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The Gendered Effects of Rainfall on Early Childhood Nutrition

Evidence from Papua New Guinea

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Abstract

Rainfall fluctuations can significantly reduce welfare for poor rural households in low- and middle-income countries dependent on rainfed agriculture for consumption, and in some contexts these adverse effects may be borne disproportionately by vulnerable household members, particularly children and girls. We present new evidence around the effects of rainfall fluctuations on child anthropometric status in Papua New Guinea, an understudied context characterized by some of the highest stunting rates in the world. We show that negative fluctuations in rainfall within a 12-month period are associated with reduced household consumption (driven by reduced consumption of own-produced food). Moreover, when these fluctuations are observed in the first year of a child's life, they lead to a reduction in height-for-age and weight-for-age (though no shift in stunting), but this effect is observed only for girls: boys seem to be protected from the adverse effects of rainfall fluctuations experienced in infancy.

Keywords: Papua New Guinea, stunting, rainfall, anthropometry, gender

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INTRODUCTION

Unexpected fluctuations in weather can have a range of adverse effects on subsistence agricultural households in low- and middle-income countries, who frequently depend on rain-fed agriculture for a substantial share of their consumption and income. Liquidity-constrained households with typically little or no access to insurance are generally forced to reduce consumption following an adverse rainfall realization, generally associated with a decline in agricultural yields (Dercon 2002; Carter and Barrett 2006). A huge literature has demonstrated that this process has particularly adverse effects on infants and young children exposed to household-level shocks during a critical period of early childhood development, and these adverse effects are manifest in a range of domains including anthropometric status, cognitive and non-cognitive skills, and long-term health and economic outcomes (Currie and Almond 2011; Almond and Currie 2011; Victora et al. 2008; Grantham-McGregor et al. 2007). However, even conditional on their greater age-based vulnerability, some children can be more vulnerable than others, and in many contexts – described in more detail below – girls are more vulnerable than boys.[1]

This paper presents evidence around the gendered effects of fluctuations in rainfall on early childhood anthropometric status (including height-for-age, weight-for-age, stunting and wasting) in Papua New Guinea, a generally understudied context characterized by some of the highest stunting rates in the world (International Food Policy Research Institute 2016), as well as pronounced patterns of gender inequity (Ganster-Breidler, 2010; Gibson & Rozelle, 2004). The objective is to analyze the effects of generally mild fluctuations in rainfall (as distinct from acute weather events such as El Niño) on anthropometric status among a sample of children under five in rural households. We then assess whether girls may be disproportionately affected by adverse rainfall fluctuations, such that they show a larger deterioration in anthropometric status compared to boys exposed to the same low realization of rainfall.

More specifically, we draw on the recent Papua New Guinea Rural Household Survey conducted in 2023 (PNG-RHS), a large survey including detailed household-level data on agriculture, consumption and expenditure, and child anthropometric status from a sample of 2,699 households in 270 communities across diverse agro-ecological zones of PNG (highlands, lowlands, and islands). Anthropometric status was assessed for all children under five in the survey sample, yielding a sample of 1,334 children. We link this data to rainfall variables constructed using Multi-Source Weather (MSWX) data, a bias-corrected global gridded dataset of rainfall at 10km resolution, estimating the locality-month specific deviation from a locality-specific rainfall trend over the thirty years preceding the survey (1993 – 2023). Our objective is to assess the effects of rainfall fluctuations on both household consumption (as measured as of the survey date), and child anthropometric status, and thus we employ two primary rainfall variables: rainfall over the 12 months prior to the survey date at the household level, and rainfall over the 12 months following birth (i.e., in the first year of life) at the child level. In both cases, we construct a continuous rainfall measure that is the average of the month-locality residual variables in that year; we also construct a binary variable equal to one if this mean is below the 25th percentile across the whole sample of households and/or children. (We abstract from using any season-specific rainfall variables given evidence that the most important staple crop in this context, sweet potato, is planted and harvested continuously across the year, as discussed further below.)[2]

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[1] A useful overview of the evidence around gendered vulnerability to early childhood rainfall shocks is provided in a broader review of the gendered effects of climate change (Fruttero et al. 2023).

[2] Detailed exploration of the patterns of crop cultivation within this PNG sample has been previously presented (Schmidt et al. 2024) and documents that these are the most common staple crops, though cultivation of vegetables is also extremely common.

Our primary findings regress household- or child-level outcomes on a locality-level rainfall variable conditional on agro-ecological zone (hereafter zone) fixed effects, and suggest that exposure to unusually low levels of rainfall leads to a significant reduction in household consumption. Real consumption expenditure per adult equivalent declines by 17% in localities experiencing a low rainfall fluctuation, and daily calorie consumption per adult equivalent declines by 14%: this drop is entirely driven by a decline in calories from own-production, as distinct from calories from purchased food. The findings using continuous rainfall patterns are similar, but noisily estimated. Though we do not have data on agricultural yield, the decline in own-produced calories is consistent with the hypothesis that the primary channel for the effect on consumption is a decline in crop productivity.

We then analyze the effects of similar adverse rainfall fluctuations on child anthropometrics for the under-five sample, focusing on rainfall in the first year of life. As previously noted, PNG is characterized by notably poor child nutritional outcomes: in the full survey sample of 1,334 children under five from 1,008 different households surveyed, 36% were identified as stunted and 5% as wasted. Around a quarter of sample children were identified as exposed to low rainfall in the first year of life, with notably higher rates (47%) in the islands survey areas. Exploring the relationship between this rainfall exposure and anthropometric outcomes, we do see that exposure to low rainfall leads to a deterioration of anthropometric status: importantly, this effect is concentrated among girls. For girls, a one standard deviation decline in the average rainfall residual in the first year of life reduces both height-for-age and weight-for-age Z-scores by about .15 (relative to average levels of -1.5 and .07 standard deviations around the reference mean for height-for-age and weight-for-age, respectively), though there is no significant increase in stunting or wasting. For boys, these effects are null: boys seem to be buffered from the adverse nutritional effects of low rainfall, a pattern that suggests they may be similarly protected from any decline in consumption generating the decline in nutritional status. Interestingly, this finding is also distinct from the simple cross-sectional pattern, in which boys are significantly more stunted, on average, though there is no gendered difference in child weight-for-height or weight-for-age.

