Weather shocks and child nutritional status in rural Bangladesh: Does labor allocation have a role to play?

Kirara Homma* Abu Hayat Md. Islam† Masanori Matsuura-Kannari‡

Bethelhem Legesse Debela§

This is an accepted version of Weather shocks and child nutritional status in rural Bangladesh: Does labor allocation have a role to play? in *Food Policy*.

*Land Economics Group, University of Bonn. E-mail: khomma@uni-bonn.de

†Department of Agricultural Economics, Bangladesh Agricultural University. E-mail: saifulislam.econ@bau.edu.bd

‡Institute of Developing Economies - Japan External Trade Organization (IDE-JETRO) / National Graduate Institute for Policy Studies. E-mail: masanori-matsuura@ide.go.jp

§International Rice Research Institute, Nairobi, Kenya. E-mail: b.debela@cgiar.org

Acknowledgment

This is a substantially revised version of "Weather shocks and child nutritional status in rural households in Bangladesh: Does labor allocation have a role to play?" which is publicly available as IDE Discussion Paper No.907. We are grateful for the comments from John Hoddinott, Yohei Mitani, Ian Coxhead, Tatsuya Shimizu, and Takeshi Aida for their valuable comments. We also thank participants of 10th Anniversary Conference: Food, Environment, and Health—Global Evidence held by TATA-Cornell Institute, a seminar of Institute of Developing Economies (IDE-JETRO), and a seminar at Kyoto University for their helpful suggestions. We appreciate financial support from Kyoto University and JSPS KAKENHI (No. JP22H03812) for participating in the conference and financial support from IDE-JETRO for a language editing service.

Abstract

Despite efforts to improve food and nutrient intake in the last decades, child undernutrition remains a challenge, particularly in rural areas of developing countries. Although household labor reallocation after weather shocks is an important ex-post strategy to mitigate weather-shock impacts, a comprehensive understanding of how households adjust their labor and its implications in the context of child health is lacking. We investigate how different forms of labor activity is associated with the impacts of rainfall shock on child nutritional status, using nationally representative panel data from rural households in Bangladesh, in conjunction with monthly precipitation and temperature data for the last three decades. We find that less rainfall during the main cropping season in the previous year worsens nutritional status of children under the age of five years, while more rainfall in the current year increases child nutrition. We also find heterogeneous associations of different types of labor with the identified linkages between rainfall shock and child nutritional status. While maternal off-farm self-employment plays a potential role in mitigating the negative impact of rainfall shortage, maternal on-farm labor may worsen child nutrition under rainfall shocks. We do not find any significant associations for household-level total labor time and other household members' labor time. Our results therefore underscore the importance of providing sufficient off-farm employment opportunities for mothers and addressing maternal time constraints through targeted policies to cope with extreme weather and improve child nutrition.

Keywords: Child nutrition, Labor allocation, Weather shock, Bangladesh

1. Introduction

Child undernutrition remains a major issue in Bangladesh. According to a nationwide survey in 2019, the percentage of children under the age of five who are underweight, stunted, and wasted are 22.6%, 28%, and 9.8% , respectively (Bangladesh Bureau of Statistics (BBS) and UNICEF, 2019).[1] The situation in Bangladesh is more severe than the global average and may be further exacerbated due to climate change. Bangladesh is one of the world's most vulnerable countries to climate change. The average monthly temperature and the variability of monthly rainfall in Bangladesh have been rising since the 1970s (Hanifi et al., 2022). Such unprecedented weather patterns or extreme weather events reduce the effectiveness of current production strategies based on the previous climate regime (Bandyopadhyay and Skoufias, 2015). This affects agricultural production (e.g., M. W. Cooper et al., 2019; Freudenreich et al., 2022) and therefore threatens food and nutritional security, especially in rural areas of developing countries where many people rely on agriculture for their livelihood (Baker and Anttila-Hughes, 2020; Vogel et al., 2019). Furthermore, excessive rainfall is also the potential threat of child nutritional outcomes in developing countries where access to clean water is limited, since it increases disease prevalence and disease exposure. This, in turn, lowers the uptake and retention of essential nutrients from food (M. Cooper et al., 2019; Omiat and Shively, 2020).

To cope with weather calamities, households adopt different coping strategies, including splitting doses of fertilizers, adopting extreme-weather-tolerant species (Pandey et al., 2007), and diversifying income (Islam et al., 2018; Matsuura-Kannari et al., 2023; Sibhatu and Qaim, 2018). Recent studies have highlighted labor reallocation between on-farm and off-farm activities as a key household coping strategy in response to rainfall shocks (Branco and

[1] The situation is more severe than the global average. Globally, the number of children under the age of five who are stunted or wasted in 2022 is 148.1 million and 45 million, respectively (UNICEF, WHO, and World Bank, 2023a), and 12.3% of children are underweight (UNICEF, WHO, World Bank, 2023b).

Féres, 2021; Musungu et al., 2024). This is an important strategy especially for rural households in developing countries, where shock coping options are limited due to restricted social safety nets and access to credit markets (Branco and Féres, 2021). Furthermore, labor reallocation is more flexible than other ex-ante strategies. While households decide their labor allocation in advance based on historical climate pattern, they can still adjust their labor allocation after observing the actual weather conditions, which optimizes their strategy to enhance household food security under the specific condition. Such labor reallocation, in turn, changes household income and childcare quality, influencing child health in different ways depending on the type of labor reallocated. In this context, whose labor is reallocated is also important. Despite the importance of labor allocation for rural households, limited evidence exists about how labor reallocation can be part of the various coping strategies (Gao and Mills, 2018; Musungu et al., 2024), especially in relation to the implication on child health.

In this paper, we examine the role of household labor allocation as a potential mechanism for mitigating the effect of rainfall shock on child nutrition. Furthermore, we investigate household labor reallocation patterns in response to recent rainfall. To address these aspects, we combine three waves of a nationally representative rural household survey in Bangladesh, which includes household-level labor data and individual-level anthropometric information of children under five years old, with georeferenced historical climate data (rainfall and temperature). We employ a two-way fixed effects model to control for potential unobserved heterogeneities in household characteristics and common trends across households, which may affect child nutrition and labor allocation choices.

This paper contributes to the existing body of knowledge in fourfold. First, while previous studies examined the link between climate and child nutritional status in various settings (e.g., Blom et al., 2022; Maccini and Yang, 2009; Tiwari et al., 2017), the mitigation strategies to the negative climate impacts remain to be clarified.[2] We focus on the potential role of household labor allocation as a mitigation strategy against rainfall shock. Second, much of the previous research on household climate-mitigation strategies has often focused on ex-ante behavior, such as splitting the doses of fertilizers, adopting extreme-weather-tolerant species (Pandey et al., 2007), and diversifying crop and income (Matsuura-Kannari et al., 2023; Sibhatu and Qaim, 2018). An exception is a recent study undertaken by Musungu et al. (2024) that investigates labor allocation in off-farm and on-farm work in response to drought shocks in the context of Ethiopia. Since farmers do not a priori know the weather during cropping season when making ex-ante labor decisions, their decisions might be suboptimal under unexpected weather changes, compared to ex-post decisions. Here, we investigate the ex-post strategy: reallocation of four different types of labor in response to rainfall shocks (measured as the deviation of current rainfall from historical rainfall patterns). Third, using the rich information on household labor in our dataset, we distinguish four different types of labor, namely self-employment and wage employment in an off-farm sector and self-employment and wage employment in an on-farm sector. This is particularly relevant as diversifying labor hours by job type within the same sector is also important for mitigating some of the entrepreneurial risks associated with self-employment (Bandyopadhyay and Skoufias, 2015). Fourth, we compare the labor reallocation of the child's mother with that of other household members, which allows us to examine heterogeneity in the importance of labor among household members.

The remainder of this article is organized as follows. In the next section, we introduce the conceptual framework. Section 3 outlines the data used for the analyses. After presenting the empirical strategy in Section 4, Section 5 reports the results. We discussed the interpretation

[2] One exception is a study by Aguilar and Vicarelli (2022), which examines the interplay between government programs and the impact of rainfall shock on children's cognitive and anthropometric outcomes in Mexico.

and robustness of our results in Section 6. Section 7 concludes the paper.

2. Conceptual framework

In this section, we conceptualize how recent rainfall affects child nutritional status and how the allocation of household labor is associated with the impacts of rainfall on child nutrition. We particularly focus on two mechanisms, namely food intake and disease exposure, through which rainfall influences child nutrition. While many factors directly or indirectly contribute to child undernutrition, these two are sensitive to household labor allocation and are identified as the direct causes of child undernutrition by UNICEF (2014).[3] **Figure 1** visually summarizes how rainfall during cropping season in the previous and current year affects child nutritional status by changing food intake and disease environment and the potential role of household labor reallocation in response to rainfall as a strategy for improving child nutrition.

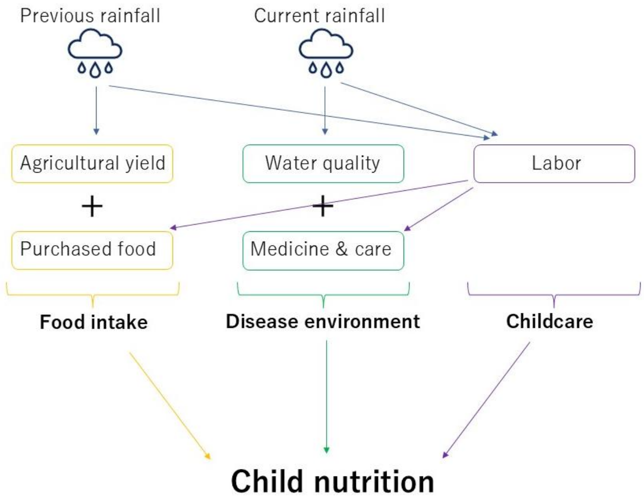


Figure 1: Conceptual framework for how rainfall influences child nutritional status and its link with household labor allocation.

Note: Previous rainfall influences child nutrition by changing the total agricultural yields for the last one year, while current rainfall does so by changing water quality. According to the literature, we expect a positive linkage between past rainfall and agricultural yields, as well as a negative linkage between current rainfall and water quality. Households allocate their labor in response to both previous and current rainfall, which leads to changes in food intake through purchased food, in disease environment through available medicines for recovery, and childcare quality due to time constraints.

[3] Although it is difficult to completely separate all channels under the association between rainfall shocks and child nutritional status (Ogasawara and Yumitori, 2019), our aim is not to fully list the potential mechanisms linking rainfall shocks with child nutritional status but rather to investigate the ability of households to mitigate rainfall shocks on child nutritional status through labor allocation.

We now model this. Following Omiat and Shively (2020), we model child nutritional status in Equation (1) such that a child *i*´s nutritional status from household *h* during cropping season in time *t* (H_{iht}) is determined by the child's health endowment (μ_{iht}), food intake of child *i* (C_{iht}), environmental conditions affecting child disease prevalence (D_{iht}), vectors of characteristics (X_i) of the child, the child's mother, the household, and the community. In addition, this study considers childcare practices (T_{iht}), such as time for breastfeeding, food preparation, and washing the body. Although longer childcare time is likely to benefit child health, the time available for childcare practices is limited by time constraints. In other words, more time spent on the labor market results in less time spent on childcare (Debela et al., 2021). The nutritional status of a child can be expressed in the following specification:

$$H_{iht} = f(\mu_{iht}, C_{iht}, D_{iht}, T_{iht}, X_i) \quad (1)$$

where

$$\begin{aligned} C_{iht} &= l\ \{ Y_{ht-1}\ (R_{ht-1}),\ PF_{ht}\ (L^{off}_{ht}),\ X^{ch}_{i}, X^{h}_{i}, X^{co}_{i} \} \\ D_{iht} &= m\ \{ R_{ht}, L^{off}_{ht}, L^{on}_{ht}, X^{ch}_{i}, X^{h}_{i}, X^{co}_{i} \} \\ T_{iht} &= n\ (L^{off}_{ht}, L^{on}_{ht}, X^{ch}_{i}, X^{m}_{i}, X^{h}_{i}, X^{co}_{i}) \end{aligned} \quad (2)$$

Equation 2 expresses how recent rainfall and current household labor can impact the nutritional status of each child. The first input into the child nutritional status is the current food intake for child *i* (C_{iht}), which consists of the agricultural production of the household in the previous year (Y_{ht-1}), the amount of food currently purchased (PF_{ht}), characteristics of the child (X^{ch}_{i}), the household (X^{h}_{i}), and the community (X^{co}_{i}). We assume that previous rainfall (R_{ht-1}) affects food intake by changing agricultural yields and that labor allocation can play a role in mitigating this fluctuation through purchased food. For example, if a household's agricultural yields are insufficient under lower rainfall than expected, they can increase off-farm labor

(L^{off}_{ht}), which generates immediate cash income and allows them to purchase more food (Nguyen et al., 2017). Meanwhile, an increase in on-farm labor under the favorable weather conditions typically improves household food consumption after harvest season via higher agricultural yields. However, in our context, we focus on the link among rainfall, child health, and labor during the cropping season. Considering the time lag between cropping and harvesting, we assume that cropping-season on-farm labor does not affect the amount of current food intake. Furthermore, due to the possibility of unequal intra-household food allocation, the amount of food consumed is unlikely to be uniform among children from the same household. Instead, the amounts can be determined depending on the child's age or gender.

The second input is the prevalence of the disease (D_{iht}), which is affected by the current rainfall (R_{ht}), off-farm (L^{off}_{ht}) and on-farm labor (L^{on}_{ht}), and other characteristics. Excessive rainfall likely worsens water quality (Delpla et al., 2009), leading to a high risk of contracting infectious diseases such as diarrhea (M. Cooper et al., 2019). Disease exposure, in turn, lowers the uptake and retention of essential nutrients from food (Omiat and Shively, 2020). However, whether a child becomes infected with a disease and how quickly a child recovers depends on household labor. For example, an increase in off-farm labor may also help the child recover from the disease by increasing household income, which allows them to purchase proper medicine for a child. Proper medication promotes a child's quick recovery, improving their nutritional status. In contrast, while a household may be incentivized to increase on-farm labor under high rainfall, expecting higher yields at the end of the season, this shift reduces off-farm labor hours and thus current household income due to time constraints, potentially leading to lower child nutritional status. Furthermore, child characteristics can capture the inherent ability to resist disease, while household characteristics can capture the ability of a household to take care of the child in the disease environment, and community characteristics can capture the impacts of health facilities.

The third input is daily childcare practices (T_{iht}), which is determined by both on-farm and off-farm labor, and other characteristics. While households adjust labor allocation based on their needs, their labor decisions directly affect the time available for childcare due to time constraints. In addition, the trade-off between longer working hours and childcare practices varies by labor type. On-farm agricultural activities are typically located close to the homestead and easier to combine with childcare than off-farm activities (Debela et al., 2021). Therefore, the shift from off-farm to on-farm labor is expected to improve the child nutritional status.

