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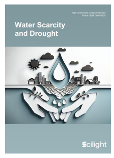

Article

Climate-Nutrition Interaction: Identifying the Mediating Roles of Water Security Using Nationally-Representative Indian Data

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Abstract: Most current research on climate-nutrition interactions centers around how climate impacts food production in ways that worsen nutritional outcomes like child stunting. Possible roles for different aspects of water availability within this dynamic are understudied. Here, we re-examine climate-nutrition interactions while accommodating the role of climatic factors, regional water availability as well as household water access. We used India's nationally representative 2019–21 Demographic and Health Survey data to estimate the impact of climatic factors on household food and water access, child anaemia, and stunting. We analyzed a sample of 166,597 children aged 6–59 months using simple probit and Generalized Structural Equation (GSEM) Modelling based on our adaptation of the UNICEF's nutrition framework. The effect of rainfall anomalies on child stunting depended upon their magnitude. Excess rainfall consistently had positive effects on household food and water access. But if exceeding 30 percent from historical average, more rainfall proved detrimental to child stunting. Rainfall deficit had a consistently negative effect on child nutrition, as did higher temperatures and higher aridity. GSEM findings explicated the mediating role of household water access in climate-nutrition interaction, even after accounting for household food access. These interactions varied regionally. Furthermore, household water access affected child stunting through both sanitation/hygiene pathway and child's diet. Our findings show that climate affects nutrition through household food security as well as household water security and child's diet. Accordingly, there is a need to broaden the policy framework on climate- nutrition relationship, recognizing a key role for household water security.

Keywords: climate; rainfall; food security; water security; temperature; child stunting; dietary diversity; anemia

1. Introduction

Climate change has major implications for food and nutrition security. For every 1 °C of temperature anomaly, there was an estimated increase in severe global food insecurity by 1.4 percent in 2014 and by 1.64 percent in 2019 [1]. Similarly, severe stunting in children is estimated to increase by 23 percent in central sub-Saharan Africa and 62 percent in South Asia by 2050 due to climate change [2]. The 2024 report of the Lancet Countdown on Climate change and health notes that the increase in drought and heatwave events since 1981–2010 has been associated with 151 million more people experiencing moderate or severe food insecurity across 124 countries assessed in 2022 [3]. Climate change effects on food and nutrition come in many forms, including systemic breakdown of food production and distribution as linked to global warming, drought, flooding, precipitation variability and extremes [4–6]. Yet there are surprisingly few studies directly testing climate-water-nutrition pathways [7,8]. There are substantive studies on impact of drought on agriculture and the environment, but studies on the effect of drought on human health are limited in general [9]. In fact, the impact of climate change on health and malnutrition in the literature has primarily been viewed through the lens of food production, food availability and food consumption (including of micronutrients) [10–16] with only recent attention to the role of water [17–22].

Here, temperature increase is conceptualized to affect the consumption of fruit, vegetable and other food groups and therefore micronutrients intake by negatively affecting their production [4,23–25]. Heatwaves and droughts under climate change are also considered as drivers of lower livestock reproduction and productivity [26–30]. Furthermore, higher atmospheric concentration of CO_2 is found to reduce protein and mineral content of cereals adversely affecting the consumption of micronutrients [27]. Some of the studies examining the role of rainfall variability and temperature on child nutrition outcomes do accommodate the underlying multidimensionality but only partially. Ahmed examines the impact of past and current weather variability on child's nutrition status but focuses only on calorie and micronutrient consumption [31]. Using multi-level and spatial regression approach, Amegbor et al. find that climatic factors such as rainfall and temperature are significantly associated with child stunting, though the direction of the association vary across contexts [32]. Based on their study in Uganda, Amondo et al. establish an indirect effect of extreme weather events on child's Height-Age z-score channelled through access to calorie and micronutrient consumption and livestock holding [33]. Extreme weather events- excess heat and drought in general have been found to be detrimental to supply of food and nutrients [34–36] potentially having adverse effect on child anthropometry [33]. However, there are contradictory results as well [37]. For example—it has been found that rise in diurnal temperature leads to decrease in likelihood of child stunting [32,38]. While rainfall has been found to have positive effect on child's linear growth [39,40], excessive rainfall is detrimental to the same [41,42]. Dimitrova and Muttarak also find that excess rainfall during Monsoon season elevates the risk of child stunting in India but there was no evidence that dry monsoon weather increases the risk of undernutrition [43]. Some of the inconsistencies in findings on climate change's impact on nutrition could also be attributed to difference in study context as well as study design. Overall, a positive association between increased average monthly precipitation and reduced risk of childhood and between increased temperature and increased risk of malnutrition has been established.

Out of the studies looking at climate-nutrition link, only one accommodated the role of water and found that districts having higher water access have higher prevalence of underweight among children [44]. We identify here an opportunity to test the role of household water security as a mechanism in these climate-nutrition pathways. Existing studies largely bypass the role of water security, except through agricultural production, except for a small emerging literature around food and water insecurity [17–22]. Our work contributes by exploring the association between climate change and human nutrition in ways that go beyond issues of availability of food or calorie consumption [45,46]. Climatic factors such as variability in precipitation, aridity, drought and temperature affect child nutrition outcomes through several pathways. They not only affect food production, and water availability but also household food access and household water security as well as any interaction among them.

Besides its much discussed role in food production and household food availability [47–50], water affects nutrition outcomes in multiple other ways. At individual level, everyone needs water for bodily functioning. At household level, water security is needed for household agriculture, food preparation and sanitation. Greater water availability in the environment promotes greater crop diversification, multi-cropping [51] and greater availability of water-based animal foods both leading to an increase in availability of the diverse foods in the market for purchase and/ or grown within household premises [52–54]. At the same time, lack of water access due to drought can cause low intake of balanced diets or intake of fruits and vegetables [55], apart from increased exposure to water, food and vector borne diseases [9].

Household water insecurity also influences household's consumption preferences. For example—in water scarce context, people may prefer to grow and eat less water-intensive food [51,52,56]. Water is required for food preparation [57,58] and has been found to affect child's access to dietary diversity [59] and through it child stunting [60,61]. Preparation of complementary food for children is water intensive and water has been identified as a critical ingredient commonly comprising 70 to 90 percent of ingredient proportions [62,63]. Furthermore, household water fetching and management is often into the domain of women [64,65] who are also responsible for caregiving and food preparation [66,67]. These two roles interact to produce varying scenarios of child's dietary intake and nutrition, particularly through competing demand on women's time and energy. Household water access interferes with household budget, where it requires market purchase and siphons off resources away from other preferred consumption items [62,68,69].

The role of household's access to safe water in containing diarrhoea among children and improving child nutrition by promoting sanitation and hygiene (WASH) is well-recognized [70–74]. In context of climate change and increasing drought patterns, water can adversely affect child health and nutrition when it becomes warmer and more stratified due to drought events and promotes the growth of microorganisms (9). A positive association between drought and elevated diarrhoea risk has been identified based on multi-country analysis wherein access to WASH mediates the association [75]. But WASH practices could only partly avert the impact of climate change induced drought. Noticeably, the role of water towards child's nutrition has been viewed predominately through sanitation and hygiene pathway [60,61]. Since child's access to dietary diversity is influenced by household water access, any factor that affects household's access to water will eventually impinge upon child's dietary pattern and therefore, child nutrition [60,61].

Moreover, broadening the climate-nutrition framework is linked to broadening the role of household water access in child nutrition. Accordingly, climate change can affect child nutrition outcomes by affecting household's access to food or water or child's access to diet and sanitation or all of these pathways. Despite the recognition of the multidimensional pathways connecting water and nutrition, discussion on climatic impact on nutrition has been food-centric.