Our findings contribute to a significant existing literature probing the gendered effects of rainfall shocks, though patterns identified in this literature to date are somewhat varied. In Indonesia, Maccini and Yang (2009) document significant effects of early childhood rainfall shocks on a range of long-term outcomes (health, education, and income) and find these effects are concentrated among women (exposed as girls). Another paper from Indonesia finds that the negative short-term effects of monsoon delay are concentrated among girls, but long-term effects are smaller and concentrated among boys (Thiede and Gray 2020). In Colombia, Carrillo (2020) finds the adverse effects of in utero rainfall shocks are generally larger for males, though the employment effects are larger for women; there is a similar pattern in Vietnam, where early-life rainfall shocks reduce the probability of formal employment for women and not for men (Feeny et al. 2021; Vu 2021), and in Brazil, where the long-term effects of extreme rainfall patterns are found to be negative for women and positive for men (Fitz and League 2020). By contrast, when focusing on child mortality rather than adult economic outcomes, exposure to rainfall fluctuations does not have a differential effect on boys' and girls' mortality in Brazil (Rocha and Soares 2015). In Nepal, boys and girls seem to be most affected by weather shocks realized at different points of development: the largest effect for boys is for in utero fluctuations, while the largest effect for girls is for post-birth fluctuations (Mulmi et al., 2016).

In sub-Saharan Africa, the site of the largest literature, the findings continue to be varied. Droughts in Zimbabwe have adverse effects on women's body mass index and not men's (Hoddinott & Kinsey, 2000), but the long-term effects of drought for black South Africans are concentrated in an increase in disability among men (Dinkelman 2017). Two separate papers show that in Rwanda the effects of weather shocks or crop failure on height-for-age z-scores are larger for girls (Farris et al. 2021; Akresh, Verwimp, and Bundervoet 2011), though in Tanzania, Uganda, Nigeria, and a cross-country African sample, the effects of weather shocks on stunting are similar for boys and girls (Nsabimana and Mensah 2020; Injete, Nshakira, and Mirzabaev 2021; Rabassa, Skoufias, and Jacoby 2014; Thiede and Strube 2020). In Sierra Leone, the adverse effects of in utero shocks on birthweight are larger for boys, but the effects on anthropometric status five years later are larger for girls (Abiona 2024). In Madagascar, negative rainfall deviations lead both boys and girls to exit school and enter work, but the effect is larger for girls (Marchetta, Sahn, and Tiberti 2019).

In general, this pattern of evidence can be summarized as follows: the effects of adverse rainfall fluctuations are either consistent across boys and girls (men and women), or have larger adverse effects on girls and women. It is rare that the adverse effects are larger for men, though this pattern has been noted in some contexts; the effects of in utero shocks are more likely to be larger for boys than girls, though this is based on a limited evidence base. There is also very wide variation in how rainfall shocks are constructed, but this variation is not necessarily linked to any systematic difference in findings.

There is a much larger literature that analyzes the effects of weather fluctuations on human capital outcomes in general, a literature that includes substantial evidence about rainfall shocks but also encompasses other types of shocks including fluctuations in temperature (predominantly high temperature, but also low temperature) and other unexpected events such as natural disasters. Some recent contributions focused specifically on rainfall fluctuations include work documenting that more rain during the monsoon season in Nepal is associated with higher child height, though this effect dissipates by age five (Tiwari, Jacoby, and Skoufias 2016). In Vietnam, excess rain during typhoon season leads to lower subjective child health status as well as school enrollment (T. Pham 2022), while positive rainfall shocks are associated with increased cognitive development in a pattern that dissipates by adolescence (Yamashita and Trinh 2022). In Uganda, increased rain variability leads to more child wasting (Boyd 2023) and in Peru, early life fluctuations in rainfall shape foundational cognitive skills development (Pazos et al. 2024). To summarize, low rainfall generally leads to worse educational and health outcomes, and higher rainfall generates better outcomes.

One important gap, however, in both the literature focused on gendered effects of fluctuations in weather and the literature estimating the average effects of this variation is evidence from the Pacific region or from Papua New Guinea specifically, a notable omission particularly given its high measured rates of stunting. One paper did document the relationship between El Niño and other extreme climate events and reported food shortages in PNG, but there is little evidence around the effects of more mild weather fluctuations or evidence that links these food shortages to nutritional outcomes (Cobon et al. 2016). Our primary contribution here is to generate evidence around the effects of rainfall on stunting in a context characterized by high nutritional vulnerability, and to explore whether this vulnerability differs between boys and girls.

CONTEXT AND EMPIRICAL STRATEGY

Context: Rural Papua New Guinea

Papua New Guinea remains a predominantly rural economy characterized by a diverse set of histories, cultures, and languages that continue to evolve to address new and unexpected challenges. However, rural poverty as well as notable spatial inequality (Rogers et al. 2011) have remained persistent (Schmidt et al., 2025; Allen et al., 2005). Poverty rates are estimated to be around three times higher in rural vis-à-vis urban areas, with rural areas characterized by poor transportation and limited participation in the cash economy (Gibson and Rozelle 2003; Kosec et al., 2022; Sonsermsawas et al., 2023). The most recent nationally representative Household Income Expenditure Survey from 2009/10 (HIES 2009/10) estimated that approximately 39.9 percent of the population was poor, a statistically insignificant difference from the 1996 estimate of 37.7 percent (Gibson, 2012; Gibson and Rozelle, 1998). Recent poverty analysis from the 2023 PNG Rural Household Survey reported that 43 percent of sample individuals in rural areas live below the standard cost of basic needs poverty line (Mahrt et al., 2025), suggesting that the incidence of poverty did not change substantially over the last several decades. Similarly, from a macro perspective, the total growth in agricultural output was just 2.5 percent per year between 2009-2017, only slightly higher than the population growth rate of 2.1 percent in the same period. With stagnant growth in agriculture, the majority of rural households did not experience improvements in their standard of living (Diao, et al., 2021).

