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Complete List of Authors:	Kabalo, Bereket; Hawassa University, School of Public Health; University of Bergen, Centre for International Health Loha, Dr Eskindir ; Hawassa University, School of Public Health Lindtjørn , Bernt ; University of Bergen, Centre for International Health
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Interventions that could reduce childhood stunting and wasting in food-insecure areas in Ethiopia: a cohort study

Authors:

Bereket Yohannes Kabalo (BYK) [1, 2, 3*], Eskindir Loha (EL) [1], and Bernt Lindtjørn (BL) [1, 2]

Authors' addresses:

Bereket Yohannes Kabalo: bkabalo@gmail.com

Eskindir Loha: eskindir_loha@yahoo.com

Bernt Lindtjørn: bernt.lindtjorn@uib.no

Authors' affiliations:

[1]School of Public Health, Hawassa University, Hawassa, Ethiopia

[2]Centre for International Health, University of Bergen, Bergen, Norway

[3]School of Public Health, Wolaita Sodo University, Wolaita Sodo, Ethiopia

*** Corresponding author**:

Bereket Yohannes Kabalo

bkabalo@gmail.com

ABSTRACT

Objective: We lack adequate information on the impacts of different interventions to reduce malnutrition in drought-prone areas in Ethiopia. The aim of this study was to identify interventions that could reduce child stunting and wasting in food-insecure areas.

Design and setting: This prospective cohort study was conducted in the rural Wolaita area in southern Ethiopia.

Participants: We randomly recruited 907 children and followed them for one year from June 2017 to June 2018, measuring height-for-age and weight-for-height every three months in the first month of each agricultural season (i.e., June, September, December, and March).

Primary outcome measures: The outcome measures were height-for-age and weight-for-height Z-scores. We used multivariable linear regression models to analyse how socio-economic background factors (e.g., poverty and education), participation in food security programmes, drinking water access, latrine possession and other intermediary variables such as household food insecurity and food intake diversity were associated with subsequent measures of stunting and wasting.

Results: Child wasting rates varied with seasonal fluctuations in household food insecurity. However, stunting rates did now show seasonal variations. Factors associated with decreased risks of stunting and wasting included household participation in a food security programme and access to drinking water, whereas absence of a household latrine, lower education level among mothers and high household poverty were associated with increased risk of child stunting.

Conclusions: Addressing seasonal household food insecurity and strengthening social protection interventions, such as household participation in a food security programme and improved water access and sanitation, could help reduce child undernutrition.

Key terms: background factors; Productive Safety Net Programme; drinking water access; intermediary variables

Strength and limitation of this study

- The height-for-age and weight-for-height were analyzed as composite measures of undernutrition to reflect shared risk factors for stunting and wasting.
- To reduce subjectivity bias in food insecurity measurements, we used household food insecurity access scale questionnaire which had been validated in the study area.
- To ensure accuracy of the current study data, the same households and data collectors were used, and measurements were repeated.
- The household wealth index was determined at baseline and could have changed during the study period.

INTRODUCTION

Over the last millennia, Ethiopia has experienced droughts and associated famine events about once per decade, on average (*1*). This had caused devastating deaths and illness in previous decades Recent research indicates a decline in precipitation in southern Ethiopia, mainly during the 'Belg' rains during February–May and more pronounced in the lowlands (*2*). Yet, in recent decades, deaths due to the famine devastations have shown a decreasing trend (*3*). Despite these trends, the Intergovernmental Panel on Climate Change predicts that climate change will lead to desertification and subsequent food insecurity in vulnerable areas like Ethiopia (*4*), especially as droughts and crop failures become more frequent (*5*).

In communities that rely on subsistence agriculture, food insecurity often peaks seasonally in the pre-harvest periods (*6, 7*). Affected households adapt by reducing the frequency and size of daily meals; selling livestock or dairy products; borrowing food or money from merchants or local social networks; selling wood, charcoal or grass; engaging in paid labour; and renting out farm land (*8*). However, such coping mechanisms are often insufficient, leading to a vicious cycle of poverty and food insecurity.

Following many years of food provision for famine-prone populations, the Ethiopian government launched the Productive Safety Net Programme (PSNP) in 2005 (*9*). PSNP is the second-largest social safety net program in Africa, and it aims to prevent household asset depletion and strengthen communities (*9*). The program provides cash or food payments in exchange for labour to produce public works, local infrastructure, and environmental projects. Households that are unable to provide labour receive safety net payments as direct support (*10*). Other program initiatives in food-insecure areas include improving access to education, clean water, and sanitation.

Child undernutrition refers broadly to inadequate nutrition for physiological growth and immune system development. Since the 1970s, undernutrition has been classified in two major ways: wasting (i.e. low weight for height or small mid-upper arm circumference) and stunting (i.e. low height for age) (*11*). However, this categorical classification neglects many children with borderline measurements who are at risk of undernourishment (*12*). Moreover, deficiencies in length-for-age and weight-for-height reflect shared risk factors for undernutrition, and increasing research indicates that these characteristics reflect various pathophysiological processes that should be viewed as composite measures of undernutrition (*13*).

Researchers use several methods to assess the impact of food scarcity on the population. One common outcome is the household level of food insecurity and occurrence of malnutrition among vulnerable groups, such as young children. Recent research has emphasised the importance of understanding seasonal variations in nutrition status among young children as an indicator of vulnerability to food insecurity (*14*).

Wolaita, a densely populated area in southern Ethiopia, experiences severe droughts and famines (*3*). As such, the population's experiences and coping mechanisms related to severe food insecurity are relevant for other famine-prone areas in the country and across Africa. Specifically, large development initiatives from both the government and organizations have attempted to reduce vulnerability to food insecurity by improving access to clean water and sanitation. We aimed to determine the success and transferability of the Ethiopian government's PSNP and similar interventions by assessing their approaches and the subsequent effects on seasonal rates of childhood malnutrition (measured using child stunting and wasting rates).

METHODS

Study design and setting

We conducted a prospective cohort study using a random sample of households in the rural Wolaita area in southern Ethiopia. We recruited 907 children and followed them for one year from June 2017 to June 2018. We measured their height-for-age and weight-for-height every three months in the first month of each season (i.e., June, September, December, and March). Wolaita is located between the Great Rift Valley and the Omo Valley. Rural villages in this area mainly represent two agroecological areas: the hot and semi-dry 'lowlands' and the relatively cooler and sub-humid 'midlands' (*2, 15*).

Mean annual rainfall ranges from 800 mm in the lowlands to 1,200 mm in the midlands, with bimodal distribution (*6*). Farming of staple crops, such as maize, occurs during the Belg rains from about March to early May (*6, 16*). Root crops, such as taro and sweet potato, are farmed in both seasons and help bridge seasonal gaps in food security (*2, 6*).

We collected data during the four seasons based on agricultural cycles: *Kiremt* is the sowing season in June, July, and August; *Belg* is the main harvest season in September, October, and November; *Bega* is the post-harvest season in December, January, and February; and *Tsedey* is the dry pre-harvest season in March, April, and May. As we previously reported, household food insecurity in Wolaita peaks in the dry pre-harvest season (*6*).

Participants

We conducted a multistage random selection of households. First, we selected two rural districts, or woredas, representing the two agroecological strata in Wolaita: Humbo district in the lowlands and Soddo Zuria district in the midland area. Next, we selected five rural kebeles (smallest administrative unit) using the complex samples selection feature in SPSS version 25.0 (IBM). We selected three kebeles in Humbo and two in Soddo Zuria. Finally, we selected households with children under five years old and enrolled one child aged 6–59 months per household.

To estimate the sample size, we followed an earlier cohort study assessing seasonal variations in stunting prevalence. The estimated sample size to estimate differences in prevalence rates of wasting 6.6% and 13% (*17*), with a 95% level of confidence and 80% power, was 820 children (OpenEpi software). Our study included 907 children (Table 1).

Patient and Public Involvement

No patient involvement

Outcomes

The main outcome measures were children's height-for-age and weight-for-height indices (Z-scores), defined based on World Health Organization (WHO) 2006 child growth standards (*18*). Wasting and stunting were defined as a weight-for-height Z-score (WHZ) or weight-for-age Z-score (HAZ) of -2 standard deviations below the respective WHO standard median. We also considered household food insecurity, household food intake diversity and child diarrhoea illness as intermediate outcome measures.

Anthropometric measurements

We trained four data collectors on standard techniques for height and weight measurements. After training, we validated the consistency of their measurements by recruiting 10 children under five years old from another rural village and having all four data collectors (observers) measure each child's height twice. The overall measurements showed about 92% average internal consistency, and these same four observers recorded height and weight measurements for the actual study. Height (or recumbent length for children younger than 24 months) was measured to the nearest of 0.1 cm using a local wooden length board. Weight was measured to the nearest 0.1 kg using a Seca weight scale (Seca GmbH & Co. Kg., Hamburg, Germany).

Each subject was measured in each season, totalling 3,636 measurements for the 909 children. We excluded 46 HAZ measurements and 126 WHZ measurements that had incomplete data or that were severe outliers (*19*). Our dataset was compiled in long format (i.e., overall measurements undertaken during the study period), including 3,571 HAZ estimates and 3,510 WHZ estimates. Table 1 summarises the data in wide format (i.e., children measured in different seasons).

