (3)	Routine Fees (4)	Vaccine Fees (5)	Delivery Fees (6)
Drought Exposure (Months)						
In Utero Drought	0.009	0.016	0.000	0.118	0.008	-0.001
	(0.010)	(0.012)	(0.014)	(0.088)	(0.009)	(0.016)
Early Life Drought	-0.022***	-0.022***	-0.022***	-0.022***	-0.020***	-0.021***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Healthcare Quality	0.139	0.208	-0.560	0.084	0.100*	0.131**
	(0.099)	(0.247)	(0.434)	(0.173)	(0.052)	(0.057)
In Utero × Healthcare Quality	0.003	-0.090	0.201	-0.117	0.039	0.024
	(0.081)	(0.114)	(0.211)	(0.095)	(0.048)	(0.024)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
Cluster	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics						
Observations	25,504	25,504	25,504	25,504	25,504	25,504
R^2	0.111	0.111	0.111	0.111	0.112	0.112
Within R^2	0.060	0.060	0.060	0.060	0.060	0.061

Notes: Examines whether healthcare quality at birth year moderates in utero drought effects using continuous exposure measure (months with SPEI01 < -1). Each column tests a different healthcare quality indicator at birth year and its interaction with months of in utero drought: (1) private facilities, (2) doctor availability, (3) IMCI training, (4) routine fees, (5) vaccine fees, (6) delivery fees. In utero drought main effects vary by specification (0.000 to 0.118 per month), none statistically significant. Early life drought shows consistent negative effects (-0.020 to -0.022 per month, p<0.01). Healthcare quality main effects significant only for vaccine fees (0.100, p<0.10) and delivery fees (0.131, p<0.05), representing prenatal care context. Interaction terms show no significant moderation effects, with coefficients ranging from -0.117 (routine fees) to 0.201 (IMCI training), suggesting healthcare quality at birth does not modify the relationship between months of in utero drought exposure and child HAZ. Sample restricted to observations with birth year healthcare quality data (N=25,504). All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

Table 17: Robustness 5: Marginal Effects (Model 3b - Early-Life Healthcare)

	Height-for-age Z-score (HAZ)					
	Private Facilities (1)	Doctor Availability (2)	IMCI Training (3)	Routine Fees (4)	Vaccine Fees (5)	Delivery Fees (6)
Drought Exposure (Months)						
In Utero Drought	0.013	0.012	0.013	0.013	0.013	0.012
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Early Life Drought	-0.027***	-0.021***	-0.021***	0.007	-0.023***	-0.026***
	(0.006)	(0.007)	(0.007)	(0.040)	(0.006)	(0.008)
Healthcare Quality	-0.059	0.447*	0.385	0.425	-0.212	0.106
	(0.167)	(0.242)	(0.406)	(0.271)	(0.429)	(0.068)
Early Life × Healthcare Quality	0.081**	-0.013	0.012	-0.030	0.042	0.015
	(0.033)	(0.035)	(0.078)	(0.042)	(0.067)	(0.014)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
Cluster	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics						
Observations	25,762	25,762	25,762	25,762	25,762	25,762
R^2	0.111	0.111	0.111	0.111	0.111	0.112
Within R^2	0.059	0.059	0.058	0.059	0.058	0.059

Notes: Examines whether healthcare quality during early 24 months can moderate early life drought effects using continuous exposure measure (months with SPEI01 < -1). Each column tests a different healthcare quality indicator at 24 months and its interaction with months of early life drought: (1) private facilities, (2) doctor availability, (3) IMCI training, (4) routine fees, (5) vaccine fees, (6) delivery fees. In utero drought shows no significant effects (0.012-0.013 per month). Early life drought main effects vary by specification: negative and significant for most models (-0.021 to -0.027 per month, p<0.01), but becomes positive and insignificant with routine fees (0.007). Healthcare quality main effects show only doctor availability marginally significant (0.447, p<0.10). Interaction terms reveal heterogeneous moderation effects: private facilities show significant positive moderation (0.081 per month, p<0.05). The continuous measure confirms findings from binary indicator: private facilities during critical early life period provide meaningful protection against drought impacts. Sample includes observations with 24-month healthcare quality data (N=25,762). All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, wealth quintiles, and urban residence. Fixed effects for DHS cluster, survey year, and birth season included. Standard errors clustered at DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