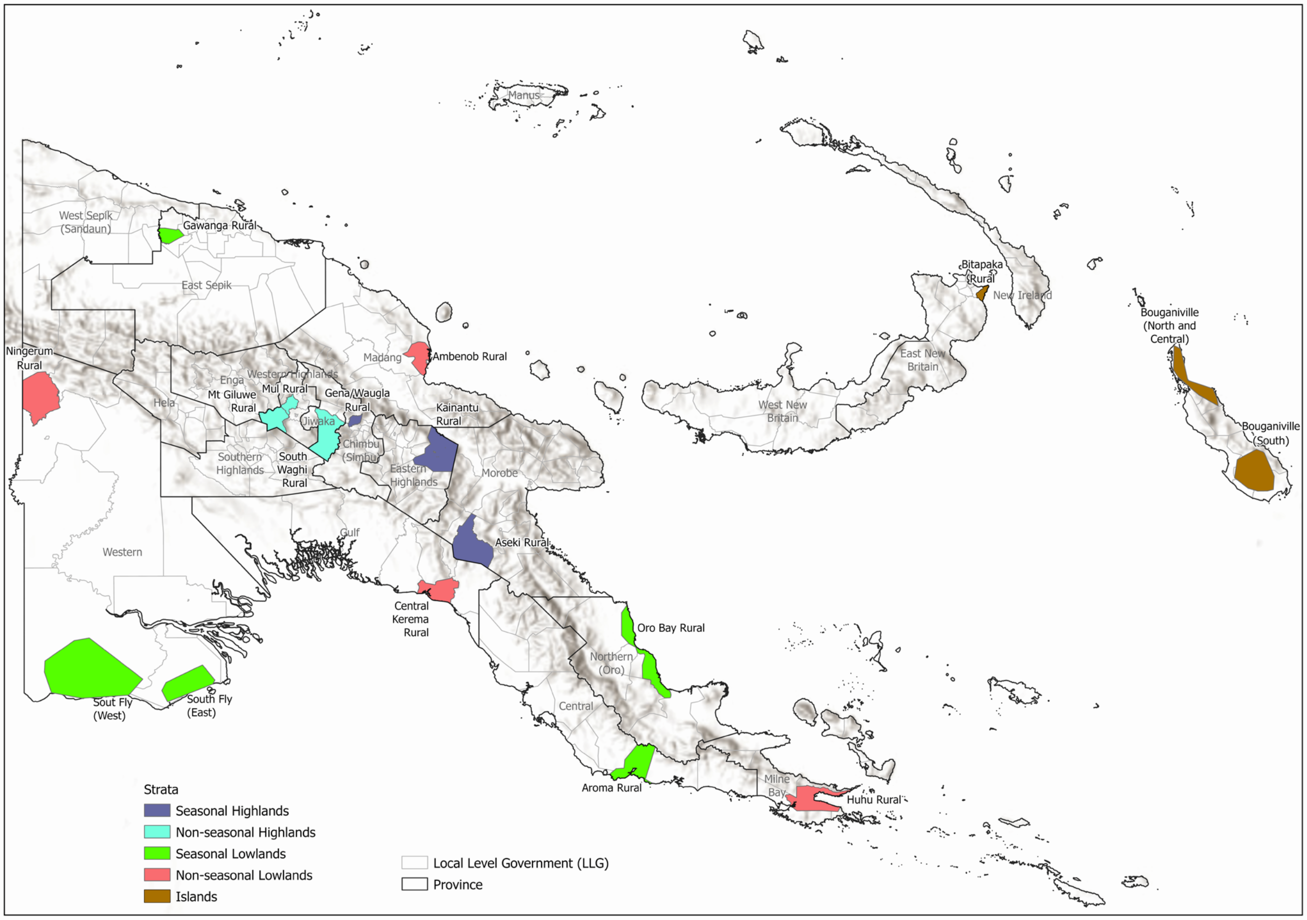
Rural households remain widely engaged in subsistence agriculture, where sweet potato is a dominant crop, followed by cooking banana, taro, cassava, and yam (Schmidt et al. 2024; Bourke et al., 2009) . Engagement in cash crop production is also non-trivial including cultivation of cacao, coconuts, coffee, and rubber, and a high level of crop diversification at the household level is common (Wickramasinghe et al. 2014). Evidence suggests that production of cash crops and/or positive sales of agricultural output are associated with a higher level of consumption (Wickramasinghe et al. 2014) and enhanced child nutrition (Heywood & Hide, 1994). Importantly, there is relatively little seasonality in the production of the dominant crop of sweet potato (especially in the highlands): it is not planted seasonally, and can be harvested year round, though other less common staple crops such as taro (predominantly in the lowlands) and yam are harvested (to some degree) more seasonally (Bourke et al., 2009). The absence of pronounced crop seasonality is associated with limited seasonality in key malnutrition indicators (Spencer and Heywood 1983).