Table 1 Number of measurements for this cohort study, rural Wolaita, Ethiopia, 2017–2018

		Height-for-age Z-score		**Weight-for-age Z-score**	
	Sample	**Excluded**	**Analysed**	**Excluded**	**Analysed**
Sowing season	909	7	902	15	894
Main harvest season	909	5	904	22	887
Post-harvest season	909	16	893	37	872
Dry pre-harvest season	909	37	872	52	857
Measurements, # (%)	3636 (100)	65 (1.8)	3571 (98.2)	126 (3.5)	3510 (96.5)
Children, # (%)	909 (100)	2 (0.2)	907 (99.8)	12 (1.3)	897 (98.7)

Exposure variables

This study included both time-invariant and time-varying measures. The time-varying exposure measures included variables for which we had repeated observations, such as household food insecurity, household dietary diversity and child diarrheal illness. Time-invariant measures were background characteristics of the child (age and sex), parent (age and education) and household (socio-economic factors) and were assessed at the start of the study. Birth dates of the children were retrieved from routine registers, such as vaccination cards, and supplemented with mothers' information. We recorded mothers' age in years and highest grade of school completed by both parents. We also collected data on family size (number of family members in a household); source of income (exclusively farming or other); participation in a Productive Safety Net Programme (PSNP) and wealth index. We collected lists of PSNP beneficiaries from local administrators in each kebele and verified this information by checking each household's programme beneficiary cards during household visits. Access to drinking water (protected vs.

unprotected) was considered at baseline, and only water piped via public tap was considered protected (*20*).

We used principal component analysis to construct a wealth index based on common household assets, such as housing material of the roof, interior ceilings, floors, and walls; number of livestock household owned; land size in hectares and possession of common assets, such as a radio, mobile telephone, bed, mattress, kerosene lamp, watch, electric or solar panels, chairs, tables, wooden boxes and donkey carts (*6*). We standardised the response scores for these inventories and performed dimension-reduction analyses of the scores (*21*).

The time-varying exposure item, household food insecurity, was measured using the nine questions in the Household Food Insecurity Access Scale (*22*), which has been validated in the study area (*6*). The overall prevalence during the study period and mean prevalence estimates in each season were used to describe the magnitude of household food insecurity in the study area. Incidence rates also were compared by calculating incidence rate ratios to estimate seasonal variations in household food insecurity.

We generated two categorical variables from the overall household food insecurity observations. A multinomial variable was generated by multiplying the overall observations of household food insecurity status (0 vs. 1) by a categorical variable for the discrete data rounds (1–4 response categories). With its four non-zero response categories, this newly generated multinomial variable classified household food insecurity into four discrete data rounds or specific seasons: (food-insecure in the sowing season; food-insecure during the main harvest season; food-insecure during post-harvest season; and food-insecure in the dry pre-harvest season). This variable was considered an exposure variable to estimate if seasonal peaks in household food insecurity affected the risks of stunting and wasting. An ordinal variable also was generated to summarise the number of seasons in which a household experienced food insecurity (1=one season; 2=two seasons; 3=three seasons; and 4=four seasons). We used this newly generated ordinal variable as an exposure variable to analyse dose–response relationships.

Household dietary diversity was scored using 24-hour recall measurements (*23*). Household members were asked about the 12 common food groups in Ethiopia: (i) cereals and breads; (ii) potatoes and other roots or tubers; (iii) vegetables; (iv) fruits; (v) eggs; (vi) dairy products; (vii) pulses; (viii) fish; (ix) meat; (x) oil, fat, or butter; (xi) sugar or honey and (xii) other foods, such as coffee and tea. The responses were used to generate a scale of food intake diversity, or household dietary diversity score (HDDS) (*23*). We estimated the standard error of the mean HDDS across increasing levels of food insecurity or increasing numbers of seasons with household food insecurity to explore dose–response relationships between HDDS and severity of household food insecurity.

Diarrheal illness was defined as the passage of three or more loose or watery stools in a 24-hour period (*24*). We assessed the occurrence of diarrhoea illness among children during the two weeks prior to the survey dates in each season.

Statistical methods

Data were double entered in EpiData software version 3.1 (EpiData Association 2000-2021, Aarhus, Denmark) and corrected for entry errors. The outcome measures, nutritional indices for HAZ and WHZ, were generated from anthropometric data using ENA and WHO Anthro software 3.2.2 (WHO, Geneva, Switzerland). Stata version 15 (Stata Corp LLC, College Station, TX, USA) was used for main statistical analysis.

Our data were structured based on the WHO conceptual framework for childhood stunting (*25*). First, we analysed the association between continuous background variables (e.g., wealth, age of mother, education level) with intermediary variables (e.g., household food insecurity and household dietary diversity) and then analysed how these variables were associated with subsequent measures of wasting and stunting.

We used chi-squared test to compare two proportions (*26*). We also extended the Mantel Hansel chi-squared test and order-directed score test for trends to assess dose-response relationships (*27, 28*). Moreover, a non-parametric test for trend across ordered groups was used to analyse trends in stunting and wasting rates, for example, across household dietary diversity scores (*29*). We used t-tests to compare two means, ANOVA tests to compare more than two means and bivariate regression analyses to test associations between two continuous variables (e.g., HAZ vs. wealth index). To estimate seasonal variations in stunting and wasting rates, risk estimate in one season was considered a control for the subsequent season. For example, the risk of wasting in the dry pre-harvest season was compared with the risk during the main harvest season by calculating relative risk (risk ratio) as an effect measure (*30, 31*).

We analysed our normally distributed continuous outcome data, HAZ and WHZ, using multivariate linear regression models. The following variables were included to control for confounding: (i) background characteristics (child sex and diarrhoea illness status, maternal age, parent education level and household drinking water access, latrine ownership, family size, wealth index, source of income and participation in PSNP) and (ii) intermediary variables (household food insecurity, household dietary diversity and child diarrhoea illness).

HAZ data were analysed using a multilevel model or hierarchical linear model to account and adjust for clustering in the risk of stunting at the primary sampling stage at the kebele level (*32, 33*). WHZ data were analysed in the same manner, except we ignored the observed insignificant clustering of the risk for wasting at the kebele level and used a likelihood ratio test to compare the ordinary least square model and multilevel model (*32, 34*). Accordingly, we reported the main effects of the independent variables using standardised beta coefficients (β) with a 95% confidence interval (CI).

We further analysed the fitted models for both outcome measures to explore interactions in terms of the effects of two interventions (e.g., protected water access and PSNP payments on the risk of stunting) or effect modification in terms of the effect of one intervention varying across strata of a second variable (e.g., effect of non-farming income across wealth indices on the risk of wasting).

RESULTS

Prevalence of malnutrition

The overall prevalence of child stunting was 32.1% (95% CI: 30.5–33.6) during the study period (1,145 of 3,571 measurements); stunting rates did not show any seasonal variations. The overall prevalence of child wasting was 10.3% (95% CI: 9.2–11.3) during the study period (360 of 3,510 measurements). The mean wasting rate was 9.4% (84 of 894) in the sowing season, 8.9% (79 of 887) in the main harvest season, 10.0% (87 of 872) in the post-harvest season, and 12.8% (110 of 857) in the dry pre-harvest season (Figure 1). The risk of wasting showed seasonal variations, peaking with an increase of about 50% in the dry pre-harvest season (χ^2=6.8, P<0.01), compared with the main harvest season, and a relative risk (RR) of 1.48 (95% CI: 1.11–1.98).

Baseline data

Table 2 summarises the background characteristics of the 907 children in the sample. Most (73.9%) households relied exclusively on farming income (i.e., they had no additional income). Exclusively farming households were more likely to receive PSNP payments than those with non-farming income (78% vs. 22%; χ^2=7.3, P<0.01). A higher proportion of households in lowland areas had protected water access, compared with midland areas (74.4% vs. 10.9%; χ^2=366.1, P<0.001).

Table 2 Baseline factors (time-invariant measures), rural Wolaita, Ethiopia, 2017–2018 (n=907)

Variable	**# (%)***
Child sex	
Male	462 (50.9)
Female	445 (49.1)
Child age in months, mean (SD)	33.4 (11.7)
Mother's age in years, mean (SD)	29.3 (3.3)
Mother's education (grade completed)	
0 (none)	178 (19.6)
1–4	147 (16.2)
5–8	136 (15.0)
9–10	149 (16.4)
11–12	145 (16.0)
Higher education	152 (16.8)
Father's education (grade completed)	
0 (none)	178 (19.6)
1–4	84 (9.3)
5–8	190 (21.0)
9–10	130 (14.3)
11–12	147 (16.2)
Higher education	178 (19.6)
Family size, mean (SD)	5 (2)
Participates in Productive Safety Net Programme	
Yes	434 (47.9)
No	473 (52.1)
Drinking water	
Protected	406 (44.8)
Unprotected	501 (55.2)
Owns latrine	
Yes	784 (86.4)
No	123 (13.6)
Work, farming only	
Yes	237 (26.1)
No	670 (73.9)
Altitude strata of villages	
Lowland	483 (53.2)
Midland	424 (46.8)

* Unless otherwise indicated

Household wealth and participation in PSNP

The median wealth index was higher for households in lowland than midland areas (0.473 vs. -0.414; t=54.4, P<0.001). As such, 33.3% (141 of 424) of households in midland areas belonged to the lowest wealth category, compared to 8.5% (41 of 483) in lowland areas. However, a higher proportion of households in the lowland areas participated in PSNP than in the midland areas (64.4% vs. 28.9%; χ^2=113.2, P<0.001). The likelihood of participating in the PSNP decreased with increasing wealth quantiles in midland areas (χ^2=44.0, P<0.01), but this trend was not observed in the lowlands.