3. Data

3.1. Household data

The primary data source for this study is the Bangladesh Integrated Household Survey (BIHS), a three-wave panel survey conducted in 2011/2012, 2015, and 2018/2019.[4] The surveys were conducted by the International Food Policy Research Institute. The survey locations are in rural areas in the county's seven administrative divisions. The total sample sizes in the first, second, and third waves are 6,503, 5,430, and 4,891 households, respectively.[5] The sample is nationally representative of rural Bangladesh.

BIHS provides individual-level detailed anthropometric data for children under five years old. To analyze child nutritional status, in each wave we keep only households with children under the age of five at survey timing from our sample. In other words, if a household does not have any children under five at survey timing, it is dropped from our analysis for that wave. We also exclude households with missing values in any of the variables used in our estimation. In the end, our sample size for the first, second, and third waves becomes 1,244, 2,385, and 1,879 children from 1,078, 2,040, and 1,578 households, respectively. On average, a

[4] The data source is available in the following link: https://dataverse.harvard.edu/dataverse/IFPRI/?q=title%3A%22Bangladesh+Integrated+Household+Survey+%28BIHS%29%22.

[5] This is the original sample, and we ignore split samples due to marriage. The attrition rate per year is low. Furthermore, Ahmed and Tauseef (2022) stated that the attrition between 2011/12 and 2018/2019 is random. Thus, we do not adjust our estimates for attrition.

household is included in our study for 1.7 survey waves. The average number of children under five per household in each wave is around 1.2 (Panel A in **Table 1**). Other key household characteristics are also summarized here.

To check if the selection of households with children under five years old affects our results, we conduct the attrition analysis following Moffit et al. (1999). We first conduct the attrition probit model to see whether excluded households are different from those households in our sample. Next, we calculate the inverse mills ratio (IMR) based on the probit estimation above, then include it in our main estimations to control for attrition bias. In the probit model, we find that while there is no statistically significant difference in exposure to shocks between the two groups at the 5% level, some household characteristics are systematically different (e.g., included households tend to be headed by younger males and have larger household size than those excluded, which are commonly linked to characteristics of households with smaller children). However, in the attrition analysis, we find that the coefficients of IMR are insignificant (**Table A1** in the Appendix), implying that our results are not affected by the attrition.[6] Hence, we report the original regression without including the IMR in Section 5.

3.1.1. Measuring Child Nutrition

As a measurement of the child nutritional status, we employ weight-for-age z-score (WAZ score) which is calculated based on the 2006 WHO growth standards. A negative WAZ score means a child's weight is lower than expected for their age and indicates prevalence of a child's status of being underweight (if below -2). We focus on the WAZ score, instead of height-for-age z-score (HAZ score) or weight-for-height z-score (WHZ score), because while the HAZ and WHZ scores indicate chronic or acute nutritional deficiencies, respectively, the WAZ score is sensitive to both chronic and acute factors, which fit with our focus on both the previous year

[6] Although we confirm that our results are not driven by the attrition bias, we underscore that our focus is on child nutrition and the implications based on our findings should be directed toward households with small children, rather than to all rural households in Bangladesh.

and current year's rainfall impacts measuring short and long-term implications. In addition, Bangladesh is one of the countries with the highest prevalence of underweight (Chowdhury et al., 2018). The average WAZ scores for waves 1, 2, and 3 in our sample are −1.590, −1.541, and −1.278, respectively (Panel B in **Table 1**), which showed a slight improvement over time but are still lower than -1. While the prevalence of underweight in waves 1 and 2 is more than 30%, it decreased to 23.9% in wave 3. The average age of children is around 29 months for all three waves. To capture the age-specific trend in nutritional status, we also create age interval dummies that indicate the age stage in six-month intervals. The gender ratio is approximately balanced for all three waves.

3.1.2. Measuring Labor Allocation

To measure labor allocation, we use weekly working time for each type of labor (off-farm and on-farm self-employment, and off-farm and on-farm wage employment).[7] We construct the labor variables at the household, maternal (individual), and other household members (except the mother) levels. Panel B in **Table 1** shows labor allocation pattern of mothers, the primary caretakers for their children (Shroff et al., 2009). Mothers spend most of their labor market time on off-farm labor. The average maternal off-farm self-employment and off-farm employment are 5-6 and 2-4 hours per week, respectively. In contrast, their average on-farm labor time (both self-employment and employment) is less than 1 hour per week. This is because the majority of mothers in our sample are not involved in on-farm activities.

Table 1: Summary Statistics – Main Variables

	Wave 1		Wave 2		Wave 3	
A. Household-level characteristics	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
Number of children under 5	1.154	(0.395)	1.169	(0.411)	1.191	(0.445)
Male HH head (=1)	0.951	(0.216)	0.844	(0.363)	0.831	(0.375)
Age of HH head	41.148	(13.250)	40.998	(13.400)	43.835	(13.606)
Schooling year of HH head	3.622	(3.923)	3.724	(3.868)	3.924	(4.012)
Household size	5.263	(1.813)	5.687	(1.992)	6.683	(2.327)
Market access (minutes to the closest market)	18.139	(11.202)	15.843	(9.557)	13.471	(8.945)

[7] The recall period is the last 7 days.

Asset index (scores for component 1)	0.379	(1.865)	-0.497	(1.968)	0.354	(1.878)
Livestock ownership (=1)	0.924	(0.265)	0.159	(0.366)	0.243	(0.429)
Farm Size (in decimal)	145.507	(175.041)	100.345	(176.302)	102.150	(157.893)
Irrigation (=1)	0.882	(0.323)	0.442	(0.497)	0.458	(0.498)
Piped water access (=1)	0.016	(0.125)	0.020	(0.140)	0.042	(0.202)
Sanitary toilet access (=1)	0.275	(0.447)	0.436	(0.496)	0.503	(0.500)
Daily wage in TK: Off farm, Emp.	27.699	(89.585)	55.129	(146.916)	73.886	(189.560)
Daily wage in TK: On farm, Emp.	40.956	(95.457)	49.639	(122.094)	47.719	(140.834)
Observations	1078		2040		1578	
B. Child-level characteristics	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
Anthropometric						
Weight-for-age Z-score	-1.590	(1.064)	-1.541	(1.053)	-1.278	(1.066)
Underweight (=1)	0.330	(0.470)	0.328	(0.470)	0.239	(0.427)
Age in months	28.991	(16.955)	29.971	(17.094)	29.850	(17.339)
Gender (= 1 if male)	0.490	(0.500)	0.525	(0.500)	0.508	(0.500)
Maternal labor						
Mother Labor hours: Off farm, Self	6.604	(8.490)	5.130	(8.536)	5.175	(18.500)
Mother Labor hours: Off farm, Emp.	2.813	(6.956)	3.181	(8.315)	4.321	(10.344)
Mother Labor hours: On farm, Self	0.349	(2.597)	0.340	(3.305)	0.173	(1.928)
Mother Labor hours: On farm, Emp.	0.198	(2.206)	0.114	(1.767)	0.136	(2.314)
Observations	1244		2385		1879	

Note: Summary statistics (mean and standard deviation) of the main variables of household characteristics and child characteristics are presented. Market access implies the time required to get from house to the closest marketplace in minutes. Asset index is constructed using principal component analysis with higher values indicating higher asset levels. A mother is identified for each child, and her labor allocation patterns are also summarized here. Other variables used in our analysis are available in **Table A2** in the Appendix.

3.2. Climate data

Climate data is derived from the Climate Hazards Group Infrared Precipitation with Station dataset, which contains monthly rainfall and temperature from January 1980 to December 2019 on a global grid with 0.5-degree latitude by 0.5-degree longitude. Climate information is merged with BIHS data at the household level using geographical location data for each household in the BIHS sample.

In Bangladesh, there are two cropping seasons: Rabi season (from November to February) and Kharif season (from March to June). We focus on rainfall during Rabi season, because it is the main cropping season in Bangladesh,[8] when the main rice type (i.e., Boro rice) and many other winter crops are grown. Thus, Rabi-season rainfall is

[8] Before the green revolution, Kharif season was the main cropping season, but today due to expansion of the irrigation system, Rabi season becomes the main cropping season in Bangladesh.

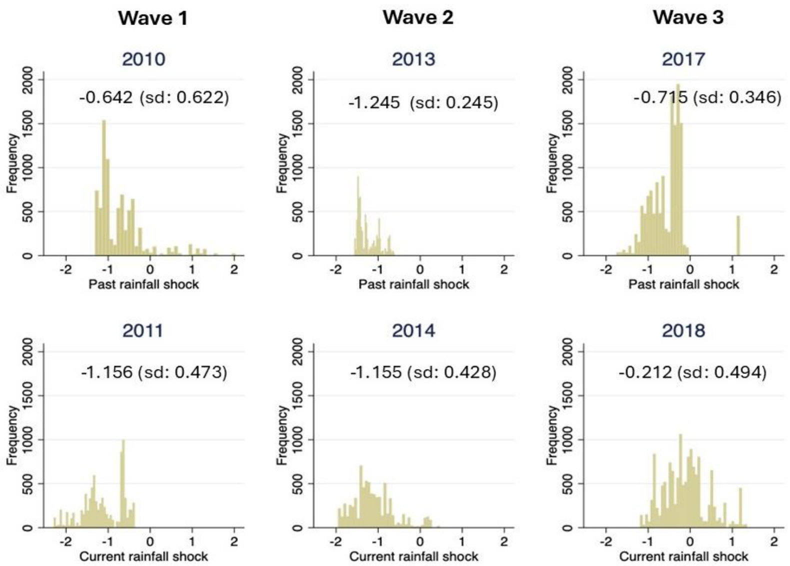
expected to play an important role in determining total agricultural harvest and thus household food consumption after the harvest season. Another reason for our focus on Rabi season is that the survey was conducted mainly during the Rabi season and recall periods of information in our dataset are included in Rabi season. Hence, to identify the acute impact of rainfall, we can only use Rabi-season rainfall. We confirm this by estimating the impact of Kharif-season rainfall on the WAZ score (see Section 6.4). Furthermore, we acknowledge that the information on specific survey timing (e.g., survey date or month) should be used to measure the precise rainfall during recall period for each household. If households are surveyed at the beginning of Rabi season, total rainfall during the entire season is less relevant to them than to those surveyed at the end of Rabi season. Unfortunately, such information is not available, which is our limitation. To address this concern, we analyze the impact of rainfall during the first month of Rabi season (November), which is relevant to all households, as a robustness check.

To capture rainfall conditions during the Rabi season, we construct rainfall shock variables for each household following the study by Makate et al. (2022). The rainfall shock variable is defined as a normalized deviation in Rabi season rainfall in a specific year from the historical average Rabi season rainfall. That is,

$$Rainshock_{ht} = \frac{rain_{ht} - \overline{rain_{ht}}}{\sigma_{rain_{ht}}} \quad (3)$$

where $rain_{ht}$ is the total rainfall that household h receives during Rabi season in year t. $\overline{rain_{ht}}$ is the average historical Rabi-season rainfall for household h over the last 31 years from year t. $\sigma_{rain_{ht}}$ is the standard deviation of the rainfall during the same period. In other words, this implies how far the seasonal rainfall in year t is from the expected amount calculated by the historical average rainfall. Because the survey was mainly conducted during Rabi season, child nutritional status measured in the survey year t is likely to be influenced by Rabi-season weather conditions at each survey year *t* through changes in the disease environment, as well as those at each year prior to the survey ($t-1$) through changes in food production. Therefore, $Rainshock_{ht}$ and $Rainshock_{ht-1}$ are our main explanatory variables of interest. Since agricultural production in Bangladesh is typically stored for less than 12 months due to the limited storage ability (Ministry of Food, Government of Bangladesh, 2015),[9] it is unlikely that household food consumption – and therefore nutritional status – is influenced by rainfall from two or more seasons earlier. Thus, we do not consider the impacts of rainfall with a two-year lag or more. Temperature shock variables are also calculated in the same way and are used as control variables

Figure 2 visually shows the rainfall shock variations and their regional heterogeneity for each year. The average rainfall shocks in each survey year are −1.156, −1.155, and −0.212 standard deviations in waves 1, 2, and 3, respectively, which means that rainfall during the Rabi season in survey periods is typically lower, compared to the historical average rainfall during the same season over the previous 31 years (i.e., 69, 71, and 67 mm for each wave). Regional heterogeneities also vary over time.



[9] The file is available in the following link:
https://dgfood.portal.gov.bd/sites/default/files/files/dgfood.portal.gov.bd/page/cb9f6c96_eeef_486e_adb9_c7b3e786f761/TOR%20for%20Individual%20Consultant-International%20for%20Research%20Program.pdf

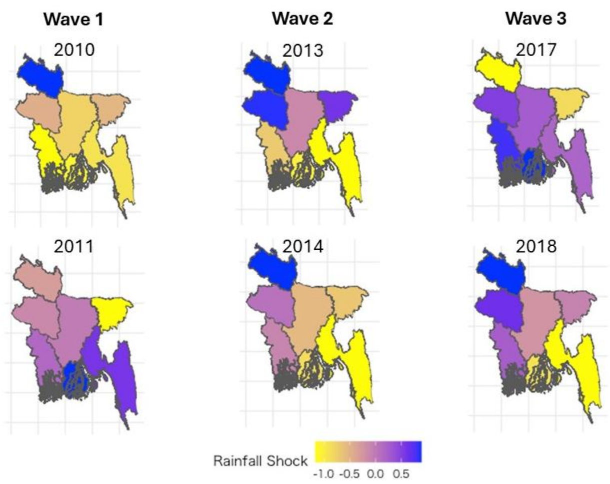


Figure 2: Histogram of rainfall shocks during Rabi season for each year and regional heterogeneity

Note: Calculation by authors. The values in each histogram are the average rainfall shock and its standard deviation. Household level rainfall shock variables are aggregated into division level by taking average for regional maps.