Shifting our focus to child malnutrition, high poverty in this context is also associated with high rates of child undernutrition, with recent estimates of stunting prevalence at nearly 50% (B. N. Pham et al. 2021), though with wide variation across regions (McGlynn et al. 2018). Higher maternal education, engagement in cash crop cultivation, and higher household income all show positive associations with reduced stunting in cross-sectional analyses (Mueller et al. 2001; Gibson 2000; 1999). However, stunting rates have remained relatively stagnant over time despite robust economic growth, a pattern attributed, in part, to inadequate infant feeding practices and limited nutrition education (Hou 2015). In addition, several studies have provided evidence of limited adherence to exclusive breastfeeding recommendations in the first six months of life (Kuzma 2013; Miyoshi et al. 2015). Some estimates suggest aggregate costs of undernutrition that are more than 8% of GDP at a national level (Save the Children 2017), and high rates of undernutrition have also been linked to increased child morbidity (Miyoshi et al. 2015).

Data

This analysis draws on two sources of data: the 2023 Papua New Guinea Rural Household Survey, and historical precipitation data provided by Multi-Source Weather (MSWX). First, we use data from the rural household survey implemented by the International Food Policy Research Institute between May and December 2023. The sample included 2,699 households from 270 communities across 14 provinces and five agro-ecological zones, as captured visually in Figure 1.[3] The questionnaire collected detailed information on agricultural production, asset ownership, employment profile, shocks and coping strategies; our analysis primarily draws on the data related to food and non-food consumption expenditure and child anthropometry.

Figure 1: 2023 PNG Rural Household sample composition



The consumption expenditure module was administered to the entire sample and is used to estimate total food and non-food consumption expenditure (in PGK) and total quantity of food consumed (reported in kilograms and then converted to calories) for each household.[4] We then estimate per adult equivalent daily consumption expenditure and calorie intake, and adjust the per-day total consumption expenditure using a survey-specific food price index to compute real household consumption. Anthropometric data was collected for all children under five years old, leading to a sample of 1,334 children across 1,008 households.[5] We use height and weight data in conjunction with the World Health Organization growth

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[3] Based on the elevation and rainfall seasonality, the survey sample was divided into five agro-ecological zones or regions: seasonal highlands, non-seasonal highlands, seasonal lowlands, non-seasonal lowlands and islands. Lowlands were defined as areas below 1,000 meters above sea level, while highlands were located 1,000 meters or above sea level. In addition, areas that experienced large seasonal variation in rainfall were classified as seasonal, in contrast to non-seasonal areas that experienced moderate to continuously heavy rainfall throughout the year. Islands are not classified as seasonal or non-seasonal.

[4] More specifically, respondents reported the quantity consumed for 75 different food items over the past seven days along with its source (whether self-produced, purchased or received as a gift) and total amount spent on purchased food items. In addition, respondents provided details on their expenditure on 47 different non-food and durable items.

[5] Age was verified using recorded birth dates in clinic books if possible: 71% of children had a clinic book recording their date of birth, of which 81% were shown to enumerators to confirm child's age. For those sampled children without a clinic book, questions about age were posed

standards for healthy children to construct height-for-age (HAZ), weight-for-height (WHZ), and weight-for-age z-scores; we also construct binary variables equal to one if a child is stunted, wasted, or underweight, defined as two standard deviations or more below the reference mean.

The MSWX database is the source of rainfall data for each sampled community over the 30 years prior to the survey ("MSWX" 2025).[6] Rainfall is measured at the community level because a given household would cultivate plots only within a single community, and communities are generally quite geographically compact (i.e., detecting any variation in rainfall within a community is not possible given the precision of existing rainfall data.) Using rainfall data at the community-month level, we then construct a community-month-specific deviation from the community-specific rainfall trend over the thirty years preceding the survey (i.e. May 1993- April 2023). Specifically, we first estimate a long-term rainfall trend for each community and calendar month by regressing monthly rainfall data on year. This resulting trend line predicts the expected rainfall based on historical patterns. We then calculate rainfall residuals for each month and community and normalize the rainfall residuals by σ, calculated as:

$$\sigma = \sqrt{\frac{\sum_{(y,m)=(1993,5)}^{(y.m)=(2023,4)} (prec_{y,m}^{2})}{n}}$$

where $prec_t$ is the rainfall residual for each month $(m)$and year (y) from May 1993 to April 2023 and n is the total number of months in this period (360 months). These standardized community-month level rainfall residuals are used to construct the rainfall variables of interest, as described in more detail in the next section.

Empirical Strategy

We construct two primary rainfall variables. Given our hypothesis that lower levels of rainfall can reduce agricultural output and thus reduce household income and consumption expenditure, we first seek to explore the effect of rainfall in the year prior to the survey on consumption as measured om the survey date. We use two variables to capture this; the first is a continuous variable equal to the mean rainfall residual at the community level in that 12-month recall period. Given the evidence previously cited that there is no pronounced seasonality in the cultivation of major crops in Papua New Guinea, we use a full-year period for simplicity as there is no compelling justification for focusing on a restricted period linked to any crop or agricultural cycle. Second, we construct a binary variable equal to one if the rainfall residual is below the 25th percentile identified across the full sample of households. In other words, a binary variable for low rainfall signifies that a household is experiencing an unusually low locality-specific rainfall residual, compared to other households in the survey sample in the survey year.

In the second part of our analysis, we use a rainfall variable constructed at the child level, using the community specific rainfall residuals over the 12 months following the child's reported birth date. For this analysis, we restrict to the sample of children who are at least six months old as of the survey date. Again, we use both a continuous variable (mean rainfall residual in the first year of life) and a binary variable (equal to one if the mean residual is below the 25th percentile, denoted low rainfall). Again, the

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twice to verify the reported birth date of the child. Within the anthropometric sample, 29 height and 15 weight observations were dropped due to unrealistic extreme values, and seven children had missing weight observations.