We use a very large nationally representative dataset from India to test some fundamental relationships between climatic factors such as rainfall anomaly, current temperature and past aridity pattern on child's stunting while simultaneously accommodating the role of both household food security and household water security. We propose that climatic factors impinge upon child's linear growth not only by affecting food availability and household food access, but also through their effect on household's water access and child's diet. Thus, both food and water security mediate the impact of climate on child nutrition while also interacting with each other. In addition, we also consider the role of regional water availability in shaping these interactions since water availability has direct implications for agriculture and food production. We adapt UNICEF's latest framework on the determinant of child nutrition to operationalize the theorized relationships [76]. In doing so, we explore the role of household water security on child nutrition through pathways that go beyond the WASH mechanism. We argue that household water access affects child nutrition directly through WASH mechanism and indirectly through child's diet.

2. Data and Methodology

This paper uses data obtained from India Demographic and Health Survey (DHS) 2019–21 [77]. DHS is a nationally representative survey (conducted usually on five yearly basis) providing comprehensive information on child nutrition, care, feeding practices and relevant socio-demographic information on the household (see supplementary file for details). The unit of analysis here is children with overall population size was 171,458. The sample accounts for approximately 96 percent (N = 166,597) of the cases. The sample includes children nested in a relatively smaller number of households. The inclusion criteria for children were; if they aged 6–59 months and they had complete data on the outcome, mediating, and predictor variables of interest.

Data on geospatial covariates—rain fall, aridity and temperature—has been obtained from DHS' spatial data repository spanning 2000 to 2020. This data set is a collection of data obtained from multiple different sources and includes a set of standardized files of commonly used geospatial covariate [78]. In this analysis, we have linked this data set to standard DHS datasets using common cluster identifier.

2.1. Dependent Variables

Our dependent variable is whether the child is stunted or not, based on child's Height and Age z (HAZ) scores. HAZ is calculated as the difference between the individual and the reference population median, divided by the standard deviation of the reference population [78]. A child with a z-score below 2 standard deviation is considered as stunted or too short for their age. Our dependent variable is dichotomous, assuming value '0' if the child is not stunted and '1' if the child is stunted.

2.2. Key Explanatory Variables: Rainfall Anomaly, Aridity Index, Maximum Temperature and Regional Water Availability

Rainfall anomaly is our first key covariate. It is a categorical variable of three levels—normal, excess and deficit. Normal rainfall in India is defined as rainfall that is within 10 percent of the long period average so that excess rainfall is above 110 percent of the long term average and deficit rainfall is less than 90 percent of the long term average [79]. We estimated normal rainfall as long term average i.e., average of rainfall between 2000 to 2020.

Aridity index is our second climatic covariate of key interest. It is calculated as average yearly precipitation divided by average yearly potential evapotranspiration and is a key parameter in drought characterization [80]. This indicator is based on data spanning 1960 to 1990 and is our variable to represent historical climatic condition. The index ranges between 0.01 (Hyper Arid) and 0.99 (Humid). Thus, higher index value indicates less aridity.

Maximum temperature (2020) is our fourth climatic covariate. It is estimated for within the 2 km (urban) or 10 km (rural) buffer surrounding the DHS survey cluster location and is calculated from the modelled mean temperature and the modelled diurnal temperature range [80].

Our fourth climatic variable is water availability region as an indicator of regional water context. We did spatial classification of India on the basis of a Surface Water Availability Index (81) (For methodology, see "India Water Tool" Technical Note [81]. The value of the indicator ranges from 1(low) to 0 (high) availability. The index classified India in six water availability regions, which have been recoded here in three categories (see Figure 1): Low water availability region (LWAR), medium water availability region (MWAR), and high water availability region (HWAR). Based on this scheme, HWAR included all north-eastern Indian states (with the exception of Arunachal Pradesh), along with West Bengal, Himachal Pradesh, Punjab, Haryana, Uttarakhand, Kerala, and Goa. Medium water availability region includes Bihar, Jharkhand, Odisha, Andhra Pradesh, Tamil Nadu, Maharashtra, Karnataka, Telangana, Jammu & Kashmir, and Gujarat come under of India. Finally, LWAR includes, Arunachal Pradesh, Madhya Pradesh, Rajasthan, Chhattisgarh, and Uttar Pradesh.

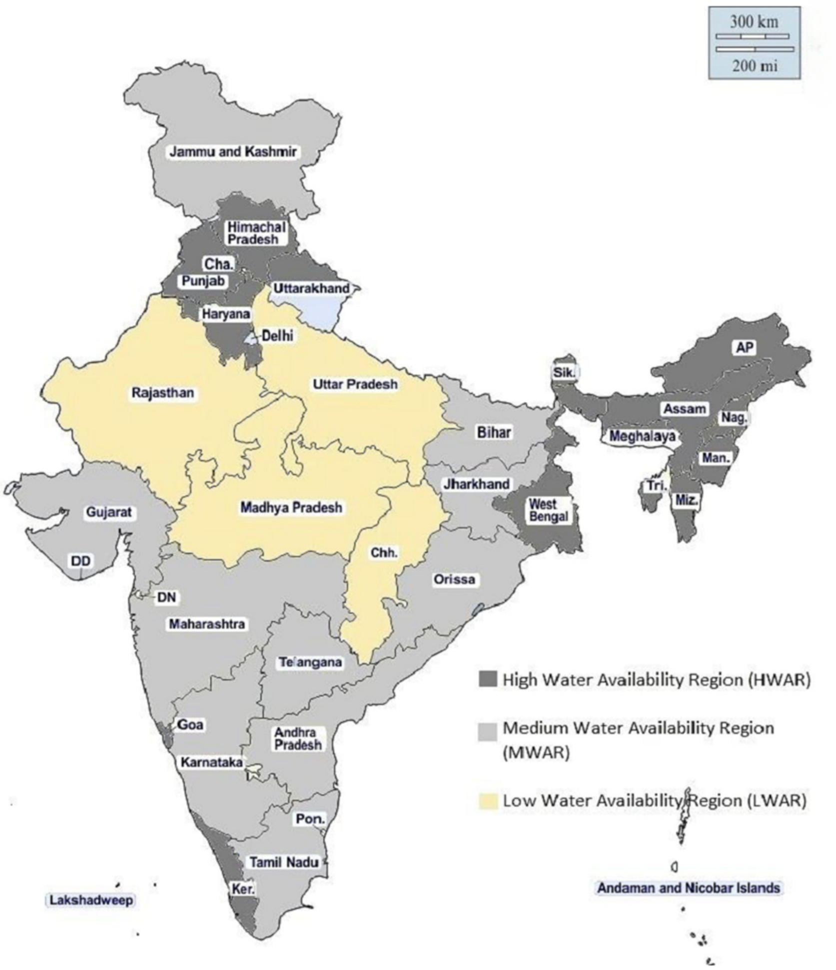

Figure 1. Classification of India based on Water Availability Index. Source: Authors' construct based on [75].

We account for temporality by creating a variable representing pre-monsoon, monsoon and post monsoon season based on month of the survey. Association between child undernutrition and exposure to excess rain during monsoon has been reported in previous studies [82,83]. Seasonality associated with monsoon affects child's dietary diversity as well as anthropometric outcomes [84].