As defined, positive (negative) values in the rainfall shock variable imply that there is more (less) rainfall than the historical average. Since wetter and drier weather conditions are likely to have different impacts on child health, we decompose it into positive and negative rainfall shock variables as follows:

$$PositiveRain_{ht} = \frac{rain_{ht} - \overline{rain_{ht}}}{\sigma_{rain_{ht}}} \tag{4}$$

if $rain_{ht} > \overline{rain_{ht}}$, and 0 otherwise.

$$NegativeRain_{ht} = \frac{rain_{ht} - \overline{rain_{ht}}}{\sigma_{rain_{ht}}} \times (-1) \tag{5}$$

if $rain_{ht} < \overline{rain_{ht}}$, and 0 otherwise. To allow positive and negative rainfall shocks to influence child nutrition differently, we replace $Rainshock_{ht}$ with $PositiveRain_{ht} + NegativeRain_{ht}$ in our estimation. Furthermore, we also consider extreme rainfall cases, flood and drought occurrence. While our main analysis, which captures rainfall shock as a continuous variable, provides a more detailed understanding of rainfall impacts and labor allocation patterns, analysis with flood and drought variables offers additional insights into the potential role of labor allocation under these extreme events, which often harm agricultural yields because small-scale farmers cannot adapt to unusual rainfall (M. Cooper et al., 2019). We define flood and drought variables as follows:

$$Flood_{ht} = 1 \text{ if } Rainshock_{ht} > 1, \text{ and 0 otherwise} \qquad (6)$$

$$Drought_{ht} = 1 \text{ if } Rainshock_{ht} < -1, \text{ and 0 otherwise} \qquad (7)$$

The results with flood and drought dummy variables are summarized in Section A3 in the Appendix.

To account for historical climate patterns, we use historical average rainfall and temperature over the last 31 years and their coefficient of variation during Rabi season. We assume that households know the suitable agricultural strategy for the typical climate trends of their location based on their own or their neighbors' experience. The coefficient of variation of historical rainfall and temperature captures the fluctuation of the climate conditions for each place. Since the fluctuation of climate conditions makes it difficult to predict climate in the future, households need specific strategies to avoid the risks caused by weather shocks. In other words, households in more fluctuating climate zones may employ systematically different labor strategies than those in less fluctuating climate spots. To distinguish such an ex-ante labor strategy based on the climate belief from an ex-post coping strategy after the shocks, we control for the coefficient of variation of historical climate conditions (rainfall and temperature) and their historical average. Our focus is on how households change their labor in response to the deviation of recent rainfall from the expected climate patterns. In **Figure 3**, we provide a visual representation of the timeline of each survey wave and the timing of our main variables' measurements.

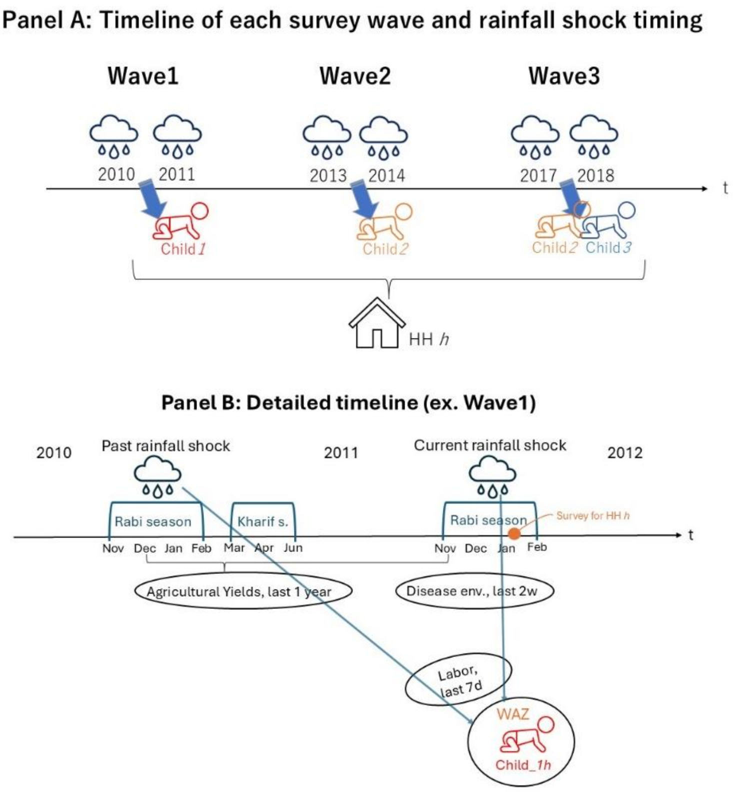


Figure 3: Timeline for measuring the main variables

Note: Panel A shows the timeline of each survey wave and year when each rainfall shock is defined. We link nutritional status of each child with rainfall shocks in the survey year and year prior to the survey. If a child becomes older than five years in the following wave, he/she is dropped from our sample. Panel B shows the detailed relationship among the main variables for wave 1 as an example. Households are visited mainly during Rabi season. Child nutritional status measured at the survey date is determined by total agricultural yields for the last one year (from December in the previous year to November in the current year), which is affected by past rainfall shock, disease environment (recall period: last 2 weeks), which is affected by current rainfall shock, and labor (recall period: last 7 days). Rice and other winter crops grown during Rabi season are harvested after February.

4. Empirical strategy

To estimate the impact of recent rainfall shocks on child nutritional status and how different types of labor are linked with child nutrition under the rainfall shock, we employ a two-way fixed effects model with household and time fixed effects. Our model leverages variations in child nutritional status within households with multiple children under five of age over time. Since children from the same household are raised in the same family environment, we assume that the nutritional status of different children from the same household are comparable after controlling for child-specific characteristics and household characteristics. In contrast, their experience of exposure to rainfall shocks during their first five years of life depends on their birth timing. Therefore, instead of tracking the changes in the same child's nutritional status over time, we link the differences in nutritional status of children within a household to the different rainfall shocks they experience in their childhood. This allows us to remove the effect of specific household time-invariant characteristics on child nutrition and estimate the impact of rainfall shock.

The main empirical concern is the endogeneity problem because household labor allocation decisions tend to be related to both observed and unobserved household characteristics.[10] For example, a husband with progressive views on gender inequality is more likely to allow his wife to work outside the home. At the same time, this progressive attitude may lead to better treatment of children by the husband (Duflo, 2012). In such a case, regardless of labor changes, unobserved differences in gender equality perspectives would affect household food consumption in favor of children after rainfall shocks. Hence, we cannot distinguish the impacts of labor reallocation after a household experiences shocks from the impacts of specific household characteristics.[11] Fixed effects estimation allows us to take into account of time invariant unobserved heterogeneity affecting both labor allocation decision and nutritional outcomes.[12] However, we acknowledge that our fixed-effect model cannot eliminate the potential endogeneity problem caused by time-variant unobservable heterogeneity affecting household labor decisions. Therefore, while we assume the rainfall is exogenous and thus claim the causality for the relationship between rainfall and child nutrition, we interpret the labor-role on nutrition outcomes as association.

[10] Simultaneity bias is another common cause of endogeneity issues, however, in our setting, reverse causality may not be problematic since weather condition is exogeneous.
[11] Although several indicators can capture women empowerment, it is difficult to directly measure household head's opinion in relation to gender equality due to limitation of our data.
[12] As robustness check, we also employ a correlated random effect model (CRE).

4.1. Model specification

4.1.1. Impact of rainfall shock on child nutritional status

First, we estimate the effect of rainfall shocks on child nutritional status in the following specification:

$$y_{ihdt} = \alpha_0 + \alpha_1 RainShock_{hd,t-1} + \alpha_2 RainShock_{hd,t} + \alpha_3 W_{hdt} + X^C_{ihdt}\alpha_C + X^H_{ihdt}\alpha_H + \theta_h + \gamma_t + \epsilon_{ihdt} \quad (8)$$

where y_{ihdt} is the WAZ score for a child i of household h living in division d and year t. Our main explanatory variables, $RainShock_{hdt-1}$ and $RainShock_{hdt}$, are rainfall shock variables during Rabi season in the previous year of the survey $t-1$ and in the survey year t, respectively. W_{hdt} captures the climate characteristics, including the temperature shock for the previous year of the survey and the survey year, the historical average rainfall and temperature during Rabi season, and their coefficient of variation. Historical climate control variables help us distinguish between household ex-ante and ex-post labor decision-making (Rose, 2001). Furthermore, we control for individual-level child characteristics (X^C) such as gender, age in month and age interval dummy variables for every six month, as well as a vector of time-variant household characteristics (X^H): household head gender, demographic indicators (age and educational attainment) of the household head and mother of child i, maternal height, household size, market access (time required to get from house to the closest weekly/ periodic market place in minutes), asset index[13], farm size, irrigation system (= 1 if a household has access), sanitary latrine access (= 1 if yes), clean drinking water access (= 1 if yes), and daily wage rate of off- and on-farm employment.

To account for non-linearities, we also include squared terms of the rainfall shock

[13] We construct asset index using principal component analysis, as asset values were not consistently recorded across all rounds of the BIHS. The index consists of various assets, including radios, televisions, telephones, computers, animal carts, bicycles, motorbikes, refrigerators, and cars or trucks.

variables ($RainShock_{hdt-1}$ and $RainShock_{hdt}$) as one variant of the regression. Furthermore, in a different regression, we replace $RainShock_{hdt-1}$ in equation (8) by $PositiveRain_{h,t-1}$ and $NegativeRain_{h,t-1}$, and $RainShock_{hdt}$ by $PositiveRain_{h,t}$ and $NegativeRain_{h,t}$ with the aim to further investigate the implications of more rainfall and less rainfall separately.

All estimations include fixed effects for households and years (θ_h and γ_t, respectively). The household fixed effect is included to remove the effect of time-invariant characteristics at the household level. The year fixed effect accounts for specific events in the survey year that affect the outcome variables. We do not include district fixed effects, because most of the households do not migrate to other districts during the study periods, thus it is absorbed by the household fixed effect. Standard errors (ϵ_{ihdt}) are clustered at the household level.

4.1.2. Role of household labor allocation: underlying mechanism between rainfall shock and child nutritional status

To investigate the role of each labor activity underlying the impact of rainfall shock on child nutrition, we interact each labor time classifications with rainfall shock variables and look at how the rainfall shock impact is mitigated by labor. To get the most detailed information, here we distinguish between positive and negative rainfall shocks. The inclusion of interaction terms is used to decompose the impacts of mediators as described in the literature for mediation analysis (e.g., VanderWeele and Vansteelandt, 2014; VanderWeele, 2016). The estimation model is written as follows:

$$y_{ihdt} = \beta_0 + \beta_1^k L_{hdt}^k + \beta_2^k \left(L_{hdt}^k \times PositiveRain_{h,t-1}\right) + \beta_3^k \left(L_{hdt}^k \times NegativeRain_{h,t-1}\right) + \beta_4^k \left(L_{hdt}^k \times PositiveRain_{h,t}\right) + \beta_5^k \left(L_{hdt}^k \times NegativeRain_{h,t}\right) + \beta_6 PositiveRain_{h,t-1} + \beta_7 NegativeRain_{h,t-1} + \beta_8 PositiveRain_{h,t} + \beta_9 NegativeRain_{h,t} + \beta_{10} W_{hdt} + X_{ihdt}^C \beta_C + X_{ihdt}^H \beta_H + \theta_h + \gamma_t + \epsilon_{ihdt}^2 \qquad (9)$$

where L_{hdt}^k is weekly working hours of labor k (i.e. off-farm self-employment, off-farm wage employment, on-farm self-employment, and on-farm wage employment) of household h living in division d in year t. β_1^k captures how labor k is directly associated with the outcome (i.e., WAZ score), and β_2^k, β_3^k, β_4^k, and β_5^k represent how labor k is associated with the impact of each rainfall shock on child nutrition: one-year prior positive rainfall shock, one-year prior negative rainfall shock, the current year positive rainfall shock, and the current year negative rainfall shock, respectively. By looking at the four different types of labor respectively, we analyze how each labor is differently associated with the effect of rainfall shock on child health. Furthermore, we investigate whose labor is important to achieve better child nutritional status under rainfall shocks by measuring the labor variable at the household level, the mother level, or household members except the mother level, depending on the specifications. Because mothers are the primary caretakers for their children (Shroff et al., 2009), their labor time is expected to have the greatest influence on their children's nutritional status. We explore the importance of maternal labor by comparing the role of maternal labor time and other household members' labor time.

4.1.3. Labor reallocation patterns in response to rainfall

Lastly, we analyze labor reallocation patterns in response to recent rainfall shocks. We use L_{hdt}^k (weekly working hours of labor activity k) as the outcome in Equation (8) and estimate the change of each labor time separately depending on the exposure to rainfall shocks. Because a household allocates the total amount of available working time to different labor activities, each labor time is likely to be decided concurrently, potentially causing endogeneity. Therefore, we do not claim causality, but the identified labor reallocation patterns would provide a vital insight to understand the potential household constraints under the current climate change situation.

5. Results

5.1. Rainfall shocks and child nutritional status

Table 2 summarizes the effect of rainfall shocks on the WAZ score of children. We find that more rainfall in the year prior to the survey year (past rainfall) than the historical average rainfall leads to higher WAZ score (Column (1)). In contrast, more rainfall in the survey year (current rainfall) than the historical average rainfall leads to lower WAZ score (Column (1)). This linkage also holds, with even larger effect sizes, when we additionally include detailed child- and maternal-level covariates, such as birth order[14], whether a child is breastfeeding or not, and the number of antenatal cares received by a mother (Column (2)). Because most children in our sample (about 95%) have received the BCG vaccine, we do not control for the BCG vaccination status. While the inclusion of these variables improves model accuracy, such information is only available for children under 24 months of age, reducing the sample size to less than half. Thus, we do not include these variables for the rest of our analysis.

To account for the potential nonlinear relationship between rainfall and child nutrition, we now include quadratic terms of the past and the current rainfall shock variables (Column (3)). We do not reject the null hypothesis of the linear relationship when including quadratic terms (coefficients of the quadratic terms are insignificant). Furthermore, we also account for the potential nonlinearity by separately including positive and negative rainfall shock variables (Column (4)). Here, we allow "more" rainfall and "less" rainfall to influence child nutrition differently. For the past rainfall, we find that while positive past rainfall shock is positively associated with the WAZ score, negative past rainfall shock is negatively associated with the WAZ score. Since both coefficients are not statistically significant, this result suggests that the positive linkages of the past rainfall shock with the WAZ score in Column (1) may be driven by either the positive effect of more rainfall or the negative effect of less rainfall, or a combination of the two.[15]

[14] Many studies show that the birth order is a factor affecting child health (Chandna and Bhagowalia, 2024; Dhingra and Pingali, 2021; Kishida et al., 2024)).
[15] We interpret this result with caution, as its statistical significance is not stable across models with different sets of control variables. This instability is likely due to small variations in the positive past rainfall shock: as not many households received higher rainfall than the average historical rainfall during our study period, the distribution of positive past rainfall shock is skewed toward zero.