Intermediary factors

Household food insecurity

The overall prevalence of household food insecurity was 74.2% (2,651 of 3,571 measurements) during the study period (95% CI: 72.8–75.6). As shown in Table 3, this risk varied across seasons (χ^2=40.6, P<0.001), peaking at 40% in the scarcest dry pre-harvest season, compared with the main harvest season (RR=1.34; 95% CI: 1.20–1.49). Quantified as person-time observations, the risk of experiencing food insecurity in just one season was 7.5%, compared to 17.0% in at least two seasons, 39.0% in three seasons and 34.8% throughout all four seasons.

Household food intake diversity

The median household dietary diversity score (HDDS) was 3 (out of the 12 food groups, interquartile range of 3–4). Unlike household food insecurity, the HDDS did not show any seasonal variation. Nonetheless, consumption patterns for certain common food groups decreased in seasons of food scarcity (Table 3). For example, the likelihood of consuming cereal was 62% in plentiful seasons but decreased to 49% in scarce seasons (χ^2= 13.0, P<0.001). Similar variations were observed for vegetables (36% vs. 25%; χ^2= 50.2, P<0.001); fruits (13% vs. 5%; χ^2=39.6, P<0.001); pulses, legumes or nuts (27% vs. 15%; χ^2= 52.0, P<0.001); milk and milk products (21% vs. 11%; χ^2=40.9, P<0.001); oils or butter (37% vs. 18%; χ^2=160.4, P<0.001) and condiments, such as coffee (45% vs. 27%; χ^2=39.2; P<0.001).

Table 3 Household food insecurity and previous day's food intake across four seasons, Wolaita, rural Ethiopia, 2017–2018

	Sowing season		Main harvest		Post-harvest		Dry pre-harvest	
	%	**95% CI**	**%**	**95% CI**	**%**	**95% CI**	**%**	**95% CI**
Food insecurity								
Prevalence rate	77.3	74.5–80.0	60.4	57.2–63.6	75.9	73.1–78.7	83.7	81.3–86.2
Incidence rate	19.5	18.3–20.9	15.3	14.1–16.5	19.0	17.7–20.3	20.4	19.2–21.8
Food groups								
Cereals*	67.0	63.9–70.0	94.8	93.4–96.3	94.8	93.4–96.3	61.6	58.3–64.8
Roots or tubers	21.2	18.5–23.8	20.0	17.4–22.6	20.3	17.6–22.9	18.1	15.6–20.7
Vegetables*	46.8	43.5–50.0	46.8	43.5–50.1	47.6	44.3–50.9	30.3	27.2–33.3
Fruits*	9.1	7.2–11.0	9.3	7.4–11.2	8.5	6.7–10.3	5.4	3.9–6.9
Meat	1.3	0.6–2.1	1.7	0.8–2.5	1.6	0.8–2.4	0.9	0.3–1.6
Eggs	0.8	0.2–1.3	1.1	0.4–1.8	1.0	0.4–1.7	1.3	0.5–2.0
Fish	1.1	0.4–1.8	1.4	0.7–2.2	1.5	0.7–2.2	9.3	7.4–11.2
Legumes*	17.7	15.2–20.2	18.0	15.5–20.5	18.4	15.8–20.9	17.1	14.6–19.6
Milk*	14.9	12.5–17.2	14.8	12.5–17.1	14.2	11.9–16.5	12.0	9.9–14.2
Oil or butter*	48.8	45.5–52.0	47.7	44.4–50.9	48.4	45.1–51.7	27.5	24.6–30.5
Sugar or honey	4.1	2.8–5.4	3.7	2.4–4.9	3.7	2.5–4.9	49.1	45.8–52.4
Condiments*	90.8	88.9–92.7	91.2	89.3–93.0	91.3	89.4–93.1	43.8	40.5–47.1
HDDS IQR		3–4		3–4		3–4		3–5

Notes: * Food groups with seasonally variable consumption patterns; CI: confidence interval; IQR: interquartile range; HDDS: household dietary diversity score

The median HDDS (out of 12 food groups) decreased with increasing food insecurity (Z=-15.5, P<0.001). Figure 2 shows an inverse dose–response relationship between HDDS (as counts) and number of seasons with household food insecurity: as household food insecurity increased, diversity decreased (Z=-8.2, P<0.001), and the association was particularly significant for households that did not participate in the PSNP (Z=-4.4, P<0.001).

Child diarrhoea

The overall prevalence of childhood diarrhoea illness was 26% (95% CI: 24.6–27.5) in the two weeks prior to visits during the study period (930 of 3,571 measurements). The mean prevalence of diarrhoea illness showed seasonal variation (χ^2=16.0, P<0.001), peaking in the sowing (rainy) season.

Child undernutrition by baseline factors

Table 4 summarises the nutritional indices of children (HAZ and WHZ) by baseline factors. Boys had lower HAZ scores than girls (t=-4.4, P<0.001). HAZ increased with increasing education among mothers (t=3.1, P<0.01), as did WHZ (t=2.3, P<0.05). The mean WHZ decreased with decreasing household wealth status (t=-3.1, P<0.01).

Table 4 Distributions of height-for-age and weight-for-height Z score indices, by baseline factors, rural Wolaita, Ethiopia, 2017–2018

		Height-for-age Z score			Weight-for-height Z score		
		Mean	**95% CI**		**Mean**	**95% CI**	
Child sex	Male	-1.057	-1.137	-0.976	-0.638	-0.690	-0.586
	Female	-1.308	-1.385	-1.230	-0.600	-0.654	-0.545
Child age in months	6–14	-1.045	-1.305	-0.786	-0.484	-0.694	-0.273
	15–23	-1.644	-1.926	-1.362	-0.400	-0.600	-0.201
	24–32	-1.277	-1.541	-1.013	-0.433	-0.595	-0.271
	33–41	-1.471	-1.734	-1.209	-0.509	-0.686	-0.331
	42–50	-0.745	-1.009	-0.480	-0.466	-0.639	-0.293
	51–59	-0.990	-1.245	-0.735	-0.804	-0.971	-0.637
Mother's age in years	15–24	-1.667	-1.761	-1.573	-0.434	-0.503	-0.364
	25–34	-1.191	-1.285	-1.097	-0.529	-0.589	-0.469
	≥35	-0.688	-0.784	-0.593	-0.902	-0.964	-0.839
Mother's education (grade completed)	0 (none)	-1.308	-1.443	-1.173	-0.599	-0.681	-0.516
	1–8	-1.220	-1.319	-1.121	-0.669	-0.737	-0.601
	9–12	-1.161	-1.257	-1.065	-0.623	-0.690	-0.555
	higher	-1.021	-1.156	-0.885	-0.542	-0.633	-0.451
Father's education (grade completed)	0 (none)	-1.308	-1.443	-1.173	-0.599	-0.681	-0.516
	1–8	-1.144	-1.247	-1.042	-0.686	-0.753	-0.619
	9–12	-1.200	-1.298	-1.101	-0.592	-0.665	-0.519
	Higher	-1.100	-1.221	-0.979	-0.576	-0.655	-0.497
Has latrine	Yes	-1.172	-1.232	-1.112	-0.620	-0.661	-0.579
	No	-1.269	-1.427	-1.111	-0.608	-0.702	-0.514
Has non-farm-related work	Yes	-1.060	-1.171	-0.950	-0.680	-0.752	-0.608
	No	-1.228	-1.293	-1.164	-0.597	-0.641	-0.553
Wealth status	Poorest	-1.203	-1.331	-1.074	-0.649	-0.726	-0.572
	Poor	-1.101	-1.223	-0.978	-0.774	-0.861	-0.686
	Medium	-1.308	-1.436	-1.181	-0.601	-0.690	-0.513
	Rich	-1.123	-1.248	-0.997	-0.501	-0.584	-0.418
	Richest	-1.190	-1.312	-1.068	-0.565	-0.647	-0.483
Household size	≤4	-1.064	-1.172	-0.956	-0.563	-0.633	-0.493
	5-7	-1.238	-1.313	-1.163	-0.667	-0.720	-0.614
	≥8	-1.217	-1.349	-1.085	-0.571	-0.651	-0.490
Drinking water access	Protected	-1.204	-1.287	-1.121	-0.395	-0.449	-0.341
	Unprotected	-1.169	-1.245	-1.093	-0.803	-0.854	-0.752
Participates in Productive Safety Net Programme	Yes	-1.051	-1.133	-0.969	-0.505	-0.560	-0.450
	No	-1.307	-1.383	-1.231	-0.723	-0.774	-0.671
Agri-ecological strata of villages	Midland	-1.325	-1.406	-1.244	-0.836	-0.890	-0.782
	Lowland	-1.062	-1.139	-0.984	-0.431	-0.482	-0.381

Notes. CI: confidence interval

Child undernutrition by some interventions

Children in households who participated in PSNP had higher HAZ and WHZ scores than children whose households did not (Table 4). Figure 3 shows the distribution of HAZ scores based on PSNP participation and drinking water access. Although HAZ scores did not differ by drinking water access, drinking water access had an additive effect in conjunction with participation in PSNP in decreasing the risk of stunting. Children in households with neither intervention (i.e., no PSNP and no protected water access) had lower HAZ scores than children whose households had both interventions, after adjusting for the observed clustering of both interventions in the lowland area: mean difference=-0.399 (95% CI: -0.632 – -0.166). With a similar adjustment for the clustering effects of the two interventions, we observed about a 0.3-unit increase in the HAZ of children with protected water access: mean HAZ = 0.289 (95% CI: 0.126–0.451).