Other covariates: we constructed an asset index to take relative household material wealth into account in the models instead of using DHS household wealth index. This is because the DHS wealth index already includes variables on water, which is our separate explanatory variable. We construct the asset using the methodology similar to the standard DHS constructed wealth index [85]. The variables used include housing characteristics, cooking fuel type, and ownership of specific consumer goods. We then construct five household asset classes by dividing the n-ranked distribution into five quartiles based on the absolute scores for the entire country sample.

We account for household sanitation by including the variable WHO toilet i.e., whether the household has access to improved toilet as per WHO/UNICEF norms [86]. The following types of toilets are categorized as improved source of sanitation provided they are “unshared” between households—toilet flush to sewer system, septic tank, pit latrine to anywhere, pit latrine ventilated, pit latrine slab, and composting toilet.

Our other explanatory variables include maternal education (uneducated, primary, secondary, higher), household characteristics like religion (Hindu, Muslim, Christian, Other), caste (Schedule Caste, Schedule Tribe, Other Backward Classes, General), gender of Household head and residence (rural, urban). We include gender of child, age of child, number of under-five children, vitamin A dose and having health card, as child characteristics.

Mediating Variables

Our first mediating variable is household water access, as a key dimension of household water insecurity [87]. There are several measures to assess household water access, such as water source, quantity of water, time to fetch water, or the perceived degree to which household water needs are being met [57,88]. We chose ‘time to fetch water’ as the measure of household water access. In the DHS, time to water is measured in minutes. Time to fetch water is a suitable indicator because water fetching is a gendered task with women mostly shouldering the water fetching burden [64]. Time to water does not only measures how difficult accessing water is, but it simultaneously accounts for women’s time spent in particular activity, which has potential implications for her other tasks such as child care and child feeding. Moreover, time to water affects mostly women, who are also managing household water tasks like fetching as well as child care [89]. We recoded the variable into three levels by following the WHO norms [88]. Household water access is considered to be ‘optimal’ (if water is available in the house or premises), Intermediate (when maximum time to fetch water is 5 min), and Low (time to fetch water is more than 5 min). The last level is categorized after collapsing “no access” and “low” categories due to small sample size. Our initial model also includes household’s access to ‘improved water sources’ as per WHO/UNICEF [86] as an independent variable.

Our second moderating variable is women’s dietary diversity (WDD score). The 2019–21 DHS India included questions on women’s consumption; ‘how often they consume various types of food (never, daily, weekly, or occasionally)’ [90]. We considered women’s consumption of seven food group viz. milk or curd, pulse or bean, leafy vegetable, fruit, egg, fish and chicken or meat. The responses for each question are coded respectively as 0, 1, 2, 3 in the DHS dataset. We recoded these responses as: 0 for never, 1 for occasionally, 2 for weekly and 1 for daily, so that higher value represents higher frequency. We create WDD by adding the recoded responses on consumption of these seven food groups so that the minimum score would be ‘0’ and maximum score would be ‘21’. We consider women’s dietary diversity score as proxy for household food security. Higher WDD score represents better food security status. Dietary diversity or the number of different food groups consumed over a given reference period—is considered as an indicator of household food security because a diverse diet is important in itself; it leads to improved child nutrition outcomes and greater calorie and protein adequacy [91]. Although dietary diversity score does not account for food preferences, it has generally been found to be associated with improved food and nutrition outcomes for individuals and households [91–93].

Our third mediating variable is anemia among children, as an indicator of child’s diet since the DHS data does not provide dietary data for children above 23 months. Inadequacy in child’s diet and dietary diversity is a key correlate of child anaemia [94]. Anemia is most commonly caused by poor dietary diversity and nutritional deficiency, particularly of iron [95]. In our model anemia is a four-level variables having following values: severe, moderate, mild and no anemia.

2.3. Conceptual Framework and Estimation Strategy

Our conceptual framework is based on the interaction between climate, regional water availability, household water access, household food security and child nutrition which is juxtaposed within the UNICEF [76] framework on determinants (enabling, underlying and immediate) of child nutrition (Figure 2). The variables have been regrouped accordingly. The UNICEF framework identifies systematically the determinants of child malnutrition at multiple levels. Enabling, underlying and immediate variables are separate but interrelated groups of determinants of malnutrition. However, this framework does not explicitly show the role of climatic variables. We have expanded this framework to incorporate the climatic factors and this expanded framework serves as our conceptual framework and guides the analysis. We propose that climatic factors and regional water availability affect both food and water security at the household level. These two further affect child nutrition outcomes by affecting child's diet and household nutrition practices. Moreover, in our model, household food and household water security mediate the effect of climate on child's diet (anemia), and then on child stunting.

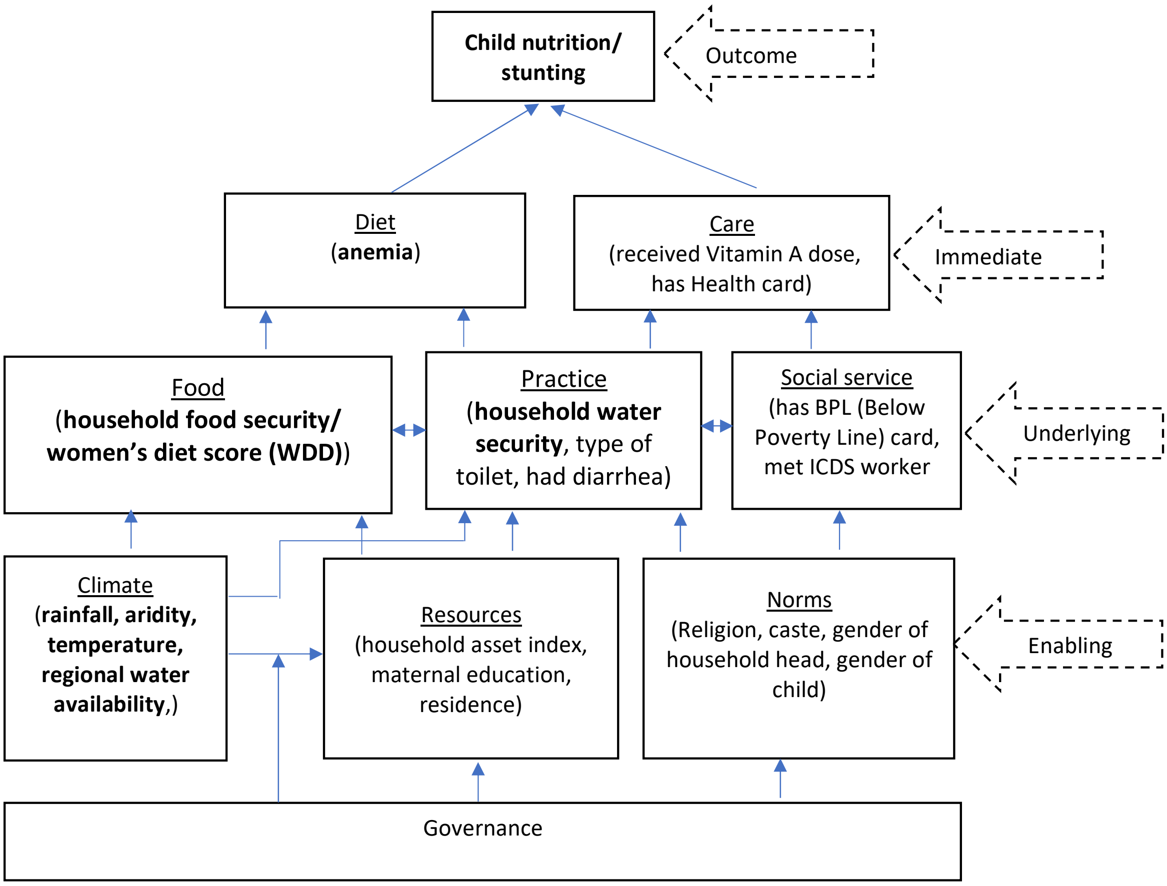

Figure 2. Conceptual framework on determinants of child nutrition and role of climatic factors. Source: Adapted from UNICEF [76].