Regarding the current rainfall shock, we find that only negative rainfall shock statistically significantly increases the WAZ score. A one-standard-deviation lower current rainfall than the historical average rainfall leads to, on average, a 0.178 standard-deviation higher WAZ score, which is around 12% of the mean WAZ score for the whole sample (−1.462). This result implies that the negative linkages of the current rainfall shock with the WAZ score in Column (1) is driven by the positive effect of less rainfall and not by the negative effect of more rainfall. Since this model provides the most detailed insights, for the rest of our analysis we distinguish between positive and negative rainfall shocks.

Table 2: The effect of rainfall shocks on the WAZ score of children under five

	(1)	(2)	(3)	(4)
Outcome	WAZ score			
Past				
Past rainfall shock	0.187*	0.532*	0.230*	
	(0.106)	(0.303)	(0.124)	
Squared past rainfall shock			0.038	
			(0.063)	
Positive past rainfall shock				0.330
				(0.213)
Negative past rainfall shock				-0.142
				(0.117)
Current				
Current rainfall shock	-0.167***	-0.377**	-0.067	
	(0.060)	(0.159)	(0.110)	
Squared current rainfall shock			0.053	
			(0.051)	
Positive current rainfall shock				-0.012
				(0.198)
Negative current rainfall shock				0.178***
				(0.062)
Year FE	Yes	Yes	Yes	Yes
HH FE	Yes	Yes	Yes	Yes
Infant characteristics	No	Yes	No	No
Squared rainfall shock	No	No	Yes	No
N	5489	2108	5489	5489

Notes: Two-way fixed effect model is employed. Robust standard errors clustered by household in parentheses. Child characteristics (gender, age, and age interval), mother characteristics (age, educational attainment, and height), household characteristics (household head's characteristics such as age and educational attainment, household size, market access, asset, livestock ownership, farm size, irrigation system access, access to sanitary latrine and clean drinking water, and daily labor wage of off-farm and on-farm employment), temperature shocks, and historical climate characteristics are controlled but not reported. *** denotes significance at 1% level, ** at 5% level, and * at 10% level.

The opposite effects of past and current rainfall shocks can be explained by the different pathways through which rainfall influences child nutrition, namely food intake path for past rainfall effect and disease path for current rainfall impact. First, to confirm the food intake path hypothesis, we examine how rainfall affects household agricultural harvest, which is the main food source for households in developing countries' rural areas. We find that less rainfall the previous year (i.e., negative past rainfall shock) leads to lower total agricultural harvest in the last 12 months (Column (1) in **Table 3**).[16] In contrast, we do not find the positive linkage between rainfall and agricultural harvest, although the coefficient of positive past rainfall shock is positive. To capture food intake changes more directly, we also analyze a household dietary diversity score (HDDS), calculated based on the last 7 days of household food consumption information. We find that more rainfall in the previous year leads to a higher HDDS (Column (2)). Furthermore, we investigate individual child-level dietary diversity score (Child DDS) for children under 24 months of age (the information is only available for them and the recall period is the last 24 hours). Here, we do not find significant linkage between rainfall and Child DDS (Column (3)), possibly because younger children are typically breastfed or fed specific infant foods. Thus, their diets may not be sensitive to household agricultural harvest or purchased food. However, their nutritional status may still be influenced by rainfall patterns, albeit indirectly, through their maternal nutritional status, as we find that rainfall significantly relates with HDDS.

Second, to test the disease path hypothesis, we examine how rainfall affects the diarrhea experience in the last 2 weeks (data is available only for children under 24 months of age), while controlling for detailed infant characteristics (birth order, breastfeeding, and antenatal

[16] The recall period of agricultural harvest data is from the beginning of Rabi season in the previous year to before the beginning of Rabi season in the current year (12 months). Thus, here we look at how rainfall during the first four months of the year affects the total annual harvest.

cares received by a mother). Since rainfall immediately affects the quality of the available water, we focus on current rainfall shocks. Here, we do not find the direct evidence supporting this hypothesis, at least for children under 24 months (Column (4)). However, an important note is that this linkage could depend on access to clean water. Water quality (and resulting disease environment) in households without clean water access is more likely to be sensitive to rainfall patterns than in those with access. To investigate this hypothesis, we analyze the impacts of rainfall on the WAZ score of children from households with sanitary toilet access and those without access separately (Columns (5) and (6)). We find supporting evidence for this: while the past rainfall shock impact is similar across the two groups,[17] the current rainfall shock significantly affects the nutritional status of children without sanitary toilet access, but not those with access. Regarding access to clean drinking water (i.e., whether piped water is used as the drinking water source), the majority in our sample (around 97%) do not have access to a piped water supply. Therefore, we do not conduct subsample analysis based on clean drinking water access. However, this situation itself suggests that households studied here face a higher risk of rainfall-related disease prevalence through their drinking water.

Table 3: Evidence for food intake path and disease path underlying the impact of rainfall shock on child nutritional status

Outcome	(1) Harvest (ton)	(2) HDDS	(3) Child DDS	(4) Diarrhea (=1)	(5) WAZ (sanitary toilet = 1)	(6) WAZ (sanitary toilet = 0)
Past						
Positive past rainfall shock	0.516	0.454*	-1.111		0.033	0.076
	(0.716)	(0.260)	(0.688)		(0.391)	(0.377)
Negative past rainfall shock	-1.552*	0.229	0.005		-0.339**	-0.448*
	(0.872)	(0.140)	(0.458)		(0.165)	(0.231)
Current						
Positive current rainfall shock				0.236	-0.252	-0.375
				(1.924)	(0.316)	(0.368)
Negative current rainfall shock				0.123	0.189	0.215**
				(0.095)	(0.116)	(0.097)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

[17] Contrary to the result in Column (4) in **Table 2**, here the coefficient of negative past rainfall shock is statistically significant.

HH FE	Yes	Yes	Yes	Yes	Yes	Yes
Infant characteristics	No	No	Yes	Yes	No	No
Sample	HH	HH	Child < 24m	Child < 24m	Child < 5y	Child < 5y
N	4667	4667	2108	1392	2323	3166

Notes: Household fixed effect model is employed. Robust standard errors clustered by household in parentheses. HDDS is constructed as the number of food groups consumed by a household in the last 7 days (food items are categorized into the following 12 groups: "Cereals”, "White tubers and roots", "Vegetables", "Fruits", "Meat", "Eggs", "Fish and seafood", "Legumes, nuts and seeds", "Milk and milk products", "Oils and fats", "Sweets", and "Spices, condiments and beverages”). Child DDS is constructed as the number of food groups consumed by a child in the last 24 hours (food items are categorized into the following 7 food groups: (1) grains, roots, tubers,; (2) vitamin A rich fruits and vegetables; (3) flesh foods such as meat, fish and poultry; (4) legumes, nuts and seeds; (5) eggs; (6) other fruits and vegetables; (7) dairy products). Columns (1)-(2) are household-level analysis, thus we include household-level child characteristics (the number of children under five years of age and the average age of these children in months) and household-level average mother characteristics (age and educational attainment). The same household characteristics and climate variables as Table 2 are also included. For Columns (3)-(4), we control for the same set of controls as Table 2 as well as detailed child characteristics available for children under 24 months. For Columns (5)-(6), the same set of controls as Table 2 are included but not reported. ** denotes significance at 5% level and * at 10% level.

5.2. Labor allocation mechanism underlying the impact of rainfall shock on child nutrition

Next, we investigate the potential role of labor allocation in mitigating the impact of rainfall on a child nutritional status: how changes in working time in each labor are associated with the effects of rainfall shocks on the WAZ score. In this section, we only report the result of maternal labor time (**Figure 4**) due to the finding that only maternal labor matters in mitigating the impact of rainfall shocks. The results for a role of labor allocation at the household-level and household members except the mother-level are summarized in the Appendix (**Table A3**).

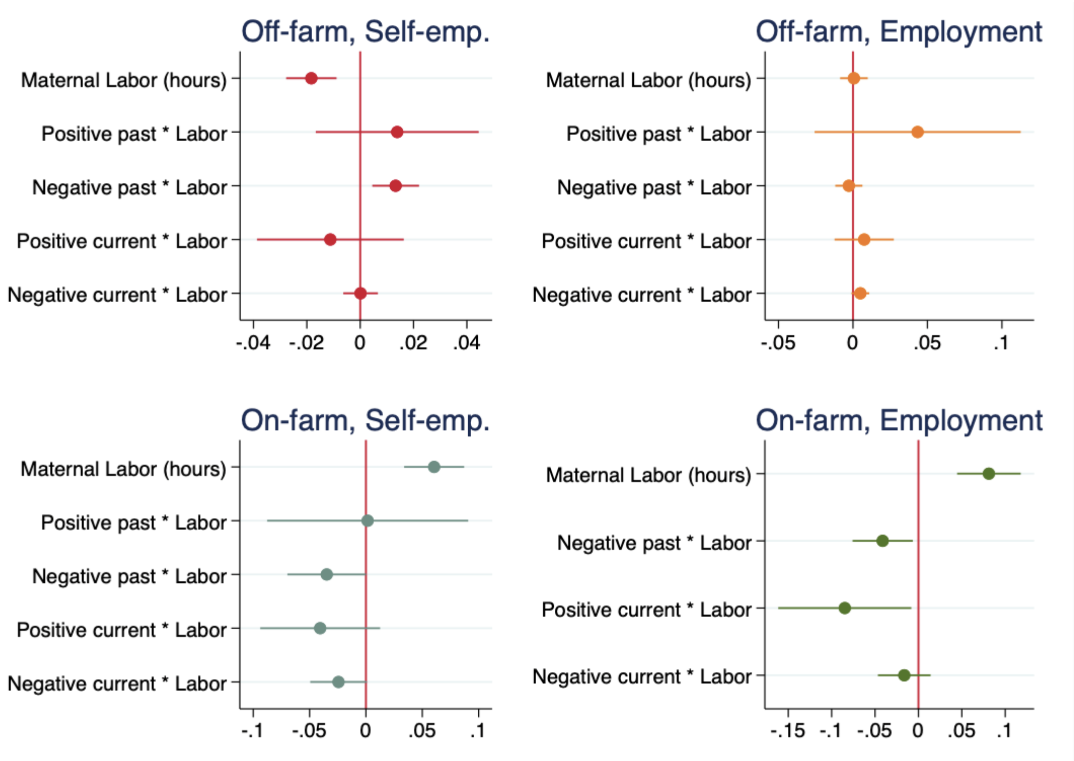


Figure 4: The role of maternal labor underlying the impact of rainfall shock on child nutritional status

Note: Points and plots are coefficients and their 90% confidence intervals, respectively. Each labor type is separately estimated. The same set of controls as Table 2 are included. For on-farm employment labor, the interaction term between positive past rainfall shock and labor is dropped because there are quite few mothers who engage in on-farm employment and also receives positive past rainfall shock.

First, we focus on the direct association between maternal labor time and the child nutritional status. While longer maternal off-farm self-employment labor time is significantly associated with lower WAZ score (upper left), longer on-farm wage employment and self-employment are significantly associated with higher WAZ score (lower right and left). We attribute this opposite association between labor time and the WAZ score for off-farm and on-farm labor to differences in their working environments. On-farm jobs tend to be located closer to homes and thus are easier to be combined with childcare. Thus, if mothers work longer hours for on-farm labor, they could have more time to spend with their children, compared to if mothers work longer hours for off-farm labor. Although we cannot explicitly identify this maternal time constraint, we analyze the association between maternal labor time and total care time for children, adults, and the elderly spent by female household members. We show that longer off-farm working hours are significantly associated with a decline in caregiving time (Panel A in **Table A4** in the appendix). Whereas the coefficients of on-farm labor are also negative, they are not statistically significant. Of course, mothers are not the only female members in households and total care time used here can also include time spent for elderly care, but our result provides supporting evidence for the maternal time constraints due to their off-farm labor. Moreover, we further examine trade-offs between maternal labor time and childcare quality by analyzing changes in breastfeeding frequency.[18] If a mother has less time to spend with her children due to her work, breastfeeding frequency is likely to decrease. Indeed, we find that while maternal off-farm labor is negatively associated with breastfeeding frequency, on-farm labor is positively associated with it (Panel B in **Table A4** in the appendix), providing additional evidence for the maternal time constraints resulting from off-farm labor.

Second, we examine how each type of maternal labor is linked to the impact of rainfall shocks on child nutrition. On the one hand, we find the important role of maternal off-farm self-employed labor in mitigating the past rainfall impacts (upper left).[19] This suggests the potential mechanism that off-farm labor is linked to food intake pathway. Longer working hours of off-farm labor, which typically leads to higher income (the main source to purchase food during the cropping season), is likely to allow households to access more food when a household does not have enough food due to poor harvests in the previous year, resulting in better food security and therefore better nutritional status for children.

On the other hand, we find that longer working hours of maternal on-farm labor (both self-employment and wage-employment) are associated with an even larger negative impact of the past rainfall shortage and of the current excessive rainfall on the WAZ score. For the past

[18] How many times a mother breastfeeds a child yesterday (recall period: the last 1 day). Based on this data, we create a categorical variable for the frequency (low, moderate, high, and very high).

[19] Increasing maternal labor time for off-farm self-employment by 1 hour per week is likely to ease the negative impact of rainfall shortage in the previous year on the WAZ score by 0.014 standard deviations.

rainfall shortage, our results imply that, when a household faces food shortage due to insufficient agricultural harvests in the previous year, longer working hours in on-farm labor leads to shorter working hours in off-farm labor, resulting in less food availability at home. For the current excessive rainfall, when a household faces higher disease risk due to excessive rainfall, the potential cost of increasing on-farm labor (i.e., less off-farm labor and thus lower household income for appropriate medical supplies) dominates the potential benefit of increasing on-farm labor (more childcare time).

We further analyze how each form of maternal labor is differently associated with the rainfall shock impacts on the nutritional status of children with different characteristics such as children aged below and above 24 months, as well as between boys and girls. Results are summarized in **Table 4**. For age heterogeneity, we first find that the association between maternal labor and older children's nutritional status under the rainfall shocks aligns with the results for the whole sample (Column (2)). Off-farm labor (both self-employment and wage-employment) tends to ease the rainfall shock impacts, while on-farm labor tends to exacerbate them. However, for younger children, on-farm maternal labor is associated with nutritional status in different ways (Column (1)). Longer working time of maternal on-farm self-employment and on-farm wage employment is associated with higher WAZ score under the negative current rainfall shock and the negative past rainfall shock, respectively. This is opposite to our findings for the whole sample in **Figure 4**. Our results suggest the potential heterogeneities in the implications of maternal labor reallocation decision depending on the age of children. More research to understand different maternal behaviors depending on child age is needed in a future work.

With regards to the child gender, we find that the trend in maternal labor role is overall consistent with the results for the whole sample, although each labor type exhibits a distinct gender pattern (see Columns (3) and (4)). Off-farm self-employment is significantly associated with only girls' nutritional status while on-farm self-employment is significantly associated with only boys' nutritional status, and on-farm wage employment is significantly associated with only girls' nutritional status. Our empirical results on gender heterogeneity do not suggest evidence on gender inequality of child health.