Figure 4 shows the distribution of WHZ scores based on PSNP participation and drinking water access, stratified by agroecological areas. Accordingly, household participation in PSNP and protected water access reduced the risk of child wasting. Children in households who participated in PSNP had higher WHZ scores than those who did not: mean difference = 0.134 (95% CI: 0.057–0.210). Similarly, children in households with protected water access had higher WHZ scores than those with no protected water access: mean difference = 0.377 (95% CI: 0.300–0.454). We observed no interaction between the effect of drinking water access and that of PSNP participation on the risk of wasting, after controlling for the observed clustering of both interventions in the lowland area.

Dose–response relationships

A higher proportion of wasted children lived in food-insecure households than in food-secure ones, both in the main harvest season (10.1% vs. 6.6%; χ^2=13.0, P<0.001) and the dry season ((13.2 vs. 8.5%; χ^2=10.0, P<0.01). As shown in Figure 5, the risk of child wasting increased with increasing numbers of seasons with household food insecurity (Z=2.3, P<0.05). For example, as the number of seasons with household food insecurity increased from 1- to 4-fold, the risk of child wasting increased by about 7.5-fold (RR=7.57; 95% CI: 4.69–12.24). As the number of seasons with household food insecurity increased in the four seasons, the risk of wasting increased about 5-fold among children whose households participated in the PSNP (RR=5.2;

95% CI: 2.8–9.4). For the same increase in the number of seasons (1 to 4) with household food insecurity, the risk of wasting increased about 13-fold among children whose households did not participate in the PSNP (RR=12.8; 95% CI: 6.6–29.5). Participation in PSNP had a buffering effect against the effect of seasonal household food insecurity on child wasting.

Predictors of wasting

Table 5 shows results of a multiple linear regression model for factors associated with wasting. Protected drinking water access and PSNP participation reduced the risk of child wasting, whereas seasonal peaks in household food insecurity increased this risk.

Table 5 Results of multiple linear regression analysis for predictors of wasting, rural Wolaita, Ethiopia, 2017–2018

	β	**95% CI**		**P-value**
Child sex (female = ref)				
Male	-0.017	-0.091	0.057	0.654
Child diarrheal illness in prior 2 weeks (no= ref)				
Yes	-0.009	-0.094	0.076	0.836
Mothers' age in years, continuous	-0.004	-0.023	0.015	0.675
Mothers' education level, continuous	0.015	-0.016	0.047	0.336
Fathers' education level	-0.019	-0.052	0.015	0.283
Owns latrine (yes = ref)				
No	0.019	-0.082	0.119	0.715
Access to drinking water (protected = ref)				
Unprotected	-0.374	-0.484	-0.264	<0.001
Participates in PSNP (yes = ref)				
No	-0.168	-0.277	-0.059	<0.01
Work, non-farming income (no = ref)	-0.009	-0.096	0.078	0.839
Household Wealth Index (continuous)	-0.103	-0.230	0.025	0.114
Interaction term 1 = PSNP × water	0.040	-0.113	0.193	0.606
Interaction term 2 = PSNP × wealth index	0.032	-0.071	0.135	0.545
Interaction term 3 = work × wealth index	0.131	0.011	0.251	<0.05
Family size (continuous)	-0.007	-0.061	0.048	0.804
Dietary diversity (continuous)	-0.031	-0.064	0.002	0.069
Food security status (food secure = ref)	0.047	-0.071	0.165	0.432
Seasonal food insecurity (main = ref)				
Sowing	0.084	-0.044	0.212	0.198
Post-harvest	-0.080	-0.206	0.046	0.215
Dry pre-harvest	-0.265	-0.390	-0.139	<0.001

Notes. PSNP = Productive Safety Net Programme. Drinking water access (1= unprotected vs. 0=protected); work (1=exclusively farming vs. 0=non-farming income); PSNP status (1=non-beneficiary vs. 0=beneficiary). Interaction term 1 included households that did not participate in PSNP and had unprotected water access. Interaction term 2 included households that did not participate in PSNP and had higher wealth. Interaction term 3 included exclusively farming households with increasing wealth. Decreased β coefficients indicate increased risk of wasting. The estimated model coefficients are adjusted for effects of child age changes during the study period.

Predictors of stunting

Table 6 shows the main effects of baseline factors associated with the risk of stunting, adjusted for clustering at the kebele level using a mixed-effects linear regression analysis. Our model estimated 4.5% residual clustering for risk of stunting at the kebele level. Accordingly, individual factors independently associated with stunting included being a boy and having a younger or less educated mother. Household contributing factors included lack of a latrine or protected drinking water, low income, low wealth status and no PSNP participation. The risk of stunting was lower among children in wealthier households, those with a latrine and those with protected water access. Household participation in the PSNP had an additive effect on the association between protected water access and decreased risk of stunting.

Table 6 Results of multivariable linear regression analysis for predictors of stunting, rural Wolaita, Ethiopia, 2017–2018

	β	**95% CI**		**P-value**
Child sex (female = ref)	-0.275	-0.384	-0.166	<0.001
Child diarrheal illness in prior 2 weeks (no = ref)	-0.058	-0.184	0.067	0.36
Mother's age in years (continuous)	0.042	0.017	0.067	<0.001
Mother's education level (continuous)	0.053	0.018	0.088	<0.001
Father's education level (continuous)	-0.028	-.077	0.021	0.265
Latrine ownership (yes = ref)	-0.209	-0.370	-0.048	<0.01
Has access to clean water (no = reference)	0.402	0.229	0.575	<0.001
Participates in PSNP (no = reference)	0.218	-0.096	0.532	0.17
Work (no = reference)	-0.173	-0.448	0.102	0.22
Wealth index, continuous	-0.068	-0.137	0.000	0.05
Interaction term 1 = PSNP × water	-0.311	-0.543	-0.080	<0.01
Interaction term 2 = PSNP × wealth index	-0.063	-0.143	0.016	0.12
Interaction term 3 = work × wealth index	0.143	0.053	0.233	<0.001
Family size (continuous)	-0.066	-0.147	0.015	0.11
Dietary diversity (continuous)	-0.041	-0.084	0.003	0.07
Food secure (food-insecure = ref))	0.022	-0.151	0.196	0.80
Seasonal food insecurity (main harvest season = ref)				
Sowing	0.078	-0.106	0.263	0.406
Post-harvest	-0.008	-0.191	0.176	0.936
Dry pre-harvest	-0.097	-0.280	0.086	0.300

Drinking water access (1=unprotected vs. 0=protected); work (1=exclusively farming vs. 0=non-farming income); PSNP status (1=non-beneficiary vs. 0=beneficiary). Interaction term 1 includes households that did not participate in PSNP and had no protected water access. Interaction term 2 included those that did not participate in PSNP with higher wealth. Interaction term 3 included exclusively farming households with increasing wealth. Decreased β coefficients (increased risk of stunting). All coefficients are adjusted for the effects of child age change during the study period and for clustering effects in level-2 sample units (at kebele level).

DISCUSSION

Our cohort study documented seasonal variations in the risk of child wasting in southern Ethiopia. This risk increased with increasing durations of household food insecurity. Major factors associated with reduced risks of stunting and wasting were participation in the Ethiopian government's PSNP and access to protected drinking water, as well as living in a household with a latrine. Lower levels of household wealth and maternal education were associated with increased risk of stunting and wasting.

Subjectivity bias in our household food insecurity measurements could be a limitation of this study (*35, 36*). We refer to our previous publication on validation of the Household Food Insecurity Access Scale questionnaire (*6*). To ensure accuracy of the current study data, the same households and data collectors were used, and measurements were repeated. Yet, it was sometimes difficult to maintain the same data collectors, which could affect our estimates. Moreover, the household wealth index was determined at baseline and could have changed during the study period. Our prevalence estimates for stunting and wasting are consistent with recent estimates from the Ethiopian demographic and health surveys (*37-39*). Poverty is often described as a basic cause of childhood undernutrition in Ethiopia (*37, 40*). Poverty threatens households' ability to cope with food insecurity, which can lead to malnutrition in vulnerable population sub-groups, such as young children (*41*).