First, we estimate separate probit models each with three different groups (enabling, underlying and immediate) of determinants as the only covariates (Equation (1)). We chose probit model because our dependent variable (stunted/not stunted) is dichotomous. The probit models help in identifying direct relationships between independent variables and child stunting. Based on performance of these models, we also conduct the mediation analysis. Since our framework has multiple mediations, we apply structural equation modelling (SEM) as the methodological strategy. SEM is particularly useful in case of linked regression style equations involving endogenous explanatory variables [96]. It is considered to be a benchmark for exploratory mediation analysis [97] and is the preferred method for mediation analysis with multiple mediators [98]. Furthermore, our dependent variable is dichotomous and mediating variables are categorical (multinomial), hence we run generalized SEM or GSEM with on a series of Equations (2)–(5). For the GSEM, we collapse enabling, underlying and immediate determinants of child stunting into a single model. Finally, we again run three separate probit models as per Equation (1) for LWAR, MWAR and HWAR, using enabling determinants only.

$$Y_{1(0,1)} = \alpha + \beta(X) + \varepsilon_1 \quad (1)$$

Let Y be the probability of child being stunted in simple probit model (Equation (1)). Here, X represents immediate, underlying or enabling determinants.

$$Y_{1(0,1)} = \alpha_1 + \beta_1\, Y_2 + \mu_1\, (X_1) + \varepsilon_1 \quad (2)$$

$$Y_{2(0,1,2,3,4)} = \alpha_2 + \beta_2\, (Y_3) + \mu_2\, (Y_4) + \varepsilon_2 \quad (3)$$

$$Y_3 = \alpha_3 + \beta_3 (Y_4) + \mu_3 (X_2) + \lambda_1 (X_3) + \delta_1 (X_5) + \varepsilon_3 \quad (4)$$

$$Y_{4(0,1,2)} = \alpha_4 + \beta_4 (X_2) + \mu_4 (X_3) + \lambda_2 (X_4) + \delta_2 (X_5) + \varepsilon_4 \quad (5)$$

Let Y_1 be the probability of child being stunted for the GSEM model. Y_2 is the risk of child being severe anemic, moderate anemic, mild anemic or not anemic. X_1 is immediate, underlying and enabling determinant. Y_3 is WDD score (Household food security score). Y_4 is the risk that household water access is optimal, intermediate or low. X_2, X_3, X_4 and X_5 are rainfall anomaly, temperature, aridity and regional water availability respectively.

3. Results

Table 1 gives the proportion of sample with various degrees of rainfall anomaly across high, medium and low water availability regions. Only 8.36 percent of sample in HWAR experiences normal rainfall, with majority of 75.6 percent experiencing excess rainfall. In contrast, in LWAR, around 15 percent of sample experiences normal rainfall and around 49 percent and 36 percent of them is exposed to excess and deficit rainfall respectively. Smaller proportion of sample in MWAR receives normal rainfall. Parallelly, the percentage of sample in MWAR exposed to deficient rain is higher than both in HWAR and LWAR. However, this is not the case for excess rainfall.

Table 1. Percentage of rainfall anomaly cases across water availability regions.

		10 Percent Variation	
War	**Normal**	**Excess**	**Deficit**
HWAR	8.36	75.64	16.00
MWAR	6.20	52.12	41.68
LWAR	14.93	49.18	35.89
		20 Percent Variation	
HWAR	45.99	41.57	12.44
MWAR	22.12	41.18	36.71
LWAR	38.10	29.18	32.72

[At 95 percent confidence level].

3.1. The Impact of Rainfall Anomaly Varies with Its Magnitude

Table 2 gives probit and linear regression estimates respectively for child's stunting and WDD with climate variable only. Since one of our dependent variables, 'stunting' is dichotomous representing the probability of stunting, we present here marginal effect for each predictor. Marginal effect shows the association between the dependent and independent variables in terms of change in probability of occurring the event (i.e., probability of dependent variable or stunting here) in response to a unit change in independent variable. However, WDD is a continuous variable and its coefficient shows increase in WDD in response to a unit increase in the independent variable. We estimate the relationship at various level of rainfall anomalies. An excess rainfall by ten percent does not affect the probability of stunting among children but raised the WDD score by 6 percent. However, a ten percent rainfall deficit has no significant effect either on stunting or on WDD. A 20 percent increase in rainfall compared to normal rainfall significantly increases the WDD score by 19 percent but does not affect child stunting. But 20 percent rainfall deficit is significantly associated with both stunting and WDD score. An excess rainfall by 30 percent raises the probability of stunting by 2.6 percent and WDD score by 21 percent while a 30 percent deficit in rainfall raises the probability of child stunting by 4.2 percent and reduces WDD score by 2.7 percent. At the same time aridity and temperature show consistent results. Irrespective of the level of rainfall anomaly, a unit increase in log of aridity index is associated significantly with a decline in probability of stunting and increase in WDD score. A unit increase in log of maximum temperature is significantly associated with an increase in probability of stunting and decrease in WDD score.

Figure 3 gives child's HAZ score and WDD score at different levels of anomaly in rainfall. The anomaly ranges from 50 percent deficit to 50 percent excess. Child's HAZ score is lower in case of both deficit and excess in rainfall. Thus, as the rainfall anomaly increases beyond certain level in either direction, the HAZ score declines.

Table 2. Probit results for stunting and linear regression estimates for WDD at various level of rain anomaly.

(N = 166,597)						
	Marginal Effect	**Marginal Effect**	**Marginal Effect**	**Coefficient**	**Coefficient**	**Coefficient**
Resources	**Stunted**			**WDD**		
Rainfall anomaly (ref: normal)	10%	(20%)	(30%)	10%	(20%)	(30%)
Excess	0.0141554 (0.0105832)	0.010873 (0.0065174)	0.0267514 ** (0.007592)	0.061355 * (0.0311839)	0.196303 ** (0.023199)	0.212832 ** (0.021766)
Deficit	0.0155515 (0.0111412)	0.0205572 ** (0.0080132)	0.0421531 ** (0.0077233)	0.0416152 (0.031790)	−0.020651 ** (0.0243629)	−0.02666 ** (0.0222519)
Log of Aridity index	−0.018686 ** (0.0030617)	−0.0190 ** (0.0029794)	−0.0185426 ** (0.0030746)	0.42106 ** (0.009719)		0.4070379 ** (0.0096668)
Log of Max temperature	0.042434 ** (0.003293)	0.0393 ** (0.0031908)	0.0388516 ** (0.0033177)	−0.24790 ** (0.0113213)	−0.23961 ** (0.0111398)	−0.227674 ** (0.0110392)