[6] MSWX, developed by GloH2O, is a global gridded meteorological database that offers unique features such as high spatiotemporal resolution and low latency (Beck et al. 2022). While MSWX consists of several sub-products, our study uses the MSWX-Past providing historical meteorological records (from 1 January 1979 to around five days from real time) and is generated by bias correcting and downscaling the European Centre for Medium Range Weather Forecasts (ECMWF) ERA5 data (Hersbach et al. 2020), using high resolution or annual reference climatologies.

binary variable for low rainfall captures a child characterized by a unusually low locality-specific rainfall residual in the first year of life, relative to the full set of sample children born across a range of years and communities.

The specification of interest for household-level consumption data can be written as follows; we regress consumption for household h in community c in zone z on community-level rainfall (both a continuous and a binary variable) conditional on zone fixed effects μ_z; standard errors are clustered at the community level.

$$Y_{hcz} = \beta\ Rain_{cz} + \mu_z + \varepsilon_{hcz} \tag{1}$$

The specification of interest for child anthropometric status is similar, but includes an interaction effect between the rainfall variablek of interest and a binary variable for a male child, as well as a control for the child's linear age in month Age_{ihcz} and calendar month-of-birth fixed effects σ_m.

$$Y_{ihcz} = \beta_1 Rain_{cz} + \beta_2(Rain_{cz} \times Male_{ihcz}) + \beta_3 Male_{ihcz} + Age_{ihcz} + \mu_z + \sigma_m + \varepsilon_{ic} \tag{2}$$

It is important to note that this specification does not use a more restrictive set of fixed effects that are common in parallel analyses (year-of-birth and community fixed effects), primarily because the sample of children of each gender may not be large enough to estimate the coefficients of interest with precision; accordingly, in this specification we cannot rule out bias associated with other unobservable characteristics of communities that may be correlated with high or low rainfall realizations in the five-year period in which the sample children were born. However, we will also explore additional specifications including both year-of-birth and community fixed effects: here, we exploit only variation in rainfall fluctuations across years for children born in the same community.

EMPIRICAL FINDINGS

Our empirical findings include evidence around the effects of rainfall fluctuations on both consumption and child anthropometric status. We conceptualize the effect on consumption as arguably the first-order effect of an adverse rainfall realization: lower yield for key crops leads to reduced output for own-consumption as well as reduced revenue to fund cash consumption. This contraction in available resources then has adverse effects on the availability of food for infants and young children (as well as breastfeeding mothers), potentially leading to a deterioration in their nutritional status. Importantly, however, the time period for these effects is slightly different: the effect on household consumption is measured contemporaneously, as of the survey date, while the relevant rainfall variable for each child is measured in the first 12 months of his/her life following the date of birth.[7] However, we generally interpret the estimated effects of low rainfall on consumption as of the survey date as a reasonable proxy for the (unobserved) shift in household consumption that occurred in the first year of life of sampled children who were exposed to similarly low rainfall after birth.

For broader context, Table 1 provides an overview of the households' sample characteristics. The average household has six members, and identifies a male household head; 67% of household heads have completed at least primary school education. On average, total consumption expenditure per capita per day is around 11 Papua New Guinea Kina (PGK), roughly equivalent to $2.50 at the prevailing exchange

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[7] Thus these two periods would overlap (at least partially) only for the very youngest children in the sample.

rate in 2023; 74% of total consumption expenditure is accounted for by food. The sampled children are aged around 30 months on average, and 54% are male.

Table 1: Summary statistics

Variables	Mean	Standard Deviation
Household characteristics		
Household size	5.99	2.60
Female-headed household	0.08	0.28
Household head: primary school or above	0.67	0.46
Agricultural plot size (ha)	0.42	0.62
Total real consumption expenditure per adult equivalent (in PGK)	10.75	7.52
Per adult equivalent real food consumption expenditure (in PGK)	7.92	5.59
Total daily calorie consumption per adult equivalent	2386.24	1151.58
Child characteristics and anthropometry		
Child sex (1= Male)	0.54	0.49
Age (months)	29.67	17.33
HAZ	-1.35	1.75
WAZ	-0.79	1.18
WHZ	0.03	1.28
Child is stunted (1= yes)	0.35	0.47
Child is wasted (1= yes)	0.05	0.22
Child is underweight (1 = yes)	0.14	0.34

Table 2 provides an overview of exposure to adverse rainfall fluctuations across regions in the year prior to the survey date: while the average prevalence is around 25%, this varies greatly across zones. There was almost no exposure to low rainfall in the highlands, but exposure is almost universal in the islands region. Within the first year of life of the sampled children, however, the patterns are somewhat more balanced: the prevalence of an adverse fluctuation over the five year period in which the children were born remains highest in the islands (47%), but ranges between 17% and 23% for the other four zones.

Table 2: Prevalence of anomalously low rainfall fluctuations

	N	Low rainfall
Panel A: Households (year prior to survey)		
Seasonal Highlands	451	0.042
Non-seasonal Highlands	450	0.000
Seasonal Lowlands	748	0.107
Non-seasonal Lowlands	600	0.250
Islands	450	0.936
Panel B: Children (first year of life)		
Seasonal Highlands	210	0.233
Non-seasonal Highlands	152	0.204
Seasonal Lowlands	377	0.170
Non-seasonal Lowlands	245	0.216
Islands	220	0.473

Source: MSWX weather data for 1993-2023

Table 3 estimates the effects of these rainfall fluctuations on household consumption measures, including both consumption expenditure and calorie consumption; Panel A uses a binary variable for low rainfall, and Panel B uses a continuous variable capturing mean rainfall fluctuation. In Panel A, there is consistent evidence that low rainfall leads to a decline in consumption, both total and food consumption; there is also a significant decline in calorie consumption per adult equivalent, but only from own-produced (rather than purchased) calories. The implied magnitude is also consistent, and suggests around a 15% decline in consumption regardless of the measure employed. In Panel B, however, the findings are more mixed: the average rainfall residual is not associated with higher consumption in real terms, and the correlations with total daily calorie consumption are insignificant and varying in sign (though importantly, the relationship with own-produced calories remains positive, albeit insignificant).