We documented seasonal variations in household food insecurity, which peaked in the dry pre-harvest period, like previous results from the Boricha area in southern Ethiopia (*42*). Seasonal peaks in household food insecurity mostly occur due to variations in food availability (*7, 14, 43*). The risk of child wasting also showed seasonal variation, peaking in the food-scarcity period (Figure 1), again similar to the results from Boricha (*42*) and eastern Ethiopia (*17, 44*). Seasonal peaks in household food insecurity were independent predictors of increased risk of child wasting (Table 5). Furthermore, the risk of wasting increased among households experiencing more seasons (i.e., longer periods) of household food insecurity (Figure 5). Stunting rates did not show seasonal variation, which differs from findings of previous studies (*17, 42*).

Our study suggests that household participation in the PSNP reduced the risk of child stunting, which aligns with previous similar studies (*45, 46*). PSNP participation also reduced the risk of child wasting, though we lack relevant literature for comparison. Previous studies suggest that

PSNP improves household food intake (*47-49*) and reduces the negative effect of seasonal household food insecurity on household diet (Fig 2). The PSNP thus could improve food intake diversity and lessen the impacts of drought on food scarcity (*47, 48*).

Our study suggests that access to clean drinking water reduced the risk of child wasting and stunting, which complements previous studies (*20, 50, 51*). Household participation in the PSNP enhanced this effect. The risk of stunting increased with increased household poverty, low maternal education and absence of a latrine, as previous studies also show (*50, 52-57*).

Seasonal household food insecurity could contribute to child wasting in rural Ethiopia, suggesting that this population is vulnerable to food insecurity (*14*). The Ethiopian government's PSNP has a protective effect against both stunting and wasting. Yet, the criteria for household PSNP eligibility remain controversial (*47*). For example, if geographic criteria prioritise the lowland areas (*9*), then poorer households in the midland villages (as in our study setting) could be neglected. To strengthen the PSNP intervention, effective targeting of the neediest households might further enhance its impacts on child undernutrition. Interventions to improve water access and sanitation could be equally important in reducing child undernutrition. Moreover, addressing seasonal variations in household food insecurity could help prevent child undernutrition (*14*).

FIGURE LEGENDS

Figure 1: Variations in prevalence rates of child wasting with 95% confidence intervals across four different seasons, rural Wolaita, Ethiopia, 2017–2018

Figure 2: Dose–response relationships between household food intake diversity and household food insecurity, rural Wolaita, Ethiopia, 2017–2018

Figure 3: Height-for-age Z-scores of children by household participation status in the Productive Safety Net Programme (PSNP) and drinking water access, rural Wolaita, Ethiopia, 2017–2018

Figure 4: Weight-for-height Z-scores of children across four seasons, by household participation in the Productive Safety Net Programme (PSNP) and water access, rural Wolaita, Ethiopia, 2017–2018

Figure 5: Dose–response relationship between child weight-for-height Z-score (WHZ) and number of seasons with household food insecurity, rural Wolaita, Ethiopia, 2017–2018

DECLARATIONS

Ethics approval and consent to participate

The institutional review committee at Hawassa University in Ethiopia (IRB/002/09) and the Regional Committee for Medical and Research Ethics in Western Norway (2016/482/REK vest) approved the study protocol. Written consent was obtained from the respondents and assent for their children's weight and height measures. Responses were anonymised using unique identification numbers.

Consent for publication

Not applicable

Availability of data and material

The data described in this manuscript will be made publicly available.

Competing interests

The authors declare that they have no competing interests.

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Authors’ contributions

BYK conceived the research idea, designed the study protocol, implemented the study, made major statistical analyses, and wrote the draft and final versions of the scientific reports. EL contributed to the design, statistical analyses, and writing. BL made substantial contributions to the design, field methods, major statistical analyses, and writing. All authors read and approved this manuscript for submission.

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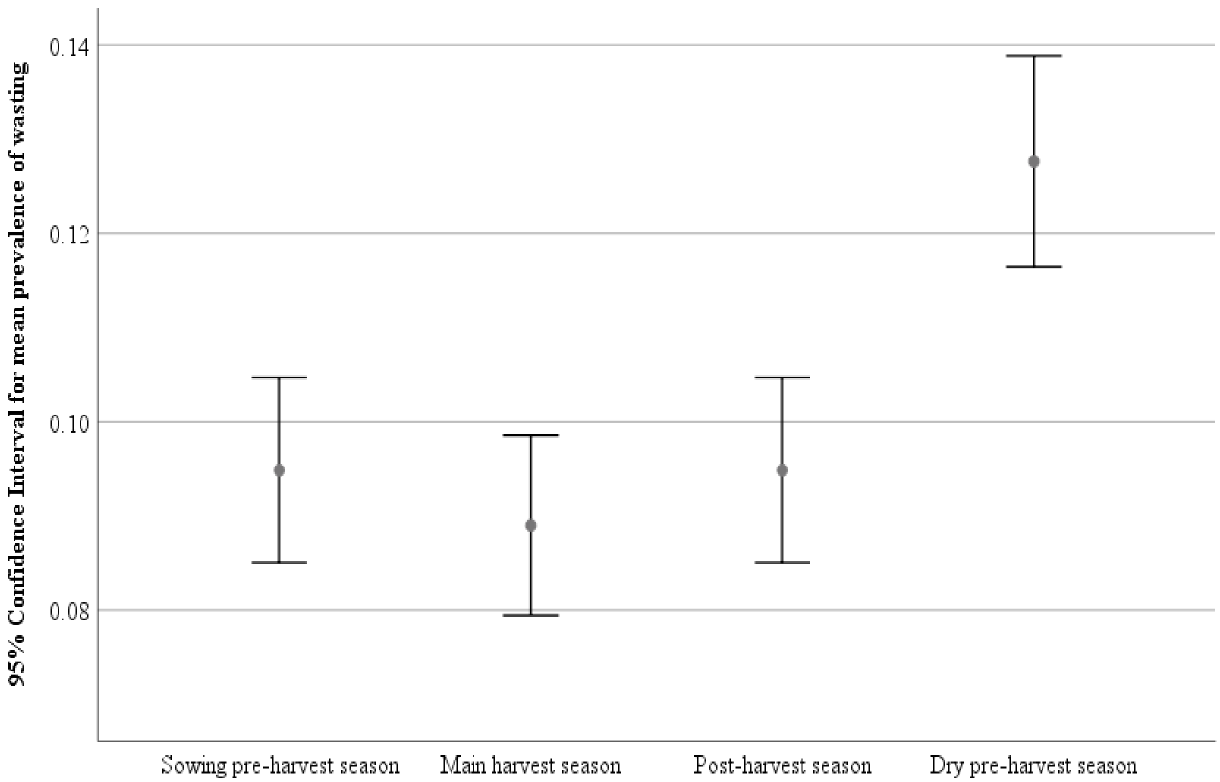

Figure 1 Variations in prevalence rates of child wasting with 95% confidence intervals across four different seasons, rural Wolaita, Ethiopia, 2017–2018

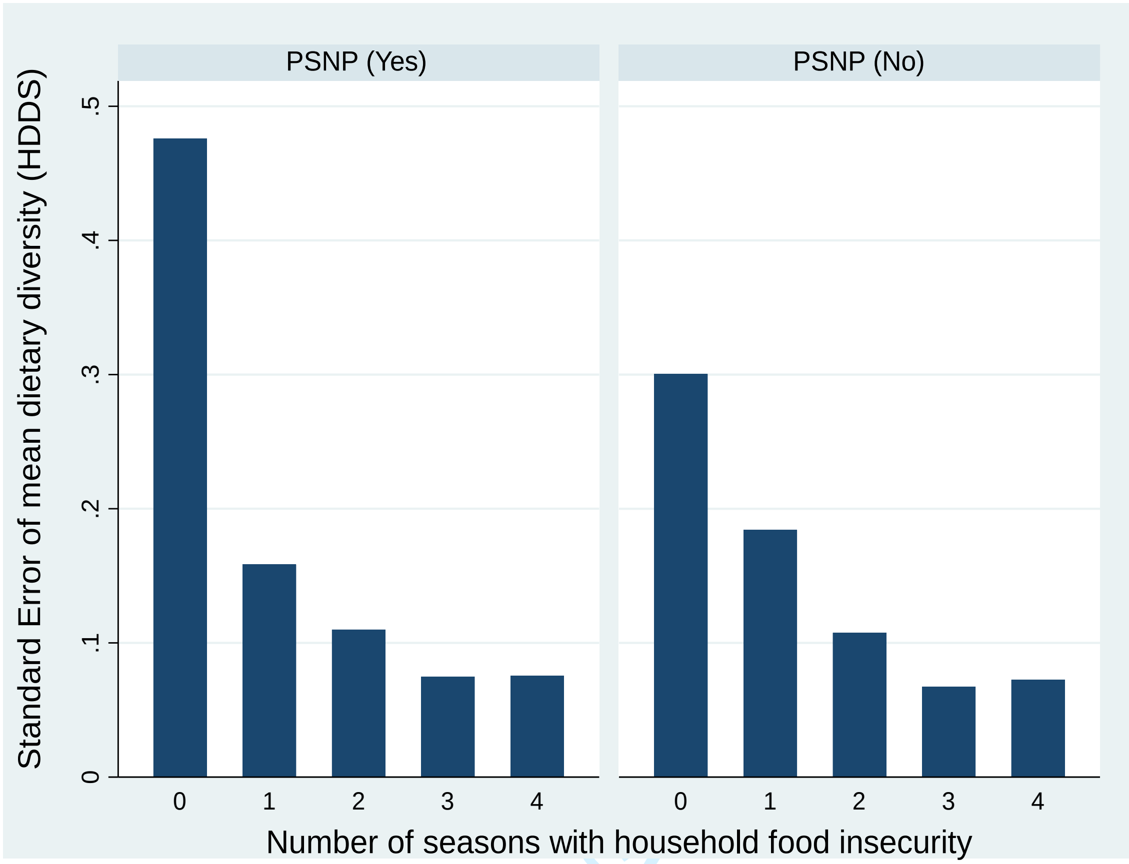

Figure 2 Dose–response relationships between household food intake diversity and household food insecurity, rural Wolaita, Ethiopia, 2017–2018