** significant at 0.01 level; * significance at 0.05 level.

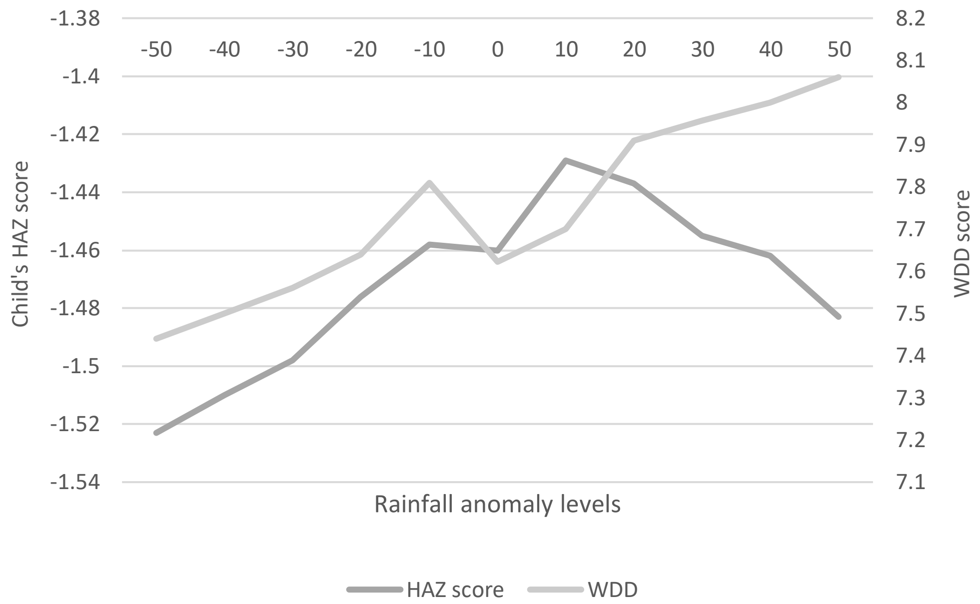

Figure 3. Child's HAZ score and WDD at various levels of rainfall anomaly.

3.2. Climate, Water Availability and Household Water Access—Each Affects Child Nutrition

Table 3 gives results from *probit* regression on stunting run separately at all the three levels of the conceptual framework (Figure 2). Since 10 percent rain anomaly (excess or deficit) does not have a significant effect on child stunting, we use a rainfall anomaly of 20 percent in further analysis. Our variables of interest are rainfall anomaly, aridity index, maximum temperature, regional water availability and household water access. All these variables appear as significant in the models at 0.01 level of significance. As compared to normal rainfall, excess rainfall by 20 percent is not significantly associated with child stunting. However, a rainfall deficit raises the probability of stunting by 3.8 percent. A unit increase in log of aridity index is associated with decrease in probability of stunting by 1.3 percent. An increase in log of maximum temperature by one unit raises the probability of child stunting by 3.9 percent. Children residing in medium and low water availability regions have higher probability of being stunted than those from high water availability region by 2.2 percent and 4.7 percent respectively. In addition, household water access also appears as significant in the model using underlying variables. As compared to children living in household with optimal water access, those in households with intermediate and low water access have higher probability of child stunting by 1.8 percent and 1.7 percent respectively. Household's access to improved water source is not significant, hence we drop it from further analysis.

The second group of variables of our interest—WDD and child's anemia status are also significant in the model using underlying and immediate determinants respectively. An improvement in WDD by one is associated with 2.1 percent decline in the probability of child stunting. The probability of stunting also decreases as child's anemia status improves. A non-anemic child has 12 percent lower probability of being stunted than a severely anemic child. Temporality also affects the probability of stunting. In pre-monsoon period, the probability of stunting is 10 percent lower than that in monsoon season. There is no significant difference in probabilities of stunting between monsoon and post monsoon season.

Other significant variables include household asset, maternal education, religion, caste, residence, gender of household head and child's gender. Being in households with higher asset score and having more educated mothers is associated with lower probability of stunting among children. Being a Muslim is associated with increased probability of child stunting as compared to a Hindu child. Similarly, belonging to SC caste is associated with higher probability of child stunting as compared to ST, OBC and General castes. Children in female headed households have higher probability of being stunted whereas female children have lower likelihood of being stunted. Access to toilet as per WHO criteria is associated with lowered risk of stunting. Having a health card is also associated with lowered risk of stunting but having experienced diarrhea is associated with increased risk of child stunting.

Table 3. Probit results for determinants of stunting at three levels of the UNICEF Framework.

Enabling (N = 166,597)		**Underlying (N = 166,597)**		**Immediate (N = 166,597)**	
	Marginal Effect		**Marginal Effect**		**Marginal Effect**
RESOURCES		**FOOD**		**DIET**	
Rainfall variation (ref: normal)		WDD	−0.0215 ** (0.0034514)	Has anemia (ref: severe)	
Excess	−0.00124 0.0102597	**PRACTICE**		Moderate	−0.0420 ** (0.0152142)
Deficit	−0.03873 ** (0.0065344)	Household water access (ref: optimal)		Mild	−0.0916 ** (0.0156841)
Log of Aridity index	−0.0130 ** (0.003794)	Intermediate	0.0182 ** (0.0141525)	Not anemic	−0.1231 ** (0.0158932)
Log of Max temperature	0.03883 ** (0.0031908)	Low	0.0172 * (0.0458682)	**CARE**	
Water availability region (ref: high)		Improved water source (ref: no)		Had vitamin A (ref: no)	
Medium	0.02260 ** (0.0062013)	Yes	0.0083 (0.0248352)	Yes	−0.0049 (0.0043248)
Low	0.04791 ** (0.006526)	Access to WHO toilet (ref: no)		Health card (ref: no)	
Season (ref: monsoon)		Yes	−0.0808 ** (0.0131902)	Yes	−0.0367 ** (0.0134792)
Pre-monsoon	−0.1061804 ** (0.0141475)	Had diarrhea recently (ref: no)			
Post-monsoon	0.0234395 (0.0156273)	Yes	0.0357 ** (0.0212535)		
Asset class (ref: lowest)		**SERVICES**			
Lower	−0.0337 ** (0.0050237)	Has BPL card (ref: no)			
Medium	−0.0788 ** (0.00517)	Yes	0.0364 ** (0.012485)		
Higher	−0.1047 ** (0.0058198)	Met Anganwadi worker (ref: no)			
Highest	−0.1503 ** (0.0063892)	Yes	0.0036 (0.0133618)		
Maternal education (ref: uneducated)					
Primary	−0.0300 ** (0058435)				
Secondary	−0.0888 ** (0.004603)				
Higher	−0.1567 ** (0.0064492)				
Residence (ref: urban)					
Rural	0.0005 (0.0050981)				

Table 3. *Cont.*

Enabling (N = 166,597)		Underlying (N = 166,597)		Immediate (N = 166,597)	
	Marginal Effect		Marginal Effect		Marginal Effect
NORMS					
Religion (ref: Hindu)					
Muslim	0.0314 ** (0.0061655)				
Christian	−0.0016 (0.0109904)				
Other	−0.0295 ** (0.0102792)				
Caste (ref: SC					
ST	−0.0213 ** (0.0058859)				
OBC	−0.0285 ** (0.0044449)				
General	−0.0634 ** (0.005901)				
Gender of household head (ref: male)					
Female	0.0380 ** (0.0047395)				
Gender of child (ref: male)					
Female	−0.0182 ** (0.003118)				

** significant at 0.01 level; * significance at 0.05 level.

3.4. Climate Affects Nutrition Both through Household Food Security and Water Security

Table 4 gives estimates from single GSEM model on child stunting including immediate, underlying and enabling variables (column 2). Marginal effects measure the effect of unit change in the independent variable on dichotomous dependent variable (stunting). However, anemia and time to water are multi-level categorical variables. This requires estimating GSEM linked through multinomial regression. Multinomial estimates give risk ratio for occurrence of each event in relation to a base outcome. Our first mediating variable household water access is significantly affected by climatic factors. Relative to normal rainfall, in case of excess rainfall, risk ratio for low water access is significantly lower while in case of deficit rainfall, risk ratio in favour of low water access is significantly higher relative to optimal water access. Increase in the log of aridity index is associated with decrease in risk ratio in favour of sub-optimal household water access while an increase in the log of maximum temperature increases the risk ratio in favour of sub-optimal (intermediate and basic) household water access. A decrease in log of aridity index is associated with reduction in the risk ratio for low water access by 22 percent as compared to optimal household water access. Household water is also significantly associated with regional water availability. Relative to HWAR, in MWAR and LWAR, risk ratio for intermediate and low water access is higher relative to optimal water access. Risk ratio of intermediate and low water access compared to optimal water access is higher during pre-monsoon period than during monsoon period.