A.6 Robustness 6: Heterogeneity Analysis

Table 18: Robustness 6: Heterogeneity Analysis (Models 1)

	Height-for-age Z-score (HAZ)						
	Gender		Wealth Terciles			Residence	
	Male	Female	Poor (Q1-Q2)	Middle (Q3-Q4)	Rich (Q5)	Rural	Urban
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Drought Effects							
In Utero Drought	0.044	-0.044	0.006	0.022	-0.229***	0.008	-0.027
	(0.034)	(0.031)	(0.033)	(0.040)	(0.074)	(0.031)	(0.038)
Early Life Drought	-0.074**	-0.115***	-0.119***	-0.075*	-0.095	-0.107***	-0.095**
	(0.032)	(0.033)	(0.036)	(0.040)	(0.078)	(0.033)	(0.041)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects							
Cluster	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics							
Observations	12,509	12,348	14,735	8,175	1,947	17,506	7,351
R^2	0.115	0.137	0.095	0.092	0.239	0.106	0.126
Within R^2	0.053	0.068	0.035	0.032	0.042	0.048	0.052

Notes: Examines heterogeneity in baseline drought effects across demographic subgroups. Columns (1)-(2) compare effects by child gender, controlling for wealth and urban residence. Columns (3)-(5) stratify by household wealth terciles: Poor (quintiles 1-2), Middle (quintiles 3-4), Rich (quintile 5), controlling for gender and urban residence. Columns (6)-(7) compare rural versus urban residence, controlling for gender and wealth. Key findings: In utero drought significantly harms only wealthy children (-0.229, p<0.01), suggesting survivor bias among the poor and middle. Early life drought shows consistent negative effects across most groups, strongest for females (-0.115, p<0.01) and poor households (-0.119, p<0.01), with effects ranging from -0.075 to -0.119 standard deviations. The wealthy show the only insignificant early life effect (-0.095), potentially due to better coping resources or small sample size. All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, and household size. Fixed effects for DHS cluster, survey year, and birth season included in all specifications. Standard errors clustered at DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

Table 19: Robustness 6: Heterogeneity Interaction Analysis

	Height-for-age Z-score (HAZ)		
	Gender Interactions (1)	Wealth Interactions (2)	Residence Interactions (3)
Main Drought Effects			
In Utero Drought	0.041	0.007	-0.027
	(0.033)	(0.032)	(0.038)
Early Life Drought	-0.070**	-0.094***	-0.101**
	(0.031)	(0.032)	(0.040)
Demographic Main Effects			
Female	0.140***	0.122***	0.120***
	(0.018)	(0.016)	(0.016)
Middle Wealth (Q3-4)		0.289***	
		(0.028)	
Rich (Q5)		0.618***	
		(0.053)	
Rural			-0.049
			(0.036)
In Utero × Demographics			
In Utero × Female	-0.085**		
	(0.040)		
In Utero × Middle		0.026	
		(0.047)	
In Utero × Rich		-0.220***	
		(0.074)	
In Utero × Rural			0.036
			(0.049)
Early Life × Demographics			
Early Life × Female	-0.034		
	(0.039)		
Early Life × Middle		0.007	
		(0.047)	
Early Life × Rich		0.038	
		(0.069)	
Early Life × Rural			0.020
			(0.053)
Controls	Yes	Yes	Yes
Fixed Effects			
Cluster	Yes	Yes	Yes
Survey Year	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes
Fit Statistics			
Observations	24,857	24,857	24,857
R^2	0.112	0.109	0.111
Within R^2	0.062	0.058	0.061

Notes: Tests heterogeneity in drought effects across demographic groups using interaction terms. Column (1) tests gender differences (Drought × Female) while controlling for wealth and residence. Column (2) tests wealth differences (Drought × Middle, Drought × Rich) while controlling for gender and residence. Column (3) tests residence differences (Drought × Rural) while controlling for gender and wealth. Reference categories: Male for gender, Poor (Q1-2) for wealth, Urban for residence. All models include controls for child age, birth order, singleton status, mother's age at birth, mother's education, household size, plus demographic controls not being tested for interaction. Fixed effects for DHS cluster, survey year, and birth season included in all specifications. Standard errors clustered at DHS cluster level in parentheses. *p<0.10, **p<0.05, ***p<0.01.