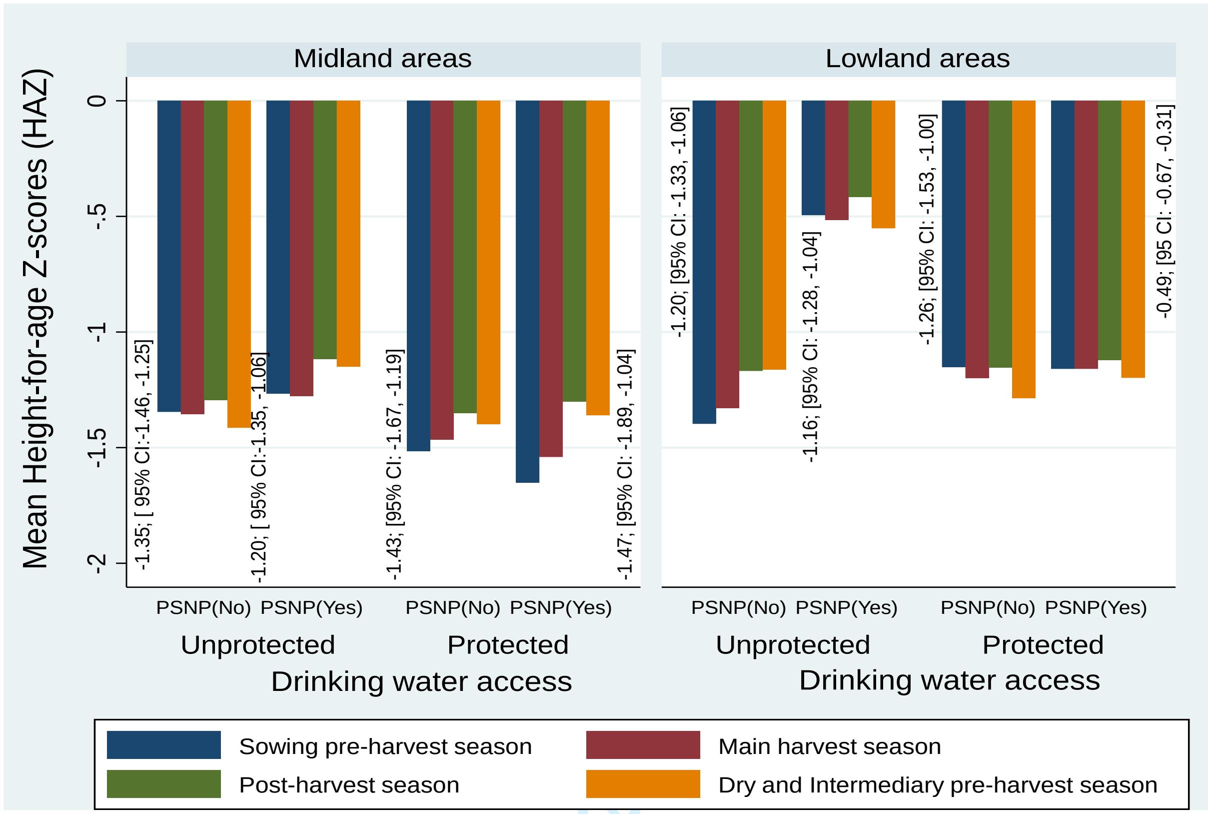

Figure 3 Height-for-age Z-scores of children by household participation status in the Productive Safety Net Programme (PSNP) and drinking water access, rural Wolaita, Ethiopia, 2017–2018

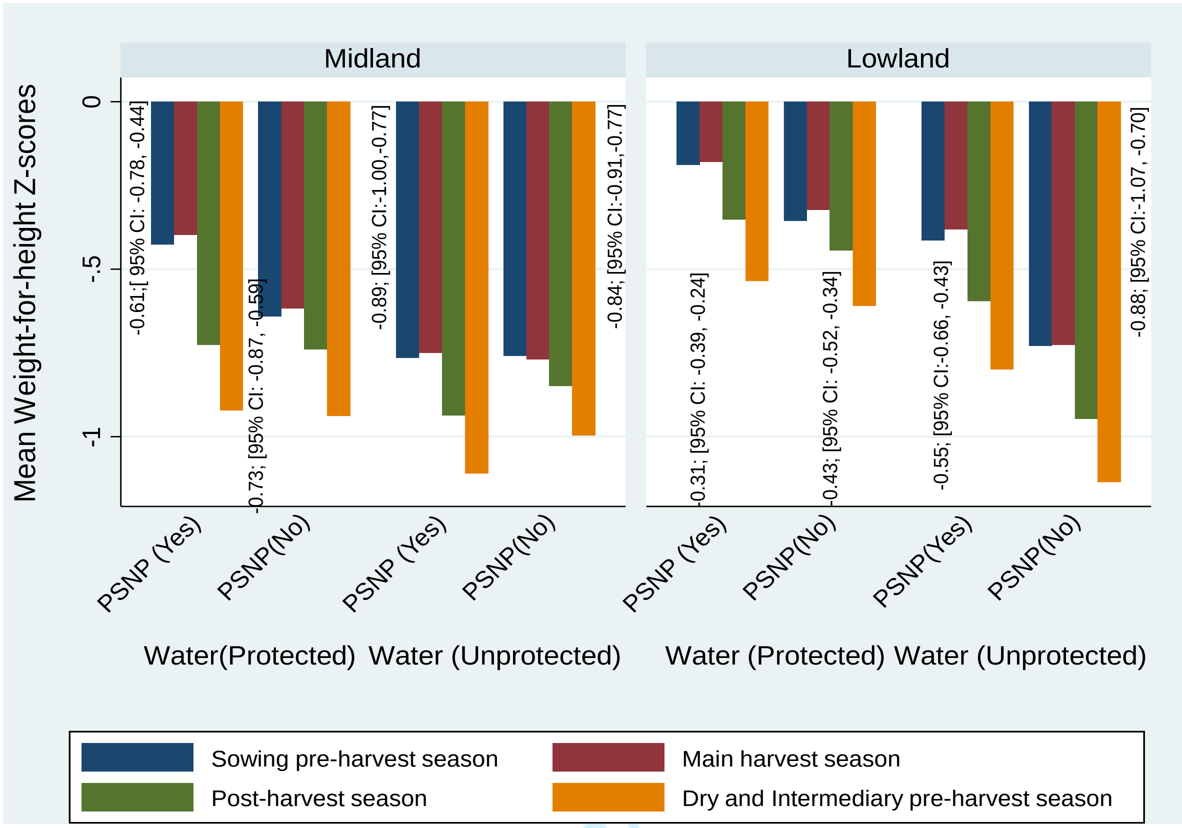

Figure 4 Weight-for-height Z-scores of children across four seasons, by household participation in the Productive Safety Net Programme (PSNP) and water access, rural Wolaita, Ethiopia, 2017–2018

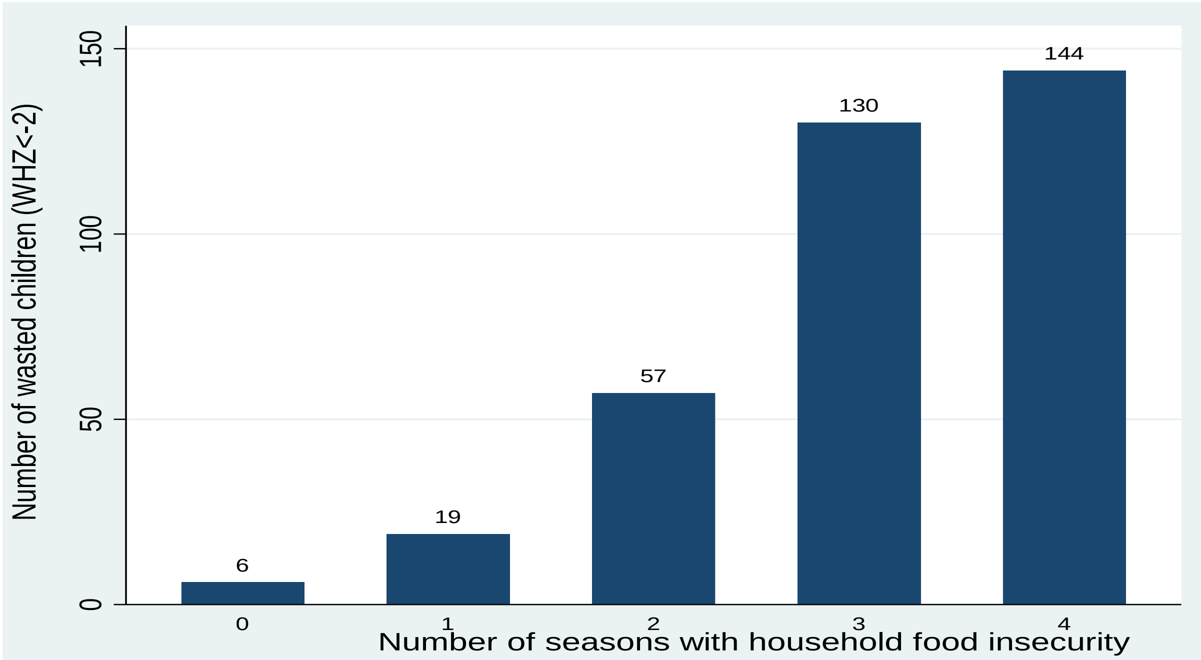

Figure 5 Dose–response relationship between child weight-for-height Z-score (WHZ) and number of seasons with household food insecurity, rural Wolaita, Ethiopia, 2017–2018

Reporting checklist for cohort study.