Table 4: Heterogeneous maternal labor role: (A) among age (B) among gender

Outcome: WAZ score	(1)	(2)	(3)	(4)
Sub sample	Age < 24m	Age ≥ 24m	Boys	Girls
Panel A: Off, Self-emp.				
Labor (hours per week)	-0.030	-0.031***	-0.014	-0.019**
	(0.018)	(0.010)	(0.010)	(0.008)
Positive past × Labor	0.019	0.021	0.022	0.014
	(0.049)	(0.020)	(0.022)	(0.036)
Negative past × Labor	0.014	0.029***	0.014	0.012*
	(0.017)	(0.010)	(0.009)	(0.007)
Positive current × Labor	0.057	-0.035	0.008	-0.055
	(0.070)	(0.036)	(0.024)	(0.035)
Negative current × Labor	0.022*	-0.005	-0.005	0.004
	(0.013)	(0.008)	(0.006)	(0.005)
Panel B: Off, Emp.				
Labor (hours per week)	0.001	0.009	0.013	0.002
	(0.021)	(0.008)	(0.013)	(0.007)
Positive past × Labor	0.095	0.036	0.011	0.111
	(0.114)	(0.076)	(0.099)	(0.074)
Negative past × Labor	-0.005	-0.012	-0.012	-0.008
	(0.018)	(0.009)	(0.011)	(0.007)
Positive current × Labor	-0.013	0.035**	0.009	0.027
	(0.050)	(0.015)	(0.037)	(0.017)
Negative current × Labor	0.003	0.010**	0.003	0.006
	(0.010)	(0.004)	(0.008)	(0.004)
Panel C: On, Self-emp.				
Labor (hours per week)	-0.029	0.032	0.055*	0.023
	(0.057)	(0.026)	(0.029)	(0.032)
Positive past × Labor	-0.109	0.007		-0.083
	(0.071)	(0.042)		(0.075)
Negative past × Labor	-0.083	-0.004	-0.029	-0.031
	(0.072)	(0.019)	(0.026)	(0.042)
Positive current × Labor		-0.050	-1.518***	0.036
		(0.035)	(0.360)	(0.112)
Negative current × Labor	0.167***	-0.047***	-0.009	0.025
	(0.038)	(0.014)	(0.015)	(0.053)
Panel D: On, Emp.				
Labor (hours per week)	-0.566***	-0.037	0.082	0.150*
	(0.200)	(0.043)	(0.104)	(0.090)
Positive past × Labor				
Negative past × Labor	3.338***	0.044	-0.070	-0.083*
	(0.869)	(0.037)	(0.105)	(0.045)
Positive current × Labor		-0.108***	0.009	-0.206***
		(0.022)	(0.071)	(0.056)
Negative current × Labor	-0.688***	-0.009		-0.061
	(0.146)	(0.014)		(0.082)
N	2167	3322	2805	2684

Note: Household fixed effect model is employed for each subsample. Robust standard errors clustered by household in parentheses. The same set of controls as Table 2 are included but not reported. *** denotes significance at 1% level, ** at 5% level, and * at 10% level. Some of the coefficients are dropped since the variation of rainfall shock variable or labor variable are quite small due to sample division.

5.3. Labor reallocation pattern in response to rainfall shocks

Lastly, we examine the flexibility of maternal labor allocation. Particularly, we investigate how each type of maternal labor time changes in response to past and current rainfall shocks. Results are summarized in **Table 5**.

We find that a one-standard-deviation increase in positive past rainfall is associated with a 5.8-hour decrease in maternal off-farm wage employment time and a 2.7-hour decrease in maternal on-farm self-employment labor time (Columns (2) and (3)). These responses are interpreted as an ex-post strategy after achieving higher agricultural harvests in the previous year due to adequate rainfall, which directly enhances household food intake after the harvest season and indirectly by increasing farm income. As a result, households may reduce their need for agricultural production to feed household members and for income to purchase food, leading to shorter labor time in the next season. Although we cannot directly observe this mechanism, our finding of an increase in household-level dietary diversity score in response to positive past rainfall shock (Column (2) in **Table 3**) is one of supporting evidence for this hypothesis.

With respect to the current rainfall shock, only maternal off-farm wage employment time significantly changes (Column (2)). While a one-standard-deviation increase in current rainfall is also associated with a 5.0-hour decrease in maternal off-farm employment labor time, a one-standard-deviation decrease in current rainfall is associated with a 2.2-hour increase in mothers' off-farm wage employment time. The observed off-farm employment changes are interpreted as an adjustment strategy after observing the current weather. If households observe more (less) rainfall during the cropping season, they decrease off-farm labor (farm labor) while increasing farm labor (off-farm labor), anticipating higher (lower) agricultural yields at the end of the season. Although we do not observe significant changes in farm labor, our findings regarding maternal off-farm labor are consistent with this pattern of household labor adjustment.

In addition, we analyze the labor changes of household members other than mothers to investigate whether labor reallocation patterns differ among different household members (**Table A5** in the Appendix). We find that other members' labor allocation is less flexible in response to rainfall shocks, compared to maternal labor allocation. A one-standard-deviation increase in previous rainfall is associated with a decrease of approximately 13.1 hours in the on-farm wage employment time (Column (4)), but other types of labor do not significantly change in response to both past and current rainfall. Our findings indicate the systematically different labor reallocation patterns among household members.

Table 5: Maternal labor reallocation in response to rainfall

Outcome	(1) Off, Self-emp. (in hours)	(2) Off, Emp. (in hours)	(3) On, Self-emp. (in hours)	(4) On, Emp. (in hours)
Past				
Positive past rainfall shock	3.888	-5.761**	-2.695**	-0.126
	(2.434)	(2.403)	(1.173)	(0.606)
Negative past rainfall shock	0.449	0.848	-0.101	-0.039
	(1.065)	(1.406)	(0.273)	(0.381)
Current				
Positive current rainfall shock	-1.138	-5.018**	-1.479	0.655
	(2.592)	(2.068)	(0.977)	(0.607)
Negative current rainfall shock	0.620	2.155***	0.203	0.025
	(0.533)	(0.545)	(0.222)	(0.121)
Controls				
HH Daily wage (TK):	-0.001	0.001	0.000	0.000
Off-farm, Emp.	(0.001)	(0.002)	(0.001)	(0.000)
HH Daily wage (TK):	0.000	-0.003*	-0.000	0.004***
On-farm, Emp.	(0.002)	(0.002)	(0.001)	(0.001)
N	5504	5504	5504	5504

Note: Household fixed effect model is employed. Robust standard errors clustered by household in parentheses. Outcome variables are weekly maternal labor time in hours for each labor type. The same set of controls as Table 2 except maternal height[20] are included but not reported. *** denotes significance at 1% level, ** at 5% level, and * at 10% level.

[20] While maternal height is an important determinant of child nutritional status and should be controlled, it is less likely to affect maternal labor time.

6. Discussion

We find positive linkages between rainfall in the previous year and the WAZ score and negative linkages between rainfall in the current year and the WAZ score. Our results are consistent with the previous literature showing a positive effect of higher rainfall in the previous monsoon season and a negative effect of higher rainfall in the current monsoon season on child nutrition (Tiwari et al., 2017). Furthermore, we investigate the potential pathways through which past and current rainfall influence child nutrition, differently. First, we find the positive linkages between past rainfall and both agricultural yields and HDDS, supporting the hypothesis of the food intake pathway through which higher past rainfall improves child nutrition. A household in developing countries' rural areas tends to rely on local agricultural products for their food consumption and rainfall is one of the key factors influencing agricultural yields (Adeleke and Babalola, 2020). Therefore, lower agricultural yields directly translate to less household food consumption, which leads to the worse nutritional status of children (Amondo et al., 2023; M. W. Cooper et al., 2019). In our setting, the surveys were conducted during the main cropping season in each year (before the harvest season), the child nutritional status at the survey timing is influenced by the agricultural yields of households in the previous year, which are determined by rainfall in the year prior to the survey (i.e., past rainfall shock).[21] Second, for the impact of current rainfall, the previous literature often discusses the disease environment pathway through which rainfall affects child nutrition: excessive rainfall increases the prevalence of diseases, which prevents essential nutrients from being absorbed and has an impact on the health status of children (Le and Nguyen, 2021; Levy et al., 2016; Omiat and Shively, 2020; Rabassa et al., 2014). We do not find direct evidence supporting this hypothesis,

[21] Although current rainfall has an impact on agricultural production in the survey year, a change in agricultural production would affect nutritional status after it is harvested at the end of the cropping season. Therefore, considering that the survey was conducted during the cropping season, current rainfall shock would not affect nutritional status through agricultural yields.

using diarrhea experience data in the last 2 weeks for children under 24 months of age. However, we find the importance of clean water access, which indirectly supports this hypothesis. Nutritional status of children from households without access to sanitary latrines is more sensitive to the current rainfall than those with, which provides additional evidence of this pathway.

Next, we find the potential role of maternal off-farm self-employment in coping with the impact of rainfall shocks on child nutrition status. Our result is consistent with previous literature finding a positive effect of off-farm income on food security (Dzanku, 2019; Gao and Mills, 2018). In contrast, we find that longer working hours of on-farm labor (both self-employment and wage-employment) are likely to worsen child nutritional status under the rainfall shocks. In summary, when a household experienced unfavorable rainfall for agricultural production in the previous year or is currently observing excessive rainfall, mothers should switch their labor to off-farm labor to improve their child's nutritional status. However, given the mother's time by an increase in off-farm labor, it is also essential to provide mothers with childcare support during their work. Off-farm jobs may be more difficult to balance work and childcare practices because their working locations tend to be more distant from homes, compared to on-farm jobs (Debela et al., 2021). Indeed, we find that, under the same rainfall conditions, longer off-farm (on-farm) labor time is associated with lower (higher) child nutrition. Moreover, we do not find any significant association between child nutrition and total household labor time as well as labor time of household members except mothers. This implies that, in the context of child nutritional status, how mothers allocate labor is more important than other household members' labor allocation.

Lastly, we summarize maternal labor reallocation patterns in response to previous and current rainfall shocks. We find that when receiving higher rainfall in the previous year, mothers are likely to decrease both off-farm wage-employment and on-farm self-employment labor time. We interpret this pattern as a response to higher agricultural yields due to adequate rainfall. We also find that mothers increase (decrease) their off-farm employment labor time if they currently observe unfavorable (suitable) rainfall for agriculture. The observed labor reallocation patterns are consistent with previous literature (Branco and Féres, 2021; Ito and Kurosaki, 2009). Although households allocate their labor in advance based on the traditional climate patterns (ex-ante strategy), they still reallocate their labor after they observe actual weather to optimize their production. It is important to mention that the flexibility of labor changes differs among the forms of labor as well as household members. We find specific labor allocation patterns for different household members. For instance, off-farm employment is the most flexible labor form for mothers. In contrast, a mother does not change her off-farm self-employment in response to rainfall, which is estimated to play a potential role in mitigating the rainfall shock impact on child health. Therefore, to improve child nutritional status in the face of increasing unpredictable rainfall patterns, adequate off-farm self-employment opportunities need to be provided to mothers.

To confirm the robustness of our findings, we conducted an additional analysis. Here, we briefly summarize it and the more detailed descriptions of each analysis and result are presented in Section A.3 of the Appendix. First, we analyze the impact of rainfall shocks on the WAZ score by using five different models: the pooled ordinary least square (OLS) model with covariates, the fixed effect model only for children from households included in our study for all three waves, the correlated random effect (CRE) model, the individual fixed effect model, and the individual CRE model. Those results show the consistent impact of rainfall shock on child nutritional status (i.e., a positive impact of past rainfall and a negative impact of current rainfall on the WAZ score), which validates the robustness of our empirical strategy.

Second, to overcome our limitation of unavailable survey date information, we reconstruct current rainfall shock by using only the first month of the Rabi season (i.e., November), as this month is relevant to all households, and compare the rainfall impacts with the impacts of the whole Rabi season rainfall. We find that the higher November rainfall than the historical average rainfall increases the WAZ score. This result does not support the disease path hypothesis; thus, we do not confirm the robustness of the positive impact of lower current rainfall by this analysis. Instead, the result suggests potential heterogeneous impacts of different timings of rainfall even within the same season. Further research is needed to explore this.

Third, using rainfall during Rabi season in the next year of the survey, we create a future rainfall shock variable and conduct placebo test. We find insignificant impact of future rainfall shock on the WAZ score, which is an important falsification test. Furthermore, we investigate the impacts of Kharif season rainfall and compare them with Rabi season rainfall impacts. We find that the past Kharif rainfall shock has a similar impact on the WAZ score as the past Rabi rainfall shock. In contrast, we do not find significant impact of the current Kharif rainfall shock on the WAZ score. This result provides further evidence of disease path hypothesis. Since rainfall affects diarrhea prevalence in the short term, the Kharif rainfall is unlikely to change diarrhea prevalence at the survey timing, due to a time lag between Kharif season (March to June) and the survey date (mainly after November).

Fourth, we investigate the extreme rainfall case, namely flood and drought impact on child nutrition and the role of maternal labor under flood and drought events. We find that, except for the current drought shock, the estimated effects of rainfall shocks on child nutrition deviate from our main results. This suggests the need for further investigation into the mechanisms under which flood and drought events influence child nutritional status. In contrast, our findings on the role of maternal labor align with our main results: a positive association between off-farm maternal labor and the WAZ score and a negative association between on-farm maternal labor and the WAZ score, under the flood and drought shocks. This suggests that even in the case of extreme rainfall, off-farm maternal labor could be a potential household coping strategy to improve child health.

Finally, we study the impacts of rainfall shocks on child malnutrition as measured by underweight occurrence, the WHZ score, and the HAZ score. We find the same pattern of rainfall shock impacts on underweight occurrence as well as association between maternal labor role and this linkage. Furthermore, we find a significant direct association between the WHZ score and maternal labor but an insignificant direct association between the HAZ score and maternal labor. This provides evidence on different sensitivities of different health indicators: the WHZ score is more sensitive to acute factor, while the HAZ score is more sensitive to chronic factor, as our labor variables capture maternal labor in the last seven days.

7. Conclusions and policy implications

Children's undernutrition remains a major issue in rural areas of developing countries. One of the causes of poor nutritional status of children is food shortage attributed to weather-related shocks. To achieve household food security in the face of rainfall shocks, rural households can allocate their labor among on-farm and off-farm activities. Understanding how each type of labor reduces the negative effect of weather shock on child nutritional status would assist farmers in selecting appropriate labor allocation to cope with weather shocks.