Table 20: Robustness 6: Heterogeneity (Model 3a - Gestational Healthcare)

	Height-for-age Z-score (HAZ)						
	Gender		Wealth Terciles			Residence	
	Male (1)	Female (2)	Poor (3)	Middle (4)	Rich (5)	Rural (6)	Urban (7)
Panel A: Private Facilities							
In Utero Drought	0.079**	-0.042	0.027	0.009	-0.222**	0.027	-0.002
	(0.040)	(0.036)	(0.044)	(0.045)	(0.094)	(0.042)	(0.044)
Early Life Drought	-0.076**	-0.129***	-0.132***	-0.069*	-0.085	-0.117***	-0.091**
	(0.035)	(0.033)	(0.037)	(0.041)	(0.081)	(0.035)	(0.042)
Healthcare Quality	0.186	0.037	-0.010	0.133	0.121	-0.146	0.075
	(0.118)	(0.128)	(0.426)	(0.136)	(0.174)	(0.247)	(0.122)
In Utero × HQ	-0.457	-0.053	-0.464	0.415	0.062	-0.486	-0.089
	(0.424)	(0.434)	(0.828)	(0.482)	(0.498)	(0.689)	(0.313)
Observations	11,846	11,627	13,874	7,750	1,849	16,525	6,948
Panel B: Doctor Availability							
In Utero Drought	0.127**	-0.005	0.076	0.010	-0.123	0.048	0.055
	(0.054)	(0.054)	(0.062)	(0.063)	(0.143)	(0.055)	(0.065)
Early Life Drought	-0.080**	-0.129***	-0.131***	-0.073*	-0.100	-0.115***	-0.096**
	(0.035)	(0.033)	(0.037)	(0.041)	(0.078)	(0.035)	(0.042)
Healthcare Quality	0.324	0.175	0.161	0.069	0.697	-0.107	0.288
	(0.300)	(0.274)	(0.433)	(0.340)	(0.652)	(0.339)	(0.415)
In Utero × HQ	-0.802	-0.459	-0.865	0.145	-0.657	-0.427	-0.600
	(0.494)	(0.492)	(0.798)	(0.518)	(0.750)	(0.603)	(0.474)
Observations	11,846	11,627	13,874	7,750	1,849	16,525	6,948
Panel C: IMCI Training							
In Utero Drought	0.052	-0.001	0.061	0.004	-0.239*	0.037	0.040
	(0.053)	(0.054)	(0.053)	(0.069)	(0.144)	(0.053)	(0.064)
Early Life Drought	-0.081**	-0.129***	-0.135***	-0.075*	-0.095	-0.118***	-0.093**
	(0.035)	(0.033)	(0.038)	(0.041)	(0.078)	(0.036)	(0.041)
Healthcare Quality	-0.610	-0.095	-0.523	-0.385	0.910	-0.485	0.052
	(0.512)	(0.449)	(0.492)	(0.636)	(1.239)	(0.450)	(0.618)
In Utero × HQ	0.133	-1.077	-1.173	0.518	0.403	-0.606	-1.198
	(1.096)	(0.987)	(0.944)	(1.261)	(2.596)	(0.915)	(1.260)
Observations	11,846	11,627	13,874	7,750	1,849	16,525	6,948
Panel D: Routine Fees							
In Utero Drought	0.267	0.442	0.480	-0.442	1.858*	0.075	0.463
	(0.432)	(0.408)	(0.428)	(0.474)	(1.042)	(0.390)	(0.553)
Early Life Drought	-0.079**	-0.134***	-0.138***	-0.074*	-0.092	-0.118***	-0.096**
	(0.035)	(0.033)	(0.038)	(0.041)	(0.077)	(0.036)	(0.042)
Healthcare Quality	0.046	-0.380*	-0.243	-0.198	-0.350	-0.199	-0.363
	(0.193)	(0.196)	(0.217)	(0.220)	(0.460)	(0.182)	(0.262)
In Utero × HQ	-0.226	-0.531	-0.506	0.508	-2.281**	-0.068	-0.519
	(0.471)	(0.441)	(0.466)	(0.519)	(1.148)	(0.424)	(0.603)
Observations	11,846	11,627	13,874	7,750	1,849	16,525	6,948
Panel E: Vaccine Fees							
In Utero Drought	0.057	-0.034	0.021	0.024	-0.214***	0.020	-0.012
	(0.037)	(0.033)	(0.036)	(0.043)	(0.082)	(0.034)	(0.042)
Early Life Drought	-0.080**	-0.131***	-0.137***	-0.073*	-0.095	-0.119***	-0.093**
	(0.035)	(0.033)	(0.037)	(0.041)	(0.078)	(0.035)	(0.042)
Healthcare Quality	0.132**	0.237***	0.205***	0.183***	-0.011	0.214***	0.135*
	(0.060)	(0.062)	(0.075)	(0.064)	(0.148)	(0.059)	(0.076)
In Utero × HQ	0.206	-0.007	0.068	0.240	-0.155	0.102	0.137
	(0.240)	(0.247)	(0.267)	(0.260)	(0.421)	(0.251)	(0.238)
Observations	11,846	11,627	13,874	7,750	1,849	16,525	6,948
Panel F: Delivery Fees							
In Utero Drought	-0.028	0.044	-0.007	0.099	-0.156	-0.024	0.109
	(0.069)	(0.067)	(0.066)	(0.094)	(0.192)	(0.067)	(0.085)
Early Life Drought	-0.074**	-0.126***	-0.123***	-0.074*	-0.098	-0.110***	-0.096**
	(0.034)	(0.033)	(0.037)	(0.041)	(0.080)	(0.035)	(0.042)
Healthcare Quality	0.148**	0.220***	0.242***	0.087	0.115	0.225***	0.221**
	(0.066)	(0.063)	(0.067)	(0.093)	(0.194)	(0.066)	(0.107)
In Utero × HQ	0.153	-0.164	0.040	-0.118	-0.117	0.066	-0.217
	(0.110)	(0.108)	(0.111)	(0.145)	(0.275)	(0.107)	(0.133)
Observations	11,846	11,627	13,874	7,750	1,849	16,525	6,948