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		Reporting Item	Page Number
Title and abstract			
Title	#1a	Indicate the study's design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	3-4
Objectives	#3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	#4	Present key elements of study design early in the paper	4
Setting	#5	Describe the setting, locations, and relevant dates, including periods	4

		of recruitment, exposure, follow-up, and data collection	
Eligibility criteria	#6a	Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up.	5
Eligibility criteria	#6b	For matched studies, give matching criteria and number of exposed and unexposed	NA
Variables	#7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5-8
Data sources / measurement	#8	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	5-8
Bias	#9	Describe any efforts to address potential sources of bias	5-9
Study size	#10	Explain how the study size was arrived at	6
Quantitative variables	#11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	8-9
Statistical methods	#12a	Describe all statistical methods, including those used to control for confounding	

8-9

Statistical methods	#12b	Describe any methods used to examine subgroups and interactions	9
Statistical methods	#12c	Explain how missing data were addressed	6
Statistical methods	#12d	If applicable, explain how loss to follow-up was addressed	5-6
Statistical methods	#12e	Describe any sensitivity analyses	

NA

Results

Participants	#13a	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible,	5-6

		included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	
Participants	#13b	Give reasons for non-participation at each stage	5-6
Participants	#13c	Consider use of a flow diagram	
6			
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	9-12
Descriptive data	#14b	Indicate number of participants with missing data for each variable of interest	
6			
Descriptive data	#14c	Summarise follow-up time (eg, average and total amount)	
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Outcome data	#15	Report numbers of outcome events or summary measures over time. Give information separately for exposed and unexposed groups if applicable.	
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Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	15-16
Main results	#16b	Report category boundaries when continuous variables were categorized	15-16
Main results	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
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Other analyses	#17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	15-16

Discussion

Key results	#18	Summarise key results with reference to study objectives	17
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	17
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	17-18
Generalisability	#21	Discuss the generalisability (external validity) of the study results	18
Other Information			
Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	19

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Can childhood stunting and wasting be reduced in drought-prone areas in Ethiopia? A cohort study

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Can childhood stunting and wasting be reduced in drought-prone areas in Ethiopia? A cohort study

Authors:

Bereket Yohannes Kabalo (BYK) [1, 2] and Bernt Lindtjørn (BL) [1, 2]

Authors' addresses:

Bereket Yohannes Kabalo: bkabalo@gmail.com

Bernt Lindtjørn: bernt.lindtjorn@uib.no

Authors' affiliations:

[1]School of Public Health, Hawassa University, Hawassa, Ethiopia

[2]Centre for International Health, University of Bergen, Bergen, Norway

*** Corresponding author**:

Bereket Yohannes Kabalo

bkabalo@gmail.com

ABSTRACT

Background and objectives: Ethiopia has over the years experienced severe famines and periods of serious droughts. As such, malnutrition remains major public health problem. The aims of this study were to estimate seasonal variations in child stunting and wasting, and identify factors associated with these both forms of child malnutrition in drought-prone areas.
Methods: This cohort study was conducted among a random sample of 909 children in the rural southern Ethiopia. We followed the same children for one year (2017-2018) with quarterly repeated measurements of their outcomes, height-for-age and weight-for-height indices (Z-scores). We used linear regression models to analyse both outcomes with baseline factors (e.g., household participation in social safety net program, drinking water access, and latrine possession) and some time-varying factors (e.g., household food insecurity).
Results: Child wasting rates varied with seasonal household food insecurity (χ^2_{trend}=15.9, P=0.001), but the stunting rates did not. Household participation in social safety net program was associated with decreased stunting (P=0.001) and wasting (P=0.002). Besides to its association with decreased wasting (P=0.001), protected drinking water access enhanced the association between household participation in social safety net programme and decreased stunting (P=0.009). Absence of a household latrine (P=0.011), lower maternal education level (P=0.001), larger family size (P=0.004) and lack of non-farming income (P=0.002) were associated with increased child stunting.
Conclusions: Seasonal household food insecurity could contribute to child undernutrition in rural Ethiopia, suggesting the population vulnerability to food insecurity. Strengthening community-based food security programs such as the Ethiopian government's social safety net program could help reduce child undernutrition in drought-prone areas. Yet, improving clean water access and sanitation could also reduce child undernutrition.

Key terms: undernutrition; water access; Productive Safety Net Programme

Limitations and strengths of this study

- We accounted for agro-ecological strata and random selection of households; yet, our one sample estimation could be one of the limitations of this study.
- We accounted for seasonality in our repeated measurements using some time-varying factors (e.g., household food insecurity and child diarrhoeal illness); yet, we did not assess other illnesses such as malaria, measles, Tuberculosis etc.
- We did not initially estimate separate samples for our repeated measurements, but our analytical sample (i.e., counts of observations compiled from the repeated measurements) showed adequate statistical power of estimation to meet the primary aims of the study.
- We analysed height-for-age Z-score and weight-for-height Z-score indices as continuous measures, using linear regression models; our estimates were adjusted for the observed clustering effects at the primary sampling stage (at kebele level) and time series effects of our repeated measurements.
- As we analysed our data in a cohort design, there could be certain underestimated time element in our repeated measurements beyond the scope of our time-varying exposures.

INTRODUCTION

Over the centuries, Ethiopia has experienced droughts and famine events averaging once per decade [1, 2]. Moreover, the Intergovernmental Panel on Climate Change predicts that climate change will lead to more desertification and crop failures in vulnerable areas like Ethiopia [3-5]; as such, malnutrition remains one of the major public health problems.

In communities that rely on subsistence agriculture, food insecurity often peaks seasonally in the pre-harvest periods [6, 7]. Affected households adapt by reducing the frequency and size of daily meals; selling livestock or dairy products; borrowing food or money from merchants or local social networks; selling wood, charcoal or grass; engaging in paid labour; and renting out farm land [8]. However, such coping mechanisms are often insufficient, leading to a vicious cycle of poverty and food insecurity.

Following many years of food provision for famine-prone populations, the Ethiopian government launched the 'Productive Safety Net Programme (PSNP)' in 2005 [9]. PSNP aims to prevent household asset depletion and strengthen communities [9]. This program provides cash or food payments in exchange for labour to produce public works, local infrastructure, and environmental projects, or direct payments for households that are unable to provide labour [10]. Additional development activities in drought-prone areas include improving access to clean water and sanitation [11, 12]. Improving household food security and access to clean drinking water and sanitation are often described as nutrition-sensitive interventions.

Researchers use several methods to assess the impact of food scarcity on the population. One common outcome is the level of household food insecurity and occurrence of malnutrition among vulnerable groups (e.g., young children). Recent research has emphasised the importance of understanding seasonal variations in nutrition status among young children as an indicator of vulnerability to food insecurity [13].

Since the 1970s, undernutrition has been classified in two major ways: wasting (i.e. low weight-for height or small mid-upper arm circumference) and stunting (i.e. low height-for-age) [14]. However, this categorical classification neglects many children with borderline measurements who are at undernourishment [15]. Moreover, deficiencies in length-for-age and weight-for-height reflect shared factors for undernutrition, and increasing research indicates that these characteristics reflect various pathophysiological processes that should be viewed as composite measures of undernutrition [16].

Wolaita, a densely populated area in southern Ethiopia, has experienced severe droughts and famines [2, 6]. As such, the population's experiences and coping mechanisms related to severe food insecurity are relevant for other famine-prone areas in the country and across Africa. The aims of this study were to estimate seasonal variations in child stunting and wasting, and identify factors associated with both these forms of child malnutrition in drought-prone areas.

METHODS

Study design and setting

We conducted a prospective cohort study using a random sample of 909 households in the rural Wolaita area in southern Ethiopia. We recruited one child per household at the start of the study (in June 2017) and followed the same children by measuring their outcomes, height-for-age and weight-for-height indices every three months for one year (June 2017 to June 2018). Our exposure variables included background factors (measured at baseline) and some time-varying factors (measured at each season). The quarterly repeated measurements were undertaken in the first month of each season (i.e., June, September, December, and March) [6].