Climatic variables are significant determinants of WDD—our second mediating variable also. As compared to normal rainfall, an excess rainfall causes around 23 percent increase in WDD score while a deficit by 20 percent causes 13.9 percent decrease in WDD score. Increase in log of temperature is associated with a decline in WDD score. Being located in LWAR is associated with significant decrease in WDD score, when compared with HWAR.

WDD is simultaneously affected by household water access. Intermediate and low access to water significantly reduces WDD when compared with households with optimal water access. WDD increases by 18 percent in post monsoon season and reduces by 35 percent in pre monsoon season when compared with monsoon season.

An increase in WDD is positively associated with our third mediating variable Anemia, as an indicator of child's diet. Furthermore, household water access is significantly associated with child anemia. Finally, stunting among children is significantly associated with anemia among them. Having no anemia reduces the odds ratio for being stunted by 0.11 and having mild anemia reduces the odds ratio by around 0.9 when compared with children with severe anemia. WDD has no direct significant association with child stunting. During pre-monsoon the probability of stunting is around 6 percent lower than in monsoon.

Table 4. GSEM results for determinants of stunting with interaction within UNICEF Framework.

	Stunted (N = 166,597)		**Anemia (N = 166,597) (Base Outcome = Severe)**		**WDD (N = 166,597)**		**Household Water Access (N = 166,597) (Base Outcome = Optimal)**	
		Odds Ratio		**Risk Ratio**		**Coefficient**		**Risk Ratio**
Immediate determinants	Anemia level (ref: severe)		Anemia **(moderate)**		Household water access (ref: optimal)		Household water access **(Intermediate)**	
	Moderate	0.9562 ** (0.01080)	WDD	1.0269 ** (0.01011)	Intermediate	−0.05708 * (0.00887)	Season (ref: monsoon)	
	Mild	0.9130 ** (0.01058)	Household water access (ref: optimal		Low	−0.55326 ** (0.0193833)	Pre-monsoon	0.22151 ** (0.0132468)
	No anemia	0.892 ** (0.01047)	Intermediate	0.9075 ** (0.04381)	Rainfall variation (20%) ref: normal)		Post monsoon	−0.0254214 (0.0155597)
	Had vitamin A (ref: no)		Basic	1.124423 0.1548259	Excess	0.239162 ** (0.00323)	Log aridity index	0.9999 (0.00558)
	Yes	1.0282 ** (0.001279)	Anemia **(mild)**		Deficit	−0.13964 ** (0.01344)	Log max temperature	1.1825 ** (0.00734)
	WDD	0.0907 (0.0009522)	WDD	1.067434 ** (0.0105879)	Log of max temperature	−0.22572 ** (0.00356)	Rainfall variation (20%) ref: normal)	
	Household water access (ref: optimal)		Household water access (ref: optimal)		Regional water availability (ref: HWAR)		Excess	0.9902434 (0.012179)
	Intermediate	1.0173 ** (0.00476)	Intermediate	0.999244 (0.041547)	MWAR	0.07789 (0.01158)	Deficit	1.27428 ** (0.0114173)
Underlying determinants	Low	1.014303 (0.01577)	Basic	0.968548 (0.1483691)	LWAR	−0.22948 ** (0.01221)	Regional water availability (ref: high)	
	Season (ref: monsoon)		**No anemia**		Season (ref: monsoon)		Medium	1.3770 ** (0.01607)
	Pre-monsoon	−0.061663 ** (0.0073815)	WDD	1.097126 ** (0108344)	Pre-monsoon	−0.35876 ** (0.0098798)	Low	1.25278 ** (0.016707)
	Post monsoon	−0.0129752 (0.0084852)	Household water access (ref: optimal)		Post monsoon	0.184267 ** (0.0113796)	Household water access **(Low)**	
	Access to WHO toilet (ref: no)		Intermediate	0.95583* (0.0379759)			Season (ref: monsoon)	
	Yes	0.9780 ** (0.0044521)	Basic	0.8892318 ** (0.1235847)			Pre-monsoon	0.573610 ** (0.0482945)
	No. of under-5 children	1.0137 ** (0.0024075)					Post monsoon	−0.22474 ** (0.0637448)
	Gender of head (ref: male)						Log aridity index	0.7806 ** (0.0119526)
	Female	1.0160 ** (0.0055837)					Log max temperature	1.0314 * (0.0214849)
	Gender of child (ref: male)						Rainfall variation (20%) ref: normal)	

Table 4. Cont.

	Stunted (N = 166,597)		**Anemia (N = 166,597) (Base Outcome = Severe)**	**WDD (N = 166,597)**	**Household Water Access (N = 166,597) (Base Outcome = Optimal)**	
		Odds Ratio	**Risk Ratio**	**Coefficient**		**Risk Ratio**
Enabling determinants (Resources and norms)	Female	0.9470 ** (0.0037447)			Excess	0.883913 ** (0.039136)
	Caste (ref: SC)				Deficit	1.16865 ** (0.0432859)
	ST	0.9923 (0.0067135)			Regional water availability (ref: HWAR)	
	OBC	0.9791784 ** (0.0052732)			MWAR	1.21809 ** (0.05901)
	General	0.9449 ** (0.0064618)			LWAR	1.5804 ** (0.09044)
	Residence (ref: urban)					
	Rural	0.9995 (0.0056417)				
	Asset class (ref: lowest)					
	Lower	0.9884 * (0.0059388)				
	Medium	0.9464 ** (0.0059849)				
	Higher	0.9390 ** (0.0065167)				
	Highest	0.9075 ** (0.0071155)				
	Maternal education (ref: unedu)					
	Primary	0.9853 * (0.0070957)				
	Secondary	0.9450 ** 0.0052143				
	Higher	0.9109 ** (0.0071127)				
	Religion (ref: Hindu)					
	Muslim	1.0133 * (0.0067043)				
	Christian	0.9764 ** (0.0082391)				
	Other	0.9635 ** (0.0100162)				

** significant at 0.01 level; * significance at 0.05 level.

3.5. The Effect of Climate on Nutrition Varies across Water Availability Regions

Table 5 gives results from probit regression on child stunting with enabling variables only and across the three water availability regions. Log of aridity index is significantly associated with decline in probability of stunting in HWAR, MWAR as well as LWAR by 2.1 percent, 0.08 percent and 1.1 percent respectively. Log of maximum temperature is significant in MWAR and LWAR and is having a positive effect on child stunting. Rainfall anomaly is not associated with child stunting in HWAR. In MWAR, excess as well as deficit rainfall is associated with an increase in the probability of child stunting. But in LWAR, excess rainfall is associate with 1.3 percent decline in child stunting while a deficit rainfall does not appear as significant. In HWAR, seasonality does not affect probability of stunting significantly. In MWAR, probability of stunting is 13 percent lower in pre-monsoon period than in monsoon period. In LWAR, probability of stunting is significantly higher in post monsoon season.