Notes: Tests whether birth year healthcare quality moderates in utero drought effects across demographic subgroups. *p<0.10, **p<0.05, ***p<0.01.

Table 21: Robustness 6: Heterogeneity (Model 3b - Early-Life Healthcare)

	Height-for-age Z-score (HAZ)						
	Gender		Wealth Terciles			Residence	
	Male (1)	Female (2)	Poor (3)	Middle (4)	Rich (5)	Rural (6)	Urban (7)
Panel A: Private Facilities							
In Utero Drought	0.044	-0.045	0.007	0.021	-0.230***	0.008	-0.027
	(0.034)	(0.031)	(0.033)	(0.039)	(0.074)	(0.031)	(0.038)
Early Life Drought	-0.103***	-0.126***	-0.106**	-0.129***	-0.132	-0.119***	-0.137***
	(0.037)	(0.038)	(0.045)	(0.047)	(0.111)	(0.040)	(0.050)
Healthcare Quality	-0.098	0.310*	0.404	0.046	0.136	-0.073	0.174
	(0.211)	(0.186)	(0.459)	(0.228)	(0.364)	(0.262)	(0.247)
Early Life × HQ	0.590	0.389	-0.444	0.979***	0.330	0.355	0.665*
	(0.372)	(0.419)	(0.964)	(0.369)	(0.499)	(0.541)	(0.372)
Observations	12,509	12,348	14,735	8,175	1,947	17,506	7,351
Panel B: Doctor Availability							
In Utero Drought	0.044	-0.044	0.004	0.023	-0.231***	0.007	-0.024
	(0.034)	(0.031)	(0.033)	(0.040)	(0.074)	(0.031)	(0.038)
Early Life Drought	-0.096**	-0.135***	-0.098*	-0.113*	-0.140	-0.101*	-0.167**
	(0.048)	(0.051)	(0.054)	(0.067)	(0.142)	(0.052)	(0.066)
Healthcare Quality	0.296	0.411*	0.716**	0.130	-0.388	0.424	-0.042
	(0.255)	(0.232)	(0.321)	(0.274)	(0.652)	(0.306)	(0.312)
Early Life × HQ	0.224	0.215	-0.342	0.364	0.276	-0.091	0.629
	(0.394)	(0.401)	(0.474)	(0.547)	(0.640)	(0.442)	(0.438)
Observations	12,509	12,348	14,735	8,175	1,947	17,506	7,351
Panel C: IMCI Training							
In Utero Drought	0.045	-0.044	0.005	0.024	-0.222***	0.007	-0.027
	(0.034)	(0.031)	(0.033)	(0.040)	(0.074)	(0.032)	(0.038)
Early Life Drought	-0.070	-0.118**	-0.089	-0.180***	0.064	-0.073	-0.180**
	(0.055)	(0.052)	(0.058)	(0.067)	(0.158)	(0.054)	(0.079)
Healthcare Quality	-0.322	0.306	-0.012	-0.782	3.393***	-0.019	-0.077
	(0.407)	(0.432)	(0.401)	(0.581)	(1.285)	(0.387)	(0.643)
Early Life × HQ	-0.098	0.100	-0.722	1.971*	-3.335	-0.755	1.619