Table 3: Effects on rainfall on household consumption

	(1)	(2)	(3)	(4)	(5)	(6)
	Real daily consumption expenditure, AE	Real daily food consumption expenditure, AE	Total daily calorie consumption, AE	Total daily calorie consumption, AE: purchased	Total daily calorie consumption, AE: own-produced	Total daily calorie consumption, AE: in-kind
			Panel A: Binary variable for low rainfall			
Low rainfall (<25th percentile)	-1.889*** (0.486)	-1.561*** (0.399)	-331.546*** (73.078)	-83.915 (75.323)	-215.403*** (66.895)	-32.228*** (10.803)
Mean	10.75	7.92	2389.24	866.86	1420.23	99.15
N	2,699	2,699	2,699	2,699	2,699	2,699
			Panel B: Continuous rainfall			
Average rainfall residual	-0.576 (0.671)	-0.037 (0.471)	-6.535 (96.339)	-91.452 (88.115)	65.477 (68.139)	19.440 (13.598)
N	2,699	2,699	2,699	2,699	2,699	2,699

Notes: Standard errors (in parentheses) are clustered at the community level. All models control for strata fixed effects. Asterisks indicate significance at the 10, 5, and 1 percent level.

We can also explore whether the relationship is moderated by access to markets, by interacting the rainfall variable with a binary variable equal to one for communities that self-report proximity to markets: proximity is defined as a walking time of less than 60 minutes to the nearest weekly market. Communities that are more proximate to markets may be more likely to have a diversified set of livelihoods activities that renders them less vulnerable to weather fluctuations, though this correlation must also be interpreted cautiously given that communities could differ on many observable and unobservable dimensions. For concision, we report this analysis only for the binary rainfall variable. The evidence presented in Table 4 suggests that communities characterized by greater market access may be weakly buffered from rainfall fluctuations (the interaction effects are positive), but the difference is generally insignificant.

Table 4: Effects on rainfall on household consumption, interactions with market access

	Real daily consumption expenditure, AE	Real daily food consumption expenditure, AE	Total daily calorie consumption, AE	Total daily calorie consumption AE: purchase	Total daily calorie consumption, AE: own produced	Total daily calorie consumption, AE: in- kind
Panel A: Binary variable for low rainfall						
Low rainfall (<25th percentile)	-1.920**	-1.748***	-391.618***	-15.109	-345.125***	-31.384**
	(0.757)	(0.552)	(107.304)	(84.288)	(74.684)	(13.010)
Low rainfall x Market access	0.101	0.346	109.907	-108.765	219.922**	-1.250
	(0.916)	(0.552)	(119.852)	(91.294)	(90.583)	(14.734)
Market access	1.758***	0.904**	242.868***	332.702***	-96.923*	7.089
	(0.519)	(0.406)	(76.388)	(60.333)	(50.288)	(10.330)
Mean	10.75	7.92	2389.24	866.86	1420.23	99.15
N	2699	2699	2699	2699	2699	2699

Notes: Standard errors (in parentheses) are clustered at the community level. All models control for strata fixed effects. Asterisks indicate significance at the 10, 5, and 1 percent level.

Table 5 then shifts to examine the effects of rainfall fluctuations on gendered patterns of stunting, again using both binary and continuous variables. In Panel A, we observe that low rainfall leads to a noisy decline in height-for-age for girls, and a decline in weight-for-age and weight-for-height that is significant at the ten percent level. There is, however, also notable heterogeneity in these effects with respect to gender. The coefficients on the interaction of the male dummy and rainfall are generally positive for the anthropometric z-scores (the opposite sign vis-a-vis the main coefficient), implying a net null effect of the rainfall fluctuations of interest on male children. At the same time, the coefficient on male captures the level difference in anthropometric characteristics comparing across boys and girls: boys are characterized by lower height-for-age (are more likely to be stunted) vis-à-vis girls in this sample, though the differences in weight z-scores are minimal.

Table 5: Effect of rainfall on child anthropometric status

	(1) Height-for-age (HAZ)	(2) Child is stunted	(3) Weight-for-height (WHZ)	(4) Child is wasted	(5) Weight-for-age (WAZ)	(6) Child is underweight
Panel A: Binary variable for low rainfall						
Low rainfall (<25th percentile)	-0.259	0.012	-0.211*	-0.002	-0.196*	0.032
	(0.182)	(0.050)	(0.120)	(0.025)	(0.116)	(0.039)
Low rainfall x male	0.563**	-0.072	0.196	0.021	0.381***	-0.029
	(0.236)	(0.060)	(0.149)	(0.033)	(0.144)	(0.048)
Male child	-0.399***	0.113***	0.107	-0.018	-0.072	0.003
	(0.121)	(0.034)	(0.076)	(0.014)	(0.078)	(0.023)
Mean of no-drought households	-1.515	0.387	0.073	0.043	-0.869	0.144
Mean of all households	-1.35	0.35	0.03	0.05	-0.79	0.14
Panel B: Continuous rainfall						
Average rainfall residual	0.364**	-0.006	0.329***	0.009	0.251**	-0.027
	(0.173)	(0.048)	(0.109)	(0.024)	(0.112)	(0.039)
Average rainfall x male	-0.459**	0.018	-0.281**	-0.000	-0.360***	0.020
	(0.230)	(0.058)	(0.134)	(0.031)	(0.138)	(0.052)
Male child	-0.287***	0.095***	0.137**	-0.012	-0.001	-0.003
	(0.108)	(0.030)	(0.068)	(0.012)	(0.066)	(0.019)
N	1,179	1,179	1,186	1,186	1,204	1,204

Notes: Standard errors (in parentheses) are clustered at the community level. All models control for region fixed effects, calendar month of birth fixed effects, and age in months. Asterisks indicate significance at the 10, 5, and 1 percent level.