Using the nationally representative panel surveys in Bangladesh, we investigate the role of each form of labor as the potential mechanism underlying the impact of rainfall shocks on child nutritional status, measured by the WAZ score. Bangladesh still suffers from the problem of child undernutrition, despite the substantial efforts to improve food and nutrition in recent decades. Our findings show that child nutritional status is improved by more rainfall in the previous year which could relate to changes in food intake, as well as less rainfall in the survey year, potentially due to less exposure to disease environment. In addition, we find the importance of maternal off-farm labor: a longer working time for maternal off-farm self-employed labor is likely to mitigate the negative impact of previous year's rainfall shortage on the WAZ score.[22] However, a longer working time for maternal on-farm labor may exacerbate the negative effect of insufficient previous rainfall on the WAZ score. Furthermore, contrary to maternal labor, we do not find significant labor roles at the household level and household members except the mother level. Our findings imply that maternal labor allocation plays an important role in coping with rainfall shocks in the context of child health. It is also important to consider the potential maternal time constraint caused by off-farm labor. Our finding suggests that off-farm working environments away from home may decrease caregiving time, leading to worse child health under same weather conditions.

This paper contributes to the literature by demonstrating the different roles of various types of labor under the same conditions as a coping mechanism to mitigate the impact of rainfall shocks on child nutrition. Given the possibility of further extreme weather in the near future, it will be more important for households to adapt to rainfall fluctuations through labor reallocation. Furthermore, by comparing labor roles at different units (i.e., household level, a mother, and other household members), we provide insights about whose labor time is important in the context of child health, which had not been well studied to our knowledge. We undertook various robustness checks supporting our findings. Nevertheless, we acknowledge that there is still a potential endogeneity problem caused by simultaneous decision-making of labor time. We therefore interpret our results of labor roles as associations and do not claim causality.

Important policy implications can be drawn based on our findings. Specific projects, such as social safety nets or money transfers, are, of course, effective ways to cope with shocks for rural households, but their recipients are limited (Branco and Féres, 2021). However, labor

[22] In addition, a longer working time for maternal off-farm wage employed labor is likely to improve nutritional status of children older than 24 months in our sample under the excessive rainfall in the current year.

reallocation in response to shocks can be adapted by any household. Therefore, our findings suggest the importance of policies that provide off-farm labor opportunities for mothers to cope with rainfall shocks. A variety of off-farm labor opportunities allows mothers to select a more suitable job based on their circumstances, leading to a higher chance of off-farm work for mothers with children. Furthermore, such a policy should take into account maternal time constraints. Supporting mothers who work and care for children would be another crucial role of these policies. Possible ways include the introduction of childcare spaces in the workplace, the adoption of kindergartens in rural areas, and the implementation of babysitter services.

References

Adeleke, B.S., Babalola, O.O., 2020. Oilseed crop sunflower (Helianthus annuus) as a source of food: Nutritional and health benefits. Food Science & Nutrition 8, 4666–4684.

Aguilar, A., Vicarelli, M., 2022. El Niño and children: Medium-term effects of early-life weather shocks on cognitive and health outcomes. World Development 150, 105690. https://doi.org/10.1016/j.worlddev.2021.105690

Ahmed, A.U., Tauseef, S., 2022. Climbing up the ladder and watching out for the fall: poverty dynamics in rural Bangladesh. Social Indicators Research 160, 309–340.

Amondo, E.I., Nshakira-Rukundo, E., Mirzabaev, A., 2023. The effect of extreme weather events on child nutrition and health. Food Security 1–26.

Baker, R.E., Anttila-Hughes, J., 2020. Characterizing the contribution of high temperatures to child undernourishment in Sub-Saharan Africa. Scientific reports 10, 1–10.

Bandyopadhyay, S., Skoufias, E., 2015. Rainfall variability, occupational choice, and welfare in rural Bangladesh. Review of Economics of the Household 13, 589–634.

BBS, UNICEF, 2019. Progotir Pathey Bangladesh: Bangladesh Multiple Indicator Cluster Survey 2019. Dhaka: Bangladesh Bureau of Statistics (BBS).

Blom, S., Ortiz-Bobea, A., Hoddinott, J., 2022. Heat exposure and child nutrition: Evidence from West Africa. Journal of Environmental Economics and Management 115, 102698. https://doi.org/10.1016/j.jeem.2022.102698

Branco, D., Féres, J., 2021. Weather shocks and labor allocation: Evidence from rural Brazil. American Journal of Agricultural Economics 103, 1359–1377.

Chandna, A., Bhagowalia, P., 2024. Birth order and children's health and learning outcomes in India. Economics & Human Biology 52, 101348. https://doi.org/10.1016/j.ehb.2023.101348

Chowdhury, T.R., Chakrabarty, S., Rakib, M., Saltmarsh, S., Davis, K.A., 2018. Socio-economic risk factors for early childhood underweight in Bangladesh. Globalization and health 14, 1–12.

Cooper, M., Brown, M.E., Azzarri, C., Meinzen-Dick, R., 2019. Hunger, nutrition, and precipitation: evidence from Ghana and Bangladesh. Population and Environment 41, 151–208.

Cooper, M.W., Brown, M.E., Hochrainer-Stigler, S., Pflug, G., McCallum, I., Fritz, S., Silva,

J., Zvoleff, A., 2019. Mapping the effects of drought on child stunting. Proceedings of the National Academy of Sciences 116, 17219–17224.
Debela, B.L., Gehrke, E., Qaim, M., 2021. Links between Maternal Employment and Child Nutrition in Rural Tanzania. American Journal of Agricultural Economics 103, 812–830. https://doi.org/10.1111/ajae.12113
Delpla, I., Jung, A.-V., Baures, E., Clement, M., Thomas, O., 2009. Impacts of climate change on surface water quality in relation to drinking water production. Environment international 35, 1225–1233.
Dhingra, S., Pingali, P.L., 2021. Effects of short birth spacing on birth-order differences in child stunting: Evidence from India. Proc. Natl. Acad. Sci. U.S.A. 118, e2017834118. https://doi.org/10.1073/pnas.2017834118
Duflo, E., 2012. Women empowerment and economic development. Journal of Economic literature 50, 1051–1079.
Dzanku, F.M., 2019. Food security in rural sub-Saharan Africa: Exploring the nexus between gender, geography and off-farm employment. World Development 113, 26–43.
Freudenreich, H., Aladysheva, A., Brück, T., 2022. Weather shocks across seasons and child health: Evidence from a panel study in the Kyrgyz Republic. World Development 155, 105801. https://doi.org/10.1016/j.worlddev.2021.105801
Gao, J., Mills, B.F., 2018. Weather shocks, coping strategies, and consumption dynamics in rural Ethiopia. World Development 101, 268–283.
Hanifi, S.M.A., Menon, N., Quisumbing, A., 2022. The impact of climate change on children's nutritional status in coastal Bangladesh. Social Science & Medicine 294, 114704.
Islam, A.H.Md.S., von Braun, J., Thorne-Lyman, A.L., Ahmed, A.U., 2018. Farm diversification and food and nutrition security in Bangladesh: empirical evidence from nationally representative household panel data. Food Sec. 10, 701–720. https://doi.org/10.1007/s12571-018-0806-3
Ito, T., Kurosaki, T., 2009. Weather risk, wages in kind, and the off-farm labor supply of agricultural households in a developing country. American journal of agricultural economics 91, 697–710.
Johnston, D., Stevano, S., Malapit, H.J., Hull, E., Kadiyala, S., 2018. Time use as an explanation for the agri-nutrition disconnect: evidence from rural areas in low and middle-income countries. Food policy 76, 8–18.
Kishida, T., Matsuura-Kannari, M., Islam, A.H.S., 2024. Revisiting Birth Order Effects on Child Health: Evidence from Bangladesh. https://doi.org/10.20561/0002000992
Le, K., Nguyen, M., 2021. In-utero exposure to rainfall variability and early childhood health. World Development 144, 105485.
Levy, K., Woster, A.P., Goldstein, R.S., Carlton, E.J., 2016. Untangling the Impacts of Climate Change on Waterborne Diseases: a Systematic Review of Relationships between Diarrheal Diseases and Temperature, Rainfall, Flooding, and Drought. Environmental Science & Technology 50, 4905–4922. https://doi.org/10.1021/acs.est.5b06186
Maccini, S., Yang, D., 2009. Under the weather: Health, schooling, and economic consequences of early-life rainfall. American Economic Review 99, 1006–1026.
Makate, C., Angelsen, A., Holden, S.T., Westengen, O.T., 2022. Crops in crises: Shocks shape smallholders' diversification in rural Ethiopia. World Development 159, 106054.
Matsuura-Kannari, M., Luh, Y.-H., Islam, A.H.Md.S., 2023. Weather shocks, livelihood diversification, and household food security: Empirical evidence from rural Bangladesh. Agricultural Economics 54, 455–470. https://doi.org/10.1111/agec.12776

Ministry of Food, Government of Bangladesh, 2015. Modern Food Storage Facilities Project –MFSP.
Moffit, R., Fitzgerald, J., Gottschalk, P., 1999. Sample Attrition in Panel Data: The Role of Selection on Observables. Annales d'Économie et de Statistique 129–152. https://doi.org/10.2307/20076194
Musungu, A.L., Kubik, Z., Qaim, M., 2024. Drought shocks and labour reallocation in rural Africa: evidence from Ethiopia. European Review of Agricultural Economics 51, 1045–1068. https://doi.org/10.1093/erae/jbae020
Nguyen, T.T., Nguyen, L.D., Lippe, R.S., Grote, U., 2017. Determinants of farmers' land use decision-making: Comparative evidence from Thailand and Vietnam. World Development 89, 199–213.
Ogasawara, K., Yumitori, M., 2019. Early-life exposure to weather shocks and child height: Evidence from industrializing Japan. SSM-population health 7, 100317.
Omiat, G., Shively, G., 2020. Rainfall and child weight in Uganda. Economics and Human Biology 38, 100877. https://doi.org/10.1016/j.ehb.2020.100877
Pandey, S., Bhandari, H., Ding, S., Prapertchob, P., Sharan, R., Naik, D., Taunk, S.K., Sastri, A., 2007. Coping with drought in rice farming in Asia: insights from a cross-country comparative study. Agricultural Economics 37, 213–224.
Rabassa, M., Skoufias, E., Jacoby, H., 2014. Weather and child health in rural Nigeria. Journal of African Economies 23, 464–492.
Rose, E., 2001. Ex ante and ex post labor supply response to risk in a low-income area. Journal of development economics 64, 371–388.
Shroff, M., Griffiths, P., Adair, L., Suchindran, C., Bentley, M., 2009. Maternal autonomy is inversely related to child stunting in Andhra Pradesh, India. Maternal & child nutrition 5, 64–74.
Sibhatu, K.T., Qaim, M., 2018. Meta-analysis of the association between production diversity, diets, and nutrition in smallholder farm households. Food Policy 77, 1–18.
Tiwari, S., Jacoby, H.G., Skoufias, E., 2017. Monsoon Babies: Rainfall Shocks and Child Nutrition in Nepal. Economic Development and Cultural Change 65, 167–188. https://doi.org/10.1086/689308
UNICEF, WHO, and World Bank, 2023a. Levels and Trends in Child Malnutrition: UNICEF/WHO/The World Bank Group Joint Child Malnutrition Estimates: Key Findings of the 2023 Edition. UNICEF, WHO, World Bank Group.
UNICEF, WHO, World Bank, 2023b. Joint Child Malnutrition Estimates (JME): Prevalence of Underweight, Weight for Age (% of Children Under 5).
VanderWeele, T., Vansteelandt, S., 2014. Mediation Analysis with Multiple Mediators. Epidemiologic Methods 2, 95–115. https://doi.org/10.1515/em-2012-0010
VanderWeele, T.J., 2016. Mediation Analysis: A Practitioner's Guide. Annual Review of Public Health 37, 17–32. https://doi.org/10.1146/annurev-publhealth-032315-021402
Vogel, E., Donat, M.G., Alexander, L.V., Meinshausen, M., Ray, D.K., Karoly, D., Meinshausen, N., Frieler, K., 2019. The effects of climate extremes on global agricultural yields. Environmental Research Letters 14, 054010.

Appendix

A.1 Supplementary tables

Table A1: Attrition analysis

Panel A: Rainfall impact	(1)
Outcome	WAZ score
IMR	0.136
	(0.142)
Positive past rainfall shock	0.320
	(0.209)
Negative past rainfall shock	-0.157*
	(0.094)
Positive current rainfall shock	-0.029
	(0.196)
Negative current rainfall shock	0.182***
	(0.064)
N	5489

Panel B: Maternal labor role	(1)	(2)	(3)	(4)
Outcome	WAZ score			
Labor type	Off, Self-emp.	Off, Emp.	On, Self-emp.	On, Emp.
IMR	0.161	0.130	0.127	0.136
	(0.133)	(0.132)	(0.139)	(0.149)
Labor hours	-0.019***	0.001	0.060*	0.081
	(0.006)	(0.006)	(0.033)	(0.075)
Positive past × Labor	0.015	0.043	0.001	0.000
	(0.026)	(0.040)	(0.140)	(0.000)
Negative past × Labor	0.014**	-0.003	-0.034	-0.041
	(0.005)	(0.005)	(0.030)	(0.067)
Positive current × Labor	-0.012	0.007	-0.041	-0.085
	(0.017)	(0.017)	(0.064)	(0.158)
Negative current × Labor	0.000	0.005	-0.024	-0.017
	(0.004)	(0.004)	(0.023)	(0.050)
N	5489	5489	5489	5489

Panel C: Labor reallocation	(1)	(2)	(3)	(4)
Outcome: Maternal labor	Off, Self-emp.	Off, Emp.	On, Self-emp.	On, Emp.
IMR	2.226	-0.939	0.092	0.066
	(1.682)	(2.916)	(0.329)	(0.147)
Positive past rainfall shock	3.727	-5.693*	-2.702**	-0.131
	(2.604)	(3.034)	(1.371)	(0.602)
Negative past rainfall shock	0.194	0.956	-0.111	-0.047
	(1.033)	(1.380)	(0.288)	(0.335)
Positive current rainfall shock	-1.433	-4.894**	-1.491*	0.647
	(2.459)	(2.052)	(1.104)	(0.634)
Negative current rainfall shock	0.690	2.125***	0.206	0.027

	(0.658)	(0.479)	(0.241)	(0.115)
N	5504	5504	5504	5504

Notes: IMR (Inverse Mills Ratio) is included in the analysis of the impact of rainfall shock on child nutrition (panel A) as well as of maternal labor role (panel B) to account for the attrition bias. In all estimations, we find that IMR is statistically insignificant, implying that our results are not affected by the attrition. Here, we employ bootstrap standard errors. *** denotes significance at 1% level, ** at 5% level, and * at 10% level.