	(0.889)	(0.824)	(0.829)	(1.011)	(2.661)	(0.829)	(1.156)
Observations	12,509	12,348	14,735	8,175	1,947	17,506	7,351
Panel D: Routine Fees							
In Utero Drought	0.042	-0.049	0.002	0.018	-0.231***	0.005	-0.032
	(0.034)	(0.031)	(0.033)	(0.040)	(0.075)	(0.031)	(0.039)
Early Life Drought	0.504	0.249	0.349	0.333	0.130	0.314	0.404
	(0.375)	(0.404)	(0.409)	(0.493)	(0.859)	(0.405)	(0.460)
Healthcare Quality	0.289	0.494**	0.444**	0.553	0.220	0.334	0.565*
	(0.246)	(0.208)	(0.210)	(0.339)	(0.621)	(0.215)	(0.339)
Early Life × HQ	-0.625	-0.390	-0.506	-0.432	-0.243	-0.454	-0.533
	(0.407)	(0.434)	(0.441)	(0.537)	(0.952)	(0.435)	(0.497)
Observations	12,509	12,348	14,735	8,175	1,947	17,506	7,351
Panel E: Vaccine Fees							
In Utero Drought	0.044	-0.047	0.003	0.023	-0.235***	0.006	-0.028
	(0.034)	(0.031)	(0.032)	(0.040)	(0.074)	(0.031)	(0.038)
Early Life Drought	-0.065*	-0.122***	-0.105***	-0.075*	-0.118	-0.103***	-0.096**
	(0.034)	(0.034)	(0.038)	(0.040)	(0.085)	(0.036)	(0.042)
Healthcare Quality	-0.298	-0.465*	-0.571**	0.306	-1.042	-0.438	-0.255
	(0.267)	(0.254)	(0.248)	(0.376)	(1.072)	(0.277)	(0.412)
Early Life × HQ	-0.505	0.230	-0.928	0.183	0.692	-0.283	0.017
	(0.578)	(0.548)	(0.701)	(0.489)	(1.148)	(0.515)	(0.730)
Observations	12,509	12,348	14,735	8,175	1,947	17,506	7,351
Panel F: Delivery Fees							
In Utero Drought	0.044	-0.044	0.009	0.021	-0.231***	0.009	-0.027
	(0.034)	(0.031)	(0.033)	(0.040)	(0.075)	(0.032)	(0.038)
Early Life Drought	-0.067	-0.181***	-0.166***	-0.141*	-0.011	-0.141**	-0.151*
	(0.066)	(0.057)	(0.056)	(0.077)	(0.202)	(0.060)	(0.082)
Healthcare Quality	0.224***	0.146**	0.192***	0.168*	0.203	0.222***	0.226**
	(0.059)	(0.062)	(0.062)	(0.087)	(0.245)	(0.062)	(0.102)
Early Life × HQ	-0.008	0.144	0.103	0.135	-0.135	0.068	0.138
	(0.115)	(0.096)	(0.105)	(0.126)	(0.331)	(0.103)	(0.140)
Observations	12,509	12,348	14,735	8,175	1,947	17,506	7,351

Notes: Tests whether healthcare quality at 24 months moderates early life drought effects across demographic subgroups. *p<0.10, **p<0.05, ***p<0.01.