This pattern is observed more precisely in Panel B, where the findings using the continuous rainfall fluctuations imply a more negative (positive) fluctuation in the first year of life leads to lower (higher) height-for-age, weight-for-age and weight-for-height, though effects on the probability of stunting and wasting are not significant. To assess the magnitude of these effects, we can estimate the effect of a one standard deviation (.45) decline in the rainfall measure: this leads to decreases in the three Z-scores of between .12 and .18, with the largest decrease observed for height-for-age. Given that the average child in this sample is 1.5 standard deviations below the reference mean corresponding to the height-for-age of a healthy developing child, this fluctuation in rainfall would account for approximately 10% of this gap: this is plausibly considered to be a minor effect, and is consistent with the absence of any significant effect on rainfall fluctuations on stunting. Again, however, these effects are evident only for girls.

Table 6 then presents the same findings using a more restrictive set of fixed effects, community and birth year fixed effects. In Panel A, using a binary variable for rainfall, the coefficients are now noisily estimated, though the pattern is consistent. In Panel B, the effects remain more precise and continue to suggest that the adverse effects of rainfall are concentrated among girls: in addition, the coefficients of interest are somewhat larger than previously observed in Table 4, and suggest a one standard deviation decline in the rainfall measure leads to a decline of around .2 in the height-for-age and weight-for-age z-scores. We also re-estimate the primary specification with additional controls for maternal height: these findings are presented in Table A1 in the Appendix, and show a pattern very similar to the primary findings.

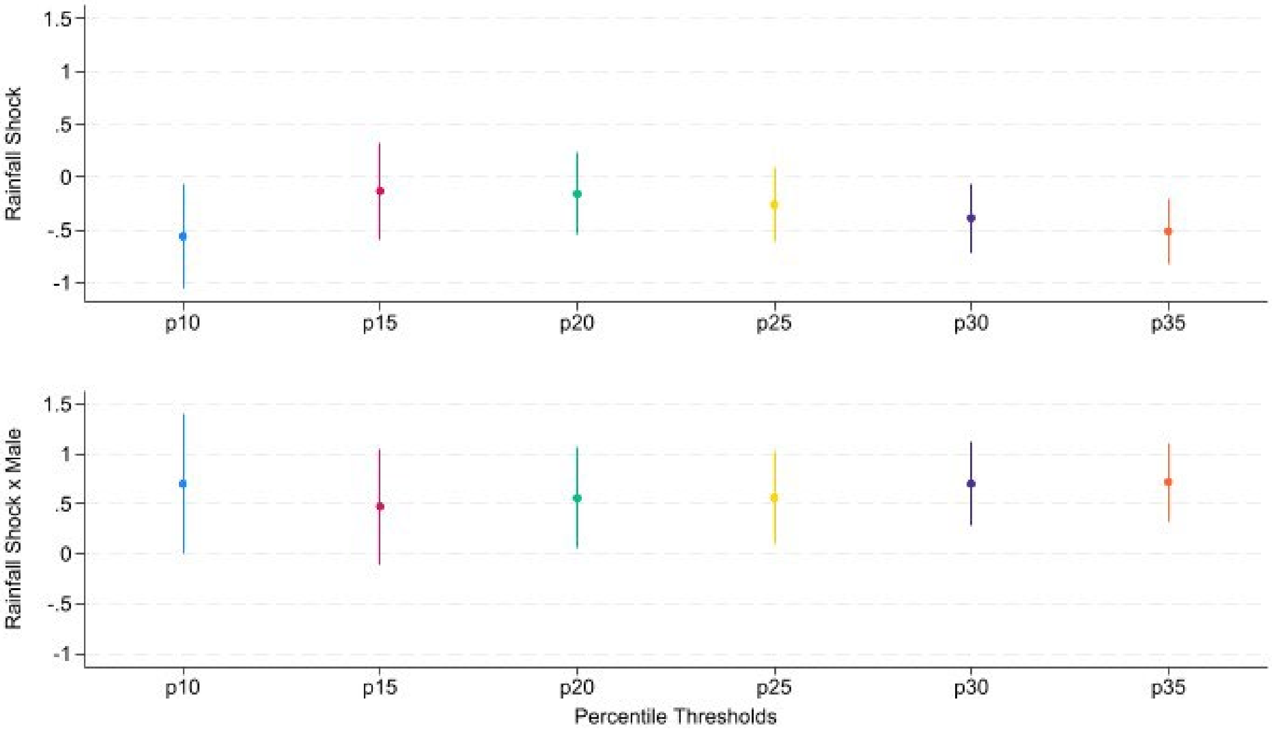
Table 6: Effect of rainfall on child anthropometric status: Community and birth-year fixed effects

	(1) Height-for-age (HAZ)	(2) Child is stunted	(3) Weight-for-height (WHZ)	(4) Child is wasted	(5) Weight-for- age (WAZ)	(6) Child is underweight
Panel A: Binary variable for low rainfall						
Low rainfall (<25th perc.)	-0.148	0.005	-0.277*	-0.009	-0.176	0.025
	(0.202)	(0.061)	(0.145)	(0.033)	(0.134)	(0.047)
Low rainfall x male	0.468*	-0.083	0.194	0.038	0.308*	-0.003
	(0.265)	(0.072)	(0.186)	(0.040)	(0.170)	(0.056)
Male	-0.372***	0.110***	-0.067	-0.014	-0.155*	0.008
	(0.138)	(0.041)	(0.093)	(0.016)	(0.093)	(0.028)
Mean of no-drought households	-1.515	0.387	0.073	0.043	-0.869	0.144
Mean of all households	1,179	1,179	1,186	1,186	1,204	1,204
Panel B: Continuous rainfall						
Average rainfall residual	0.492**	-0.047	0.491***	-0.003	0.416***	-0.042
	(0.210)	(0.062)	(0.138)	(0.034)	(0.142)	(0.049)
Average rainfall x male	-0.557**	0.061	-0.408**	0.006	-0.463***	0.013
	(0.277)	(0.072)	(0.171)	(0.039)	(0.175)	(0.065)
Male	-0.288**	0.092**	-0.050	-0.004	-0.108	0.009
	(0.121)	(0.036)	(0.080)	(0.015)	(0.077)	(0.023)
N	1,179	1,179	1,186	1,186	1,204	1,204

Notes: Standard errors (in parentheses) are clustered at the community level. All models control for community fixed effects, birth of year fixed effects, and calendar month of birth fixed effects. Asterisks indicate significance at the 10, 5, and 1 percent level.