Table 5. Probit results on enabling determinants of stunting across water availability regions.

	HWAR (38,328)		**MWAR (N = 58,732)**		**LWAR (N = 62,024)**	
	Marginal Effect	**Std. Error**	**Marginal Effect**	**Std. Error**	**Marginal Effect**	**Std. Error**
Rainfall variation (20%) (ref: normal)						
Excess	0.0038055	0.0054993	0.014309 **	0.0054945	−0.01309 **	0.0050259
Deficit	−0.0173762	0.0083356	0.020598 **	0.0058346	0.0046914	0.0049039
Log of aridity	−0.02138 **	0.0019887	−0.00803 **	0.0029244	−0.01121 **	0.0020986
Log of temp	0.0137859	0.0030269	0.02013 **	0.0028017	0.025305 **	0.0041544
Season (ref: monsoon)						
Pre-monsoon	−0.0389711	0.038090	−0.1303118 **	0.0212084	−0.0058658	0.0321818
Post monsoon	−0.0076617	0.035653	0.0425959*	0.019653	0.0664833 **	0.0377019
Asset class (ref: lowest)						
Lower	−0.014855*	0.0075062	−0.02169 **	0.006346	−0.03883 **	0.0057184
Medium	−0.05621 **	0.0077577	−0.07302 **	0.0066726	−0.07205 **	0.0060333
Higher	−0.08355 **	0.0084614	−0.10837 **	0.0070158	−0.09063 **	0.0067865
Highest	−0.12611 **	0.0090825	−0.14898 **	0.007828	−0.14303 **	0.0075724
Maternal education (ref: unedu)						
Primary	−0.012840	0.009546	−0.03615 **	0.0073412	−0.012778 *	0.0064824
Secondary	−0.07761 **	0.0081037	−0.09633 **	0.0054361	−0.06122 **	0.0049601
Higher	−0.15141 **	0.0103088	−0.15779 **	0.0079054	−0.12791 **	0.007157
Religion (ref: Hindu)						
Muslim	0.056558 **	0.0097798	0.016117 **	0.0065757	.03573 **	0.0069059
Christian	0.0013763	0.008659	−0.04495 **	0.0135532	−0.04196 **	0.0136417
Other	−0.04784 **	0.00828	0.04596 **	0.0142898	−0.0586 **	0.0143939
Caste (ref: SC)						
ST	−0.010239	0.0094986	−0.02714 **	0.0066438	−0.03650 **	0.0065791
OBC	−0.03976 **	0.0078412	−0.03440 **	0.0053085	−0.03172 **	0.0051504
General	−0.05948 **	0.0075499	−0.07793 **	0.007056	−0.07846 **	0.0071142
Residence (ref: urban)						
Rural	−0.0024236	0.0066232	0.0186584 **	0.0055217	−0.0002194	0.0059118
Gender of household head (ref: male)						
Female	0.026084 **	0.006232	0.0124497 **	0.0054786	0.0077984	0.0058677

** significant at 0.01 level; * significance at 0.05 level.

Figure 4 gives predicted probability of child stunting at different levels of household water access across three water availability regions. The probability of stunting among children is the highest in case of intermediate water access in LWAR and is the lowest in case of optimal water access in HWAR. Furthermore, in case of optimal water access, the probability of stunting is similar in MWAR and LWAR. The probability of child stunting varies insignificantly between intermediate and low water access.

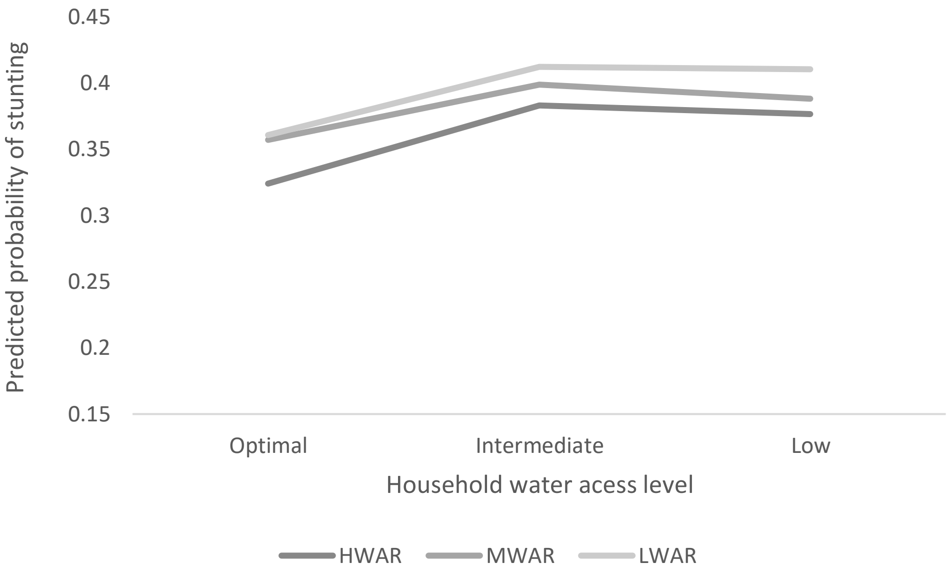

Figure 4. Predicted probability of child stunting by household water access levels across three water availability regions.

3.6. Sensitivity Analysis

GSEM was followed by likelihood ratio test for various climatic variables. Likelihood ratio test showed that the model with climatic variables is a better fit than the constrained model. The Hausman test confirms that our efficient model is better fit than a more complex model with maximum likelihood estimates. The results from these analyses are given in the supplementary file.

4. Discussion

Using a large nationally representative dataset from India, we have been able to test predictions of how climatic factors (rainfall anomaly, aridity and maximum temperature) impinge upon child's linear growth not only by affecting household food access, but also through their interactional effect on household's water access. Our work contributes to a recent growing field of scholarship around food and water insecurity [17–22,99]. Our paper contributes by examining the impact of climatic factors on child nutrition while simultaneously accommodating the role of both household food and household water security as well as the role of varied geographical context. A major strength of this study is to capture the impact of climate change on household water insecurity, along with household food security. The study also incorporates the interactional effect between water and food security and child nutrition. Application of Structural Equation Modelling approach for mediation analysis in context of climate change gives a sound methodological basis to the paper.

We find that excess rainfall has a positive effect on household food security as well as household water security, but not necessarily on child stunting. However, as rainfall deficit increases it consistently has an exacerbating effect on child stunting. The effect of rainfall varies by the magnitude of rainfall anomaly. For example—a 10 or 20 percent rainfall excess has no significant effect on child stunting but 20 percent deficit in rainfall raises the probability of stunting. Furthermore, a 30 percent anomaly in rain weather excess or deficit raises the probability of child stunting. Child's HAZ score is the highest when rainfall is excess by 10 percent and is the lowest when rainfall deficit is the highest. Exposure to excessive rain has been found to be detrimental to child stunting through poor hygiene practices at home [43]. Exposure to deficient rainfall can affect child nutrition through elevated incidence of vector borne disease, reduced household income on increased demand on women's labour [100]. WDD score is the lowest when the deficit is the highest (50 percent) and it increases securely as the level of rainfall increases, even beyond normal. Increase in precipitation has been found to increase dietary diversity independent of mediating socio-economic factors [40]. Improved household food security due to excess rain might have a positive effect on child nutrition, but this improvement is likely compensated by child's increased exposure to waterborne disease particularly diarrheal diseases [101,102]. Our findings also show that overall, the probability of stunting is higher during monsoon season when compared with pre monsoon season. Higher probability of child undernutrition during monsoon season has been reported in earlier studies [83]. Excess rain, especially exposure to flood during monsoon is detrimental to household food security and child's dietary diversity [84,103] and therefore to child nutrition. In contrast, a rainfall deficit is always associated with low WDD score and higher probability of stunting. The negative effect of dry spells on child's diet and through it on child stunting has been reported in other studies [33,104].