Table A2: Summary Statistics – Other Variables

	Wave 1		Wave 2		Wave 3	
A. Household-level characteristics	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
Total harvest (ton)	3.278	(4.955)	1.643	(3.647)	1.762	(4.835)
Dietary diversity score (12 food groups)	9.391	(1.271)	9.900	(1.155)	10.136	(1.007)
HH Labor hours: Off farm, Self	16.972	(28.504)	22.160	(33.576)	23.442	(37.585)
HH Labor hours: Off farm, Emp.	10.179	(22.822)	14.378	(28.868)	16.549	(33.732)
HH Labor hours: On farm, Self	32.934	(25.941)	18.228	(20.204)	17.509	(20.985)
HH Labor hours: On farm, Emp.	14.438	(23.358)	12.277	(21.502)	12.639	(21.332)
Observations	1078		2040		1578	
B. Child-level characteristics	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
Age of Mother	27.358	(6.251)	27.384	(5.683)	27.527	(5.916)
Schooling year of Mother	5.029	(3.562)	5.422	(3.499)	6.318	(3.587)
Maternal height (cm)	150.866	(5.495)	150.907	(5.546)	151.037	(5.616)
Observations	1244		2385		1879	
C. Infant-level characteristics	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
Breastfeeding (= 1)	0.969	(0.172)	0.975	(0.155)	0.963	(0.189)
Number of antenatal care sessions received by mother	2.440	(2.249)	3.016	(2.484)	3.326	(2.556)
Birth order (number)	2.273	(1.442)	2.351	(1.362)	2.395	(1.402)
Dietary diversity score (7 food groups)	2.308	(1.924)	2.276	(1.847)	2.343	(1.800)
Diarrhea (= 1)	0.110	(0.313)	0.071	(0.257)	0.200	(0.414)
Breastfeeding frequency[23]	2.071	(0.882)	2.436	(0.849)	2.373	(0.833)
Observations	494		891		731	

Table A3: Role of labor allocation on child nutrition: (A) HH-level and (B) Other HH members-level

Outcome: WAZ score	(1)	(2)	(3)	(4)
Panel A: Household				
Labor type	Off, Self-emp.	Off, Emp.	On, Self-emp.	On, Emp.
Labor hours	-0.000	-0.003	-0.001	0.000
	(0.001)	(0.002)	(0.002)	(0.002)
Positive past × Labor	-0.005	0.000	0.003	-0.001
	(0.005)	(0.006)	(0.006)	(0.007)
Negative past × Labor	-0.000	-0.001	-0.000	0.000
	(0.001)	(0.002)	(0.002)	(0.002)
Positive current × Labor	-0.006	0.002	0.007	0.005
	(0.004)	(0.006)	(0.006)	(0.007)

[23] This is a categorical variable, which equals 1 if low (0-7 times), 2 if moderate (8-12 times), 3 if high (13-24 times), and 4 if very high frequency (more than 25 times).

Negative current × Labor	-0.000	0.002	-0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
N	5489	5489	5489	5489
Panel B: Except mothers				
Labor type	Off, Self-emp.	Off, Emp.	On, Self-emp.	On, Emp.
Labor hours	0.001	-0.003	-0.002	-0.001
	(0.001)	(0.002)	(0.002)	(0.002)
Positive past × Labor	-0.005	-0.000	0.003	0.000
	(0.004)	(0.006)	(0.006)	(0.007)
Negative past × Labor	-0.001	-0.000	0.000	0.001
	(0.001)	(0.002)	(0.002)	(0.002)
Positive current × Labor	-0.006	0.001	0.008	0.008
	(0.004)	(0.005)	(0.006)	(0.007)
Negative current × Labor	-0.000	0.002	-0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
N	5489	5489	5489	5489

Notes: Two-way fixed effect model is employed. Robust standard errors clustered by household in parentheses. The same set of controls as in Table 2 are included but not reported. Year and household fixed effects are included but not reported. Rainfall shock variables are also included but not reported. * denotes significance at 10% level.

Table A4: Maternal labor time (weekly hours) and care time (weekly minutes) spent by household female member

Panel A	
Outcome	Care time (minutes)
Mother Labor hours: Off farm, Self (hours)	-7.754***
	(2.459)
Mother Labor hours: Off farm, Emp. (hours)	-6.873***
	(2.333)
Mother Labor hours: On farm, Self (hours)	-6.104
	(4.537)
Mother Labor hours: On farm, Emp. (hours)	-22.729
	(14.225)
N	5502
Panel B	
Outcome	Breastfeeding frequency
Maternal Labor hours: Total off farm	-0.003*
	(0.002)
Maternal Labor hours: Total on farm	0.002
	(0.007)
N	2060

Notes: **Panel A)** Outcome variable is calculated based on total time in the last 24 hours spent in care for children, adults, and elderly by household female member. Although the recall period of care time is short, this analysis suggests evidence that longer working time of off-farm labor is likely to reduce care time. Robust standard errors clustered by household in parentheses. The same set of controls as in Table 2 except rainfall and temperature shocks and maternal height are included but not reported. Year and household fixed effects are included but not reported. *** denotes significance at 1% level. Since such time constraints can be offset by the help of other household members (Johnston et al., 2018), here we control for the working capacity of the household (number of working-age (order than 12) household members). **Panel B)** Outcome variable is calculated based on total number that a mother breastfed a child yesterday (available only for children under 24 months), which is categorized into low (0-7 times), moderate (8-12 times), high (13-24 times), and very high (more than 25). We also analyze the outcome in its original continuous form, in the continuous form with outliers removed (excluding values above 25), and in a winsorized form (with the top 5% winsorized). Results are consistent. Here, our sample is limited to mothers with small children still breastfed, reducing sample size and variations of maternal labor variables. To increase maternal labor time variations, we combine self-employment and employment labor time and create total off-farm labor time and total on-farm labor time variables (hours per week), and employ correlated random effect model, instead of fixed effects model. * denotes significance at 1% level.

Table A5: Labor reallocation in response to rainfall: Other HH members' labor (except mother)

Outcome	(1) Off, Self-emp. (in hours)	(2) Off, Emp. (in hours)	(3) On, Self-emp. (in hours)	(4) On, Emp. (in hours)
Past				
Positive past rainfall shock	-9.701	-1.739	-4.582	-13.089***
	(7.937)	(6.389)	(5.338)	(4.428)
Negative past rainfall shock	0.289	-1.067	-2.538	-0.944
	(4.119)	(3.647)	(2.931)	(3.016)
Current				
Positive current rainfall shock	-5.204	-0.208	-0.995	-2.735
	(7.327)	(5.186)	(5.189)	(3.979)
Negative current rainfall shock	1.086	-0.936	-0.035	0.959
	(2.044)	(1.426)	(1.455)	(1.550)
N	5504	5504	5504	5504

Note: Household fixed effect model is employed. Robust standard errors clustered by household in parentheses. Outcome variables are weekly maternal labor time in hours for each labor type. The same set of controls as Table 5 are included but not reported. *** denotes significance at 1% level.

A.2 Extended conceptual framework

We assume that a household maximizes the utility by improving the nutritional status of the current child. Based on the assumptions explained in Section 2, we discuss how a household should allocate its labor to mitigate the rainfall impacts on child nutrition. The effects of rainfall on each input of the child's nutritional status can be written as follows:

$$\frac{dC}{dR_{t-1}} = \frac{dC}{dY_{t-1}}\frac{dY_{t-1}}{dR_{t-1}} + \frac{dC}{dPF}\frac{dPF}{dL^{off}}\frac{dL^{off}}{dR_{t-1}}$$

$$\frac{dD}{dR_t} = \frac{dD}{dR_t} + \frac{dD}{dL^{off}}\frac{dL^{off}}{dR_t} + \frac{dD}{dL^{on}}\frac{dL^{on}}{dR_t} \qquad \text{(A1)}$$

$$\frac{dT}{dR_{t-1}dR_t} = \frac{dT}{dL^k}\left(\frac{dL^k}{dR_{t-1}} + \frac{dL^k}{dR_t}\right) \text{ (k = off or on)}$$

The first line in Equation A1 represents the impact of previous rainfall on child health through food intake. $\frac{dC}{dY}\frac{dY}{dR_{t-1}}$ is likely to be positive, since more (less) rainfall in the previous year leads to higher (lower) agricultural yields and increases (decreases) current food intake, which results in a better (worse) nutritional status of the child. Meanwhile, $\frac{dC}{dPF}\frac{dPF}{dL^{off}}\frac{dL^{off}}{dR_{t-1}}$ can capture the ability of households to cope with agricultural yield loss due to rainfall shock. Therefore, if a household can reallocate its labor to compensate for the impact of agricultural yield change because of rainfall in the previous year on food intake,

$$\frac{dC}{dY_{t-1}}\frac{dY_{t-1}}{dR_{t-1}} + \frac{dC}{dPF}\frac{dPF}{dL^{off}}\frac{dL^{off}}{dR_{t-1}} = 0 \qquad \text{(A2)}$$

Intuitively, a higher amount of purchased food increases food intake ($\frac{dC}{dPF}$>0). Furthermore, an increase in off-farm labor is likely to lead to higher household income, mitigating budget constraints, including food purchase ($\frac{dPF}{dL^{off}} > 0$). Thus, Equation A2 requires $\frac{dL^{off}}{dR_{t-1}} < 0$. In this case, the reallocation of labor plays a role in mitigating the impact of rain on the health status of the child through the food intake path.

The second line in Equation A1 represents the impacts of rainfall on child health through the prevalence of diseases. $\frac{dD}{dR_t}$ is likely to be positive, since larger rainfall increases the prevalence of disease. Whereas, $\frac{dD}{dL^{off}}\frac{dL^{off}}{dR_t}+\frac{dD}{dL^{on}}\frac{dL^{on}}{dR_t}$ can capture the ability of the household to deal with a severe disease environment due to current heavy rainfall. Therefore, if a household can reallocate its labor to offset the negative disease prevalence effect as a result of current rainfall,

$$\frac{dD}{dR_t}+\frac{dD}{dL^{off}}\frac{dL^{off}}{dR_t}+\frac{dD}{dL^{on}}\frac{dL^{on}}{dR_t}=0 \qquad \text{(A3)}$$

Equation A3 requires $\frac{dD}{dL^{off}}\frac{dL^{off}}{dR_t}+\frac{dD}{dL^{on}}\frac{dL^{on}}{dR_t}<0$. The labor should be reallocated to satisfy this requirement. In this case, there are two scenarios. The first focuses on the role of off-farm labor. Off-farm labor can improve the quality of childcare practices by increasing the available household income for healthcare, which is likely to decrease the prevalence of disease ($\frac{dD}{dL^{off}}<0$). Thus, a household should increase off-farm labor in response to current heavy rain ($\frac{dL^{off}}{dR_t}>0$), while decrease on-farm labor ($\frac{dL^{on}}{dR_t}<0$) due to time constraints. The second focuses on the role of on-farm labor. Longer working time in on-farm labor is likely to increase time available for childcare and decrease disease prevalence when compared to off-farm work ($\frac{dD}{dL^{on}}<0$). Thus, a household should increase on-farm labor in response to current heavy rain ($\frac{dL^{on}}{dR_t}>0$), while decrease off-farm labor ($\frac{dL^{off}}{dR_t}<0$) due to time constraints. In conclusion, to deal with a severe disease environment due to current heavy rainfall, a household can increase either off-farm labor or on-farm labor, but not both of them because of time constraints.[24]

The last line in Equation A1 represents the impact of childcare practices on child health.

[24] We assume that the change in labor in response to previous rainfall is motivated by the change in agricultural yield and does not influence disease prevalence ($\frac{dD}{dL^k}\frac{dL^k}{dR_{t-1}}=0 \mid \text{k=off or on}$).

The availability of childcare is directly determined by labor reallocation following shock. There are two possibilities. On the one hand, on-farm labor can improve childcare practices by increasing parents' time to care for their children. The working time of a childcare provider is especially important for this. On the other hand, off-farm labor can improve childcare practices by increasing household income, which allows a household to purchase necessary goods for children. To deal with rainfall shocks through childcare practices, labor allocation should satisfy the following equation:

$$\frac{dT}{dL^k}\left(\frac{dL^k}{dR_{t-1}} + \frac{dL^k}{dR_t}\right) = 0 \tag{A4}$$

This requires $\frac{dL^k}{dR_{t-1}} = -\frac{dL^k}{dR_t}$, which implying that labor should react to previous and current rainfall in opposite directions. From Equations A2, A3, and A4, we derive the following possible household labor strategy to mitigate recent rainfall shocks on child health:

$$\frac{dL^{off}}{dR_{t-1}} < 0, \frac{dL^{off}}{dR_t} > 0, \ \frac{dL^{on}}{dR_{t-1}} > 0, \frac{dL^{on}}{dR_t} < 0 \tag{A5}$$

Although there could be other possible household labor strategies, we aim to show evidence for the impact of this household labor strategy in the empirical analysis.

A.3 Robustness check

We begin with an analysis of the impact of rainfall shocks on the WAZ score using five different methods: the pooled OLS model with covariates, the fixed effect model only for children from households included in our study for all three waves, the CRE model, the individual fixed effect model, and the individual CRE model. Results are summarized in **Table A6**. The pooled OLS result shows that, without a household fixed effect, the impact of rainfall on the WAZ score is consistent with our main result of two-way fixed effects model (Column (1)): A positive impact of past rainfall on the WAZ score (past rainfall shortage is worse for child nutrition), as well as a negative impact of current rainfall on the WAZ score (less current rainfall is better for child nutrition). Next, we consider the potential bias posed by our unbalanced panel data setting. Since the surveys span almost 10 years, some households do not always have a child under five years old during the study period. If a household is included in our study only once, the household fixed effect cannot control for the time invariant household-specific characteristics. To address this concern, we limit our sample to only children from households included in our study across all three waves and employ the two-way fixed effects model. We find that the estimated rainfall impacts are consistent with the findings from the whole sample and the coefficient size is also close, although the impact of past rainfall is not statistically significant (Column (2)). Third, to account for between-household variations in addition to within-household variations, we employ the CRE model and confirm that the result is consistent (Column (3)). Fourth, to control away all time-invariant individual-level characteristics, we include child fixed effect. Here, instead of comparing different children with the same household over time, we track the same child over time. Since we only include children under the age of five, the same child cannot be observed across all three waves, but only one or two, therefore within-individual variations over time are small. However, we find the consistent rainfall effect, although it is not statistically significant (Column (4)). Lastly, we employ the CRE model for this individual-child level panel setting and find the consistent result (Column (5)). Taking all together, we confirm the robustness of our results on the impact of rainfall shocks on child nutritional status.