As an additional robustness check, we seek to verify that the relationship between rainfall and the anthropometric measures of interest is relatively consistent regardless of how we define low rainfall (again, in the primary analysis, the binary variable for low rainfall is defined as equal to one if the average rainfall residual in the first year of life is below the 25th percentile across the full sample.) We re-define the low rainfall variable using a range of cutoffs (from the 10th to the 35th percentile) and re-estimate the regression of interest using height-for-age as the dependent variable; Figure 2 then captures the coefficient and 95 percent confidence interval for the main low rainfall variable and the interaction of low rainfall and the male dummy. It is evident that the magnitude and statistical significance is relatively stable across specifications: the primary effect of a low rainfall realization is weakly negative (and sometimes statistically significant), and the interaction effect with male is positive and consistently significant.

Figure 2: Effects of low rainfall given alternate definition of low rainfall



We can also explore the effects of rainfall in the in utero period (the nine months prior to birth), given the hypothesis that adverse rainfall realizations may have an adverse effect on maternal nutrition during pregnancy. Here, we use self-reported birth weight as the dependent variable; birth weight data was recorded from a child's clinic card, if available, and is thus only available for a subsample of 548 children.[8] Given the reduced sample, we estimate a pooled effect for both male and female children, as reported in Table 7 below. The effect of low rainfall during the in-utero period is weakly negative, though in the first trimester, the effect is significant at the ten percent level: an infant exposed to low rainfall in this trimester is around 100 grams smaller on average at birth. However, this evidence should be interpreted cautiously given the smaller sample and the possibility of selection into the sample reporting birth weight.

Table 7: Effect of rainfall in utero on birth weight

	In-utero	Trimester 1	Trimester 2	Trimester 3
	Birth weight (kilograms)			
Low rainfall (<25th percentile)	-0.039	-0.109*	-0.039	-0.039
	(0.057)	(0.059)	(0.057)	(0.057)
Mean of no-drought households	2.823	2.847	2.829	2.825
N	548	548	548	548

We also conducted an exploratory analysis of high rainfall given multiple reports of low food availability during flooding. We find some evidence that flooding leads to a decline in consumption. However, there

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[8] Around 80% of these children are born in a hospital or medical facility, suggesting birth weight was plausibly recorded by medical professionals at the delivery.

is no robust evidence in this sample that flooding leads to adverse effects on child growth. During focus group discussions, flooding was reported as experiencing river overflow and destroyed cropstands. Given that the rainfall data we are using for this analysis is at a resolution of 10 kilometers, these very localized flooding events would not be captured sufficiently to pinpoint crop failures due to high rainfall anomalies.

CONCLUSION

This paper presents evidence around the effects of rainfall fluctuations on household consumption and child nutritional status in Papua New Guinea. Using a new and comprehensive rural household survey, we demonstrate that adverse rainfall fluctuations are associated with a decline in household consumption as well as a deterioration in child anthropometric status, but this effect is concentrated entirely among girls. These findings constitute suggestive evidence that patterns of gendered vulnerability to rainfall fluctuations in this context may be extremely important.

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APPENDIX

Table A1: Effect of rainfall on child anthropometric status, additional controls

	(1)	(2)	(3)	(4)	(5)	(6)
	Height-for-age (HAZ)	**Child is stunted**	**Weight-for-height (WHZ)**	**Child is wasted**	**Weight-for-age (WAZ)**	**Child is underweight**
	Panel A: Binary variable for low rainfall					
Low rainfall (<25th percentile)	-0.295	0.031	-0.198	0.006	-0.193	0.060
	(0.181)	(0.054)	(0.134)	(0.029)	(0.119)	(0.043)
Low rainfall x male	0.555**	-0.084	0.225	0.005	0.369**	-0.053
	(0.262)	(0.066)	(0.177)	(0.035)	(0.159)	(0.053)
Male child	-0.406***	0.120***	0.098	-0.023	-0.063	0.016
	(0.128)	(0.036)	(0.089)	(0.016)	(0.086)	(0.026)
Mean of no-drought house-holds	-1.515	0.387	0.073	0.043	-0.869	0.144
	Panel B: Continuous rainfall					
Average rainfall residual	0.523***	-0.039	0.377***	-0.010	0.392***	-0.078*
	(0.184)	(0.052)	(0.128)	(0.027)	(0.120)	(0.041)
Average rainfall x male	-0.613**	0.075	-0.339**	0.018	-0.457***	0.065
	(0.268)	(0.067)	(0.158)	(0.032)	(0.154)	(0.056)
Male child	-0.310***	0.104***	0.130	-0.020	-0.004	0.007
	(0.114)	(0.032)	(0.079)	(0.014)	(0.072)	(0.022)
N	891	891	892	892	907	907

Notes: Standard errors (in parentheses) are clustered at the community level. All models control for region fixed effects, calendar month of birth fixed effects, biological mother’s height, and age in months. Asterisks indicate significance at the 10, 5, and 1 percent level.

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