A.7 Robustness 7: Excluding Survey Year Fixed Effects

Table 22: Robustness 7: Excluding Survey Year FE (Models 1 & 2)

	Height-for-age Z-score (HAZ)						
	Baseline	Private Facilities	Doctor Availability	IMCI Training	Routine Fees	Vaccine Fees	Delivery Fees
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Main Variables							
In Utero Drought	0.001	0.000	0.001	0.001	-0.001	0.004	0.003
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Early Life Drought	-0.073***	-0.069***	-0.074***	-0.073***	-0.070***	-0.071***	-0.066***
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Healthcare Quality at 24 Months		0.228	0.417**	-0.113	0.182	0.383**	0.174***
		(0.145)	(0.164)	(0.292)	(0.156)	(0.163)	(0.045)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects							
Cluster	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics							
Observations	24,857	24,857	24,857	24,857	24,857	24,857	24,857

Notes: Model (1) shows baseline effects. Models (2)-(7) add each healthcare quality indicator separately. All models include controls for child characteristics (age, sex, birth order, singleton status), maternal characteristics (age at birth, education), and household characteristics (wealth quintile, urban/rural, household size). Fixed effects for DHS cluster and birth season included. Standard errors clustered at DHS cluster level. *p<0.10, **p<0.05, ***p<0.01.

Table 23: Robustness 7: Excluding Survey Year FE (Model 3a - Gestational Healthcare)

	Height-for-age Z-score (HAZ)					
	Private Facilities	Doctor Availability	IMCI Training	Routine Fees	Vaccine Fees	Delivery Fees
	(1)	(2)	(3)	(4)	(5)	(6)
Main Variables						
In Utero Drought	0.013	0.049	0.033	0.311	0.011	0.009
	(0.030)	(0.042)	(0.044)	(0.321)	(0.027)	(0.055)
Early Life Drought	-0.083***	-0.085***	-0.085***	-0.087***	-0.080***	-0.078***
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Healthcare Quality at Birth Year	0.092	0.238	-0.181	-0.150	0.135***	0.155***
	(0.093)	(0.231)	(0.355)	(0.145)	(0.042)	(0.049)
In Utero × Healthcare Quality	-0.185	-0.526	-0.695	-0.333	0.100	-0.006
	(0.281)	(0.378)	(0.781)	(0.348)	(0.175)	(0.088)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
Cluster	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics						
Observations	23,473	23,473	23,473	23,473	23,473	23,473

Notes: Testing whether healthcare quality at birth year moderates in utero drought effects. Sample restricted to observations with birth year healthcare quality data. Each column represents a separate regression with the specified healthcare quality indicator and its interaction with in utero drought. All models include controls for child characteristics (age, sex, birth order, singleton status), maternal characteristics (age at birth, education), and household characteristics (wealth quintile, urban/rural, household size). Fixed effects for DHS cluster and birth season included. Standard errors clustered at DHS cluster level. *p<0.10, **p<0.05, ***p<0.01.

Table 24: Robustness 7: Excluding Survey Year FE (Model 3b - Early-Life Healthcare)

	Height-for-age Z-score (HAZ)					
	Private Facilities (1)	Doctor Availability (2)	IMCI Training (3)	Routine Fees (4)	Vaccine Fees (5)	Delivery Fees (6)
Main Variables						
In Utero Drought	0.001	0.001	0.002	-0.001	0.003	0.004
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Early Life Drought	-0.100***	-0.098***	-0.076*	0.277	-0.075***	-0.093**
	(0.028)	(0.037)	(0.040)	(0.296)	(0.025)	(0.046)
Healthcare Quality at 24 Months	0.150	0.343*	-0.126	0.271	0.349**	0.165***
	(0.152)	(0.192)	(0.313)	(0.184)	(0.176)	(0.047)
Early Life × Healthcare Quality	0.638**	0.259	0.070	-0.377	0.203	0.053
	(0.274)	(0.302)	(0.636)	(0.320)	(0.427)	(0.080)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
Cluster	Yes	Yes	Yes	Yes	Yes	Yes
Birth Season	Yes	Yes	Yes	Yes	Yes	Yes
Fit Statistics						
Observations	24,857	24,857	24,857	24,857	24,857	24,857

Notes: Testing whether healthcare quality during early 24 months can moderate negative effects of early-life drought exposure. Each column represents a separate regression with the specified healthcare quality indicator measured at 24 months and its interaction with early life drought. All models include controls for child characteristics (age, sex, birth order, singleton status), maternal characteristics (age at birth, education), and household characteristics (wealth quintile, urban/rural, household size). Fixed effects for DHS cluster and birth season included. Standard errors clustered at DHS cluster level. $^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$.

Statement of Authorship

I hereby confirm that the work presented has been performed and interpreted solely by myself except for where I explicitly identified the contrary. I assure that this work has not been presented in any other form for the fulfillment of any other degree or qualification. Ideas taken from other works in letter and in spirit are identified in every single case.

(Date)	(Signature)