Table A6: The effect of rainfall shock on the WAZ score: Different models

Outcome: WAZ score	(1)	(2)	(3)	(4)	(5)
Past					
Positive past rainfall shock	0.072	0.337	0.036	0.300	0.038
	(0.128)	(0.336)	(0.120)	(0.312)	(0.123)
Negative past rainfall shock	-0.144***	-0.154	-0.144***	-0.116	-0.134***
	(0.048)	(0.225)	(0.046)	(0.172)	(0.048)
Current					
Positive current rainfall shock	0.067	-0.008	0.006	0.037	0.065
	(0.101)	(0.379)	(0.096)	(0.307)	(0.097)
Negative current rainfall shock	0.087*	0.192*	0.080*	0.097	0.071
	(0.046)	(0.104)	(0.044)	(0.082)	(0.044)
Model	Pooled OLS	Fixed effect	CRE	Fixed effect	CRE
Year FE	Yes	Yes	Yes	Yes	Yes
HH FE	No	Yes	No	No	No
Child FE	No	No	No	Yes	No
N	5489	810	5489	5489	5489

Notes: Robust standard errors clustered by households in parentheses. The same set of controls are included in all regressions but not reported. In column (2), we exclude households that show up only one round. *** denotes significance at 1% level, ** at 5% level, and * at 10% level.

Next, we address our limitation of unavailable survey date information. Although the survey was conducted mainly during the Rabi season, the date of interview varies between households. Unfortunately, interview date information is not available, thus we cannot control for survey timing differences. To overcome this limitation, we reconstruct current rainfall shock by using only the first month of the Rabi season (i.e., November), as this month is relevant to all households in the sample, and compare the rainfall impacts with the impacts of the whole Rabi season rainfall. We find that the positive November rainfall shock in the current year is positively associated with the WAZ score (**Table A7**). This result does not align with the disease path hypothesis, suggesting that rainfall at the beginning of cropping season may influence child nutrition through different pathways. It is also possible that rainfall earlier in the season affects the disease environment less for households interviewed later in the season, due to a time lag. One note is that not many households received higher rainfall in November compared to the average historical November rainfall, thus the variations of the positive November rainfall shock are small, making the estimate less reliable. Further research on how different timing of rainfall within the same season influences child health differently would be our future work.

Table A7: The effect of whole Rabi-season rainfall in the past year and November rainfall in the current year on the WAZ score

Outcome: WAZ score	(1)
Past	
Positive past rainfall shock	0.347*
	(0.197)
Negative past rainfall shock	-0.190*
	(0.111)
Current	
Positive November rainfall shock	3.499**
	(1.600)
Negative November rainfall shock	0.381
	(0.237)
N	5489

Notes: Two-way fixed effect model is employed. Robust standard errors clustered by households in parentheses. The same set of controls as Table 2 are included but not reported. ** denotes significance at 5% level and * at 10% level.

Third, we conduct a placebo test with future rainfall shock. Using Rabi season rainfall data in the next year of the survey (i.e., total rainfall between November and February in 2012 and the following year for wave 1, those in 2015 for wave 2, and November and December in 2019 for wave 3[25]), we construct the future rainfall shock variable. We find insignificant impact of future rainfall shock on the WAZ score, which is an important falsification test (Columns (1) and (2) in **Table A8**). Furthermore, we investigate the impacts of another cropping season,

[25] We have climate data merged with each household location only until December in 2019. Therefore, a future rainfall shock variable for wave 3 is calculated based on November and December rainfall.

Kharif season rainfall. We find that the past Kharif rainfall shock has a similar impact on the WAZ score as the past Rabi rainfall shock, in terms of both the coefficient size and statistical significance (Columns (3) and (4) in **Table A8**). In contrast, we do not find significant impact of the current Kharif rainfall shock on the WAZ score. This result provides further evidence of disease path underlying the current rainfall impact on child nutritional status. Since rainfall affects diarrhea prevalence in the short term, the Kharif rainfall is unlikely to change diarrhea prevalence at the survey timing, due to a time lag between Kharif season (March to June) and the survey date (mainly after November). This results in insignificant impacts of Kharif season rainfall shocks in the survey year on child nutritional status.

Table A8: Placebo test (future rainfall shock) and the effect of Kharif season rainfall shocks on the WAZ score

Outcome: WAZ score	(1)	(2)	(3)	(4)
Future				
Future Rabi rainfall shock	-0.060			
	(0.099)			
Positive future Rabi rainfall shock		-0.490		
		(0.373)		
Negative future Rabi rainfall shock		0.027		
		(0.106)		
Past				
Past Kharif rainfall shock			0.103*	
			(0.057)	
Positive past Kharif rainfall shock				0.349***
				(0.131)
Negative past Kharif rainfall shock				0.041
				(0.087)
Current				
Current Kharif rainfall shock			-0.083	
			(0.088)	
Positive current Kharif rainfall shock				0.079
				(0.209)
Negative current Kharif rainfall shock				0.160
				(0.131)
N	5218	5218	5489	5489

Notes: Household fixed effect model is employed. Robust standard errors clustered by household in parentheses. The same set of controls as Table 2 are included but not reported. *** denotes significance at 1% level and * at 10% level.

Fourth, we investigate the extreme rainfall case, namely flood and drought. Since extreme rainfall is likely to cause more severe impacts on both agricultural yields and disease prevalence, analysis with flood and drought variables would provide additional insights into the importance of maternal labor for child health. Using flood and drought dummy defined in Equations (6) and (7), we show the impact of extreme rainfall on the WAZ score (**Table A9**). For the past rainfall, we do not find significant effects of flood and drought shocks. Our previous finding of a positive past rainfall impact of child nutrition is explained by the food intake pathway, driven by rainfall-induced changes in agricultural yields. In the case of extreme rainfall, both flood and drought events are likely to harm agricultural yields and do not contribute to an improvement of household food intake, thereby not influencing child nutrition. One may expect that flood and drought events would potentially reduce the WAZ score through a decrease in agricultural yields, however, we do not find empirical evidence of this. For the current rainfall, we find a positive effect of both flood and drought shocks on the WAZ score. While the drought impact is consistent with our main result of the negative current rainfall shock, the positive impact of flood events does not align with the disease hypothesis. However, this result should be interpreted with caution, as flood events were rare during our study period (i.e., less than 1% of our sample experienced flood events). In future work, we will further investigate the impacts of extreme rainfall, especially flood events, on child health and the underlying mechanisms.

Table A9: The effect of flood and drought shocks on the WAZ score

Outcome: WAZ score	(1)
Past	
Past flood shock	0.238
	(0.218)
Past drought shock	-0.055
	(0.058)
Current	
Current flood shock	0.444*
	(0.234)
Current drought shock	0.103*
	(0.059)

N	5489

Notes: Two-way fixed effect model is employed. Robust standard errors clustered by households in parentheses. The same set of controls as Table 2 are included but not reported. * denotes significance at 10% level.

Although the impacts of flood and drought shocks on the WAZ score are not completely consistent with our main results in **Table 2**, we now estimate the role of maternal labor under the extreme rainfall events. Results are summarized in **Table A10**. We find the consistent pattern of maternal labor role with our main results in **Figure 4**: While longer working time of off-farm maternal labor is positively associated with the WAZ score even under the flood and drought shocks, longer working time of on-farm maternal labor is negatively associated with the WAZ score here. Our results suggest that even in the case of extreme rainfall, off-farm maternal labor can be a household coping strategy against rainfall shock in the context of child health.

Table A10: Maternal labor role on child nutrition under flood and drought shocks

Outcome: WAZ score	(1)	(2)	(3)	(4)
Labor type	Off, Self-emp.	Off, Emp.	On, Self-emp.	On, Emp.
Labor hours	-0.011***	-0.001	0.028***	0.052***
	(0.003)	(0.002)	(0.009)	(0.015)
Flood past × Labor	0.029***	0.037	-0.357***	
	(0.010)	(0.050)	(0.071)	
Drought past × Labor	0.008**	-0.001	-0.016	-0.046***
	(0.004)	(0.004)	(0.011)	(0.017)
Flood current × Labor	-0.080	0.016		-0.154***
	(0.059)	(0.025)		(0.017)
Drought current × Labor	0.004	0.009*	-0.033***	-0.018
	(0.004)	(0.005)	(0.010)	(0.023)
N	5489	5489	5489	5489

Notes: Two-way fixed effect model is employed. Robust standard errors clustered by households in parentheses. The same set of controls as Table 2 are included but not reported. *** denotes significance at 1% level and ** at 5% level. Coefficients of flood current interaction in Column (3) and flood past interaction in Column (4) are dropped due to small variations in flood variables.

Lastly, we analyze the impacts of rainfall shocks on child malnutrition captured by other measures: underweight dummy, weight for height z-score (WHZ), and height for age z-score (HAZ). Those measurements are calculated based on the 2006 WHO growth standards. Underweight dummy equals 1 if the WAZ score is less than −2 standard deviations, capturing a child's status of being underweight. While the WHZ score is more sensitive to acute nutritional deficiencies, the HAZ score is more sensitive to chronic nutritional deficiencies.

Table A11: The effect of rainfall shock on child malnutrition: Other child health measurements

	(1)	(2)	(3)
Outcome	Underweight	WHZ	HAZ
Past			
Positive past rainfall shock	-0.201*	0.179	0.288
	(0.106)	(0.281)	(0.305)
Negative past rainfall shock	0.054	0.205	-0.482***
	(0.060)	(0.153)	(0.172)
Current			
Positive current rainfall shock	-0.062	0.314	-0.397
	(0.105)	(0.275)	(0.294)
Negative current rainfall shock	-0.054*	0.031	0.234***
	(0.030)	(0.076)	(0.084)
N	5489	5464	5465

Notes: Household fixed effect model is employed. Robust standard errors clustered by household in parentheses. The same set of controls as in Table 2 are included but not reported. *** denotes significance at 1% level and * at 10% level.

We find that higher past rainfall and lower current rainfall significantly decrease the occurrence of underweight, which is consistent with our main result using the WAZ score (Column (1) in **Table A11**). This result implies that recent rainfall shocks tend to influence not only the severity but also the occurrence of children underweight. For the WHZ score, we do not find any significant impacts of rainfall shocks (Column (2)), suggesting that the WHZ score is not sensitive to total rainfall over the entire season, rather it may be more affected by rainfall during specific acute periods. For the HAZ score, we find the same patterns of rainfall impacts on child health (Column (3)). The significant impact of current rainfall on the HAZ score is unexpected, as it is typically influenced by more chronic factors. Further research is needed to explore how the HAZ score changes in response to recent rainfall.

Given our findings, we also analyze the role of maternal labor using these three alternative measurements. First, we find consistent results for underweight (Panel A in **Table A12**): on the one hand, off-farm maternal labor is associated with lower occurrence of undernutrition caused by rainfall shocks, while longer working hours of off-farm labor may directly increase the underweight occurrence. On the other hand, on-farm maternal labor is likely to accelerate the occurrence of undernutrition due to rainfall shocks, despite the positive direct association of on-farm working time with underweight. One exception is that a longer working time for on-farm self-employment is associated with a further decrease in underweight occurrence after experiencing more rainfall in the previous year. This result implies that mothers should switch their labor from on-farm to off-farm, when they experience higher risk of disease prevalence due to excessive rainfall. Regarding the WHZ score, we find significant direct associations with maternal labor and child nutrition (Panel B in **Table A12**). This provides evidence that the WHZ score is sensitive to acute factors, as our labor variables capture maternal labor in the last seven days. We also find that longer on-farm maternal labor is negatively associated with child nutrition under different rainfall shocks. In contrast, we do not find significant direct associations with maternal labor and the HAZ score (Panel C in **Table A12**). This provides further evidence on different sensitivities of different nutritional indicators: the HAZ score is sensitive to more chronic factors, compared to the WAZ score and WHZ score.

Table A12: Mitigating impacts of maternal labor time: other child health measurements

	(1)	(2)	(3)	(4)
Panel A	*Outcome: Underweight*			
Labor type	Off, Self-emp.	Off, Emp.	On, Self-emp.	On, Emp.
Labor hours	0.006**	0.003	-0.015*	-0.007
	(0.003)	(0.002)	(0.009)	(0.013)
Positive past × Labor	0.001	-0.041**	-0.048***	
	(0.008)	(0.020)	(0.016)	
Negative past × Labor	-0.006**	-0.001	0.002	0.006

	(0.003)	(0.002)	(0.008)	(0.009)
Positive current × Labor	0.003	-0.006	0.026**	0.002
	(0.007)	(0.007)	(0.013)	(0.009)
Negative current × Labor	0.002	-0.003*	0.012*	-0.008
	(0.002)	(0.002)	(0.007)	(0.007)
N	5489	5489	5489	5489

Panel B	*Outcome: WHZ score*			
Labor type	Off, Self-emp.	Off, Emp.	On, Self-emp.	On, Emp.
Labor hours	-0.021**	0.007	0.064**	0.132***
	(0.010)	(0.008)	(0.028)	(0.021)
Positive past × Labor	0.017	0.131**	0.003	
	(0.026)	(0.058)	(0.047)	
Negative past × Labor	0.015	0.000	-0.027	-0.073***
	(0.009)	(0.007)	(0.023)	(0.020)
Positive current × Labor	-0.025	-0.032*	-0.095***	-0.054
	(0.031)	(0.017)	(0.029)	(0.040)
Negative current × Labor	0.004	0.002	-0.025**	-0.040*
	(0.005)	(0.004)	(0.011)	(0.023)
N	5464	5464	5464	5464

Panel C	*Outcome: HAZ score*			
Labor type	Off, Self-emp.	Off, Emp.	On, Self-emp.	On, Emp.
Labor hours	-0.010	-0.005	0.032	-0.009
	(0.009)	(0.008)	(0.038)	(0.032)
Positive past × Labor	0.002	-0.074**	0.010	
	(0.018)	(0.037)	(0.065)	
Negative past × Labor	0.010	-0.006	-0.027	0.016
	(0.008)	(0.007)	(0.036)	(0.025)
Positive current × Labor	0.025	0.044**	0.050	-0.085
	(0.036)	(0.018)	(0.057)	(0.052)
Negative current × Labor	-0.006	0.007	-0.017	0.010
	(0.006)	(0.005)	(0.022)	(0.019)
N	5465	5465	5465	5465

Notes: Household fixed effect model is employed. Robust standard errors clustered by household in parentheses. The same set of controls as in Table 2 are included but not reported. *** denotes significance at 1% level, ** at 5% level, and * at 10% level. Coefficients for positive past rainfall interaction with on-farm wage-employment are dropped due to small variations in rainfall shock variable or labor variable.