Secondly, an increase in aridity index (based on 1960 to 1990 data), as a measure of climatic context, consistently has a positive effect on child nutrition while increase in maximum temperature has a negative effect, both mediated by household food and water security, even after controlling for household economic status. Studies on climate-nutrition linkage have scantly accounted for aridity. Ahmed (2024) have accounted for past weather variability and found its negative effect on household nutrition [31]. Amegbor et al. (2020) find that in arid context, increase in rainfall reduces the likelihood of child stunting [32]. Unlike our finding here, they report positive effect of temperature increase in child stunting. In fact, in certain contexts, temperature is found to have positive effect on agricultural output and child nutrition [44,105]. However, studies on relationship between temperature increase and child's linear growth, have produced conflicting results [37]. Our findings confirm earlier evidence that weather variability, particularly heat stress and drought have a negative effect on dietary intake and nutrition [34,36,42,104,106–108] since it has a damaging effect on crop production [109,110]. In particular, greater variation in temperature can lead to more pronounced changes in dietary diversity [111].

Thirdly, we find that both regional climate and water availability affect stunting among children. Our GSEM results (Table 4) show that climatic variables (rainfall, aridity and temperature) and regional water availability affect child stunting through both household food security and household water security. This is a novel finding since the impact of climate change or the climate-nutrition link has mostly been seen from the perspective of food security or availability [10,46,112,113]. Where role of water is considered, it is primarily from perspective of sanitation and hygiene [114]. As known, climatic factors significantly affect household food security (WDD), which in turn affects stunting among children through affecting child's diet (anaemia) (Table 4).

Regional climate also affects household water access which is significantly associated with rainfall anomaly, regional water availability and maximum temperature wherein excess rainfall reduces the probability of sub-optimal water access and temperature increase raises the probability. Household water access is significantly associated with child stunting with sub-optimal water access raising the probability of stunting. Household water access affects child stunting through its impact on child's diet (anemia) and household food security (WDD) (Table 4). Probability of less or no anemia among child increases with increase in WDD score and vice versa. As compared to optimal water access, sub-optimal (intermediate and low) household water access is associated with reduced WDD. While the role of household food security in child nutrition is well-researched [115–118], the role of household water insecurity (other than WASH) as mediated by child's diet, has only received recent attention. For example- Choudhary et al. [60,61] find that the effect of household water access on child nutrition is mediated by child's dietary diversity even after accounting for the role of sanitation. Household water access can affect child's dietary diversity also through gendered and competing demands on caregiver time [59]. Studies have found that household water insecurity is qualitatively associated with child's dietary diversity in several ways including, delays in infant feeding, as the caregiver spent more time obtaining water [67], budget constraints that may force low-resource households to choose between buying water, food, or fuel [62,68] and greater water need of complementary foods have high water requirements [119].

Finally, we accounted for regional water availability in our model and it also affects child nutrition both through household food security (WDD) and household water access (Table 4). Compared to HWAR, MWAR and LWAR are associated with lower household food and water security. This is likely because households can access diversified food facilitated by water-intensive agricultural and allied activities as well as water-based animal products [51–54]. Similarly, higher regional water availability might enhance household's access to water while water scarcity can reduce the same [120,121].

We show that the effect of climate on nutrition varies across water availability regions but remains consistently significant (Table 5). While in HWAR, positive rainfall anomaly has no significant effect on child stunting, in MWAR it is associated with increased probability of child stunting and in LWAR, it is associated with lower probability of child stunting. This is possible because in the absence of floods, high rainfall may translate into better availability of diverse food for households, thus encouraging good nutrition [33]. Also, the availability of water in LWAR is very low, so excess rain to some extent may not cause excess increase in water availability. The role of context in shaping up the climate-nutrition link has been highlighted elsewhere [7,32]. Finally, an increase in aridity is associated with reduced probability and an increase in temperature is associated with increased probability of child stunting in all regions. Seasonality also has varying effect on child nutrition across different water availability regions. In fact, in HWAR seasonality does not appear to be a significant determinant of stunting in our model. The changing impact of climate and rainfall across varying water availability regions emphasizes the need for an integrated yet context specific water policies. In LWAR water policy should be designed to conserve rainfall water, for example through rain water harvesting. In HWAR and MWAR, flood management along with water run-off management and using methods such as check dams or creating ditches can use used to avert the impact of excess rainfall.

5. Future Direction

Our findings have significant implications for research and policy when addressing child nutrition within a climate change scenario. As rainfall anomaly and rising temperature threaten child nutrition, dedicated social protection programmes are needed for regions prone to climatic variation. Our findings establish the need to broaden the framework on climate change and child nutrition relationship in future research, in particular acknowledging the interaction between climate, household food and household water access. Climate risk mitigation approach needs to be tailored according to the finding that both household food security and household water security mediate the effect of climate and therefore child nutrition comes under threat during excessively low rainfall or relatively higher temperature. However, the dynamics underlying this fact varies geographical context. Since excess rainfall may exacerbate levels of stunting in certain context like MWAR, but may help in reducing stunting in LWAR, different types of policy interventions would be required for these two contexts. Future research can account for interaction between regional water availability and climatic factors to gauge the effects that are interplayed. Our findings also show that the water-nutrition pathway is multidimensional wherein household water security affects child nutrition not only through WASH but also through child's access to diet. More ethnographic studies can be considered for capturing these pathways in holistic way. This finding also shows that interventions to improve household water access can have a direct effect on reducing child stunting through their impact on child's diet, even though the association between WASH intervention may be statistically insignificant [121,122]. Explicating the role of child's diet provides additional window of research and policy intervention for child nutrition in water scarce contexts. Finally, capturing time dimension household water insecurity can enable both research and policy to accommodate women's reproductive role within climate and nutrition framework.

6. Study Limitations

This is a cross-sectional study; hence it does not test causality. In measuring water insecurity, we are unable to account for water quality, which might have additional implications for child nutrition. The survey pertains to 2019–21 and this period may not adequate to represent entire variability or temporality in proposed relationships. Finally, the paper has not been able to account for the Covid scenario. The results may be interpreted accordingly.

7. Concluding Remarks

The impact of climate on child nutrition has received limited research attention. In this study we have examined this impact by accounting for multiple climatic factors as well as geographical context. We find that climate together with regional water availability affects child stunting through both household food and water security. The inter-connection between climate, household water access and nutrition has been hardly examined. Our findings call for broadening the climate-nutrition framework by accommodating more direct role of water.

Supplementary Materials

The additional data and information can be downloaded at: https://media.sciltp.com/articles/others/2507111353002316/WSD-1093-Supplementary-final.pdf.

Author Contributions

N.C.: conceptualization, methodology, initial draft; A.B.: conceptualization, writing, reviewing, editing; A.W.: reviewing, editing. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The data used in this study have been obtained from the Demographic and Health Survey, which is available upon request free of cost.

Conflicts of Interest

The authors declare no conflict of interest.

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