Wolaita is located between the Great Rift Valley and the Omo Valley in southern Ethiopia. Rural villages in this area mainly represent two agro-ecological areas: the hot and semi-dry 'lowlands' and the relatively cooler and sub-humid 'midlands' [3, 17]. Mean annual rainfall ranges from 800 mm in the lowlands to 1,200 mm in the midlands, with bimodal distribution [6]. Farming of staple crops, such as maize, occurs during the *Belg* rains from about March to early May [6, 18]. Root crops, such as taro and sweet potato, are farmed in both seasons and help bridge seasonal gaps in food security [3, 6].

Outcomes

The main outcome measures were height-for-age and weight-for-height indices (Z-scores), measured at each season for one year and defined based on the World Health Organization (WHO) 2006 child growth standards [19]. Stunting and wasting were defined as HAZ (height-for-age Z-scores) and WHZ (weight-for-height Z-scores) of -2 standard deviations below the respective WHO standard median.

Exposures

Our exposure variables included background factors (baseline data) and some time-varying factors (measured at each season). Baseline factors included child age and sex; parent age and education; household socio-economic conditions such as family size, source of income, wealth index, and participation in food security programme (PSNP); household latrine ownership and drinking water access. We considered household food insecurity, dietary diversity, and child diarrhoeal illness as time-varying exposures for which we had repeated measurements.

Repeated measurements

Our repeated measurements were undertaken during the four seasons based on agricultural cycles: *Kiremt* is the sowing season in June, July, and August; *Belg* is the main harvest season in September, October, and November; *Bega* is the post-harvest season in December, January, and February; and *Tsedey* is the dry pre-harvest season in March, April, and May [6]. These quarterly repeated measurements were undertaken at the same time for outcomes and time-varying exposures.

Participants

We conducted a multistage random selection of households. First, we selected two rural districts, or Woredas, representing the two agro-ecological strata in Wolaita: Humbo district in the lowlands and Soddo Zuria district in the midland area, assuming household food insecurity would be more prevalent in the lowland areas [20, 21]. The population density was higher in the midland villages than in the lowland villages in the study area. As such, we selected three kebeles (smallest administrative unit) from the lowland district and two kebeles from the midland district using the complex samples selection feature in SPSS version 25.0 (IBM). Finally, we selected households with children under five years old and enrolled one child aged 6–59 months per household.

To estimate the sample size, we followed an earlier cohort study assessing seasonal variations in wasting prevalence [22]. The estimated sample size to estimate differences in prevalence rates of wasting 6.6% and 13%, with a 95% level of confidence and 80% power, was 820 children (OpenEpi software). Our study included 909 children.

Patient and Public Involvement

No subject involvement

Outcome measurements

We did height and weight measurements each season. We trained four data collectors on standard techniques for height and weight measurements. After the training, we validated the consistency of their measurements by recruiting 10 children aged below 5 years from another rural village and having all four data collectors (observers) measure each child's height twice. The overall measurements showed about 92% average internal consistency. These four observers recorded height and weight measurements for the actual study. Height (or recumbent length for children younger than 24 months) was measured to the nearest of 0.1 cm using a local wooden length board. Weight was measured to the nearest 0.1 kg using a Seca weight scale (*Seca* GmbH & Co. Kg., Hamburg., Germany).

Exposure measurements

<u>Time-invariant factors (baseline)</u>

We recorded child age in months, and mothers' age in years and highest grade of school completed by both parents. We recorded family size (number of household members), source of income (exclusively farming vs. generates other additional income), possession of common household assets, and participation in food security programme (data collectors observed the PSNP beneficiary cards during household visits). Besides, we recorded household latrine ownership (yes vs. no) and drinking water access (protected vs. unprotected), only water piped via public tap was considered protected [23]. We used principal component analysis to construct a wealth index based on common household assets: (i) housing material of the roof, interior ceilings, floors, and walls; (ii) number of livestock household owned; (iii) land size in hectares; and (iv) possession of common assets such as a radio, mobile telephone, bed, mattress, kerosene lamp, watch, electric or solar panels, chairs, tables, wooden boxes and donkey carts [6, 24].

<u>Time-varying factors (measured at each season)</u>

Time-varying variable, household food insecurity (HFI) was measured using the nine questions in the Household Food Insecurity Access Scale, which has been validated in the study area [6]. Household dietary diversity was scored using 24-hour recall measurements. Household members were asked about the 12 common food groups in Ethiopia: (i) cereals and breads; (ii) potatoes and other roots or tubers; (iii) vegetables; (iv) fruits; (v) eggs; (vi) dairy products; (vii) pulses; (viii) fish; (ix) meat; (x) oil, fat, or butter; (xi) sugar or honey and (xii) other foods or condiments (e.g., coffee, tea, or other spices etc.,). The responses for the twelve food-groups were used to generate a scale of food intake diversity, the household dietary diversity score (HDDS) [25]. We assessed the occurrence of childhood diarrhoeal illness which was defined as the passage of three or more loose or watery stools in the preceding 24-hours [26, 27], and was assessed during the two weeks prior to the survey dates [28].

We generated two categorical variables from the actual HFI observations in our dataset and the time series of our repeated measurements. Quantified as person-time observations, we generated an ordinal HFI measure (i.e., number of seasons with HFI) as an exposure variable to explore dose-response relationships (e.g., between child wasting and HFI). Quantified also as person-time observations, we generated a multinomial HFI measure summarising incidence rates of HFI by the four seasons (0=Food-secure; 1=HFI in the sowing season; 2=HFI in the main harvest season; 3=HFI in the post-harvest season; and 4=HFI in the dry pre-harvest season) as an exposure variable in our main analysis (i.e., multivariable models). As the household food security and dietary diversity are highly correlated entities, we accounted for the HDDS as the null category for HFI multinomial measure (i.e., 0=Food-secure) as an exposure variable in our main analysis. Moreover, child diarrhoeal illness was considered as a covariate for the effect of the other time-varying exposures (e.g., seasonal HFI).

Conceptual framework

Based on a systematic review paper, Phalkey et al., suggested complex pathways from climate variability to undernutrition in subsistence communities [29]. Our current work used their work, but we adapted to the scope of our study, and we focused on the human nutrition (Figure 1).

Data and measurements

Data entry and cleaning

Data were double entered in EpiData software version 3.1 (EpiData Association 2000-2021, Aarhus, Denmark) and corrected for entry errors. First, we entered our baseline data by unique identification numbers for the subjects (ID). We then entered repeated measurements by the subject ID, but we recorded each round of measurement with different variable names for each variable. After cleaning our data in the short format (by ID), we reshaped the dataset into long format for statistical analysis with which a new variable (season) was generated to specify the discrete time series of our repeated measurements. We generated nutritional indices (HAZ and

WHZ) from anthropometric data using ENA and WHO Anthro software 3.2.2 (WHO, Geneva, Switzerland).

Units of analysis

As we measured each child in each of the four seasons, we compiled counts of observations totalling 3636 HAZ and WHZ measurements at the end of the study period. However, we excluded 46 HAZ and 126 WHZ observations that had incomplete data or that were severe outliers [30]. Accordingly, our units of analysis were counts of measurements totalling 3,571 HAZ estimates and 3,510 WHZ estimates (Figure 2). We analysed complete WHZ data (N=3,510) of 897 children and complete HAZ data (N=3,571) of 907 children.

Time-varying data considerations

As we measured the same children in each season, age changes during the study period could lead to certain deviations in outcome estimates (i.e., cohort effects). As such, we generated a separate variable (age in months divided by age in the logarithmic scale) to account for the cohort effect. Time-varying effects could also be due to external factors (e.g., seasonality). As such, we considered HFI as a multinomial variable to estimate seasonally variable effect of household food insecurity on child undernutrition. Moreover, we accounted for the time series of our repeated measurements using some dummy variables as measurement components of time-varying exposures.

Statistical methods

We used Stata version 15 (Stata Corp LLC, College Station, TX, USA) for our statistical works. To explore our data distributions (bivariate analysis), we used parametric such as t-tests to compare two means, ANOVA tests to compare more than two means, and correlation tests to assess the associations between two continuous variables. We analysed our normally distributed data for both outcomes with background factors (baseline data) and some time-varying factors (repeated measurements) using hierarchical linear regression models. Our data had hierarchies as (i) clustering effects at the primary sampling stage (at the kebele level) or (ii) time-varying effects within our repeated measurements.

Multivariable analysis

We first estimated between variations as main effects of baseline factors on our outcome measures and then analysed within variations as main effects to explore time-varying exposure effects on outcome estimates (more details are under separate subheadings hereafter).

Between variation models

HAZ data were analysed using multivariable linear regression model with adjustment for the clustering effect of the stunting at the primary sampling stage, but we ignored the observed insignificant clustering when analysing the WHZ data [31, 32]. We considered HAZ and WHZ estimates in the preceding season to control for the cohort-effect when analysing baseline factors associated with stunting and wasting.

Within variation models

At this stage, we aimed to estimate the time-varying exposure effects on outcome estimates and further analysed the fitted between variation models to account for exposure-season interaction effect (e.g., household food insecurity by the four seasons as a multinomial exposure variable) to estimate seasonally variable effects of relevant exposure variables on outcome estimates. Time-varying exposure effects were estimated as main effects with adjustment for other time-varying effects (i.e., cohort and time series effects) and main effects of all baseline factors included in the fitted models for between variations.

Further analysis

We further analysed the fitted models for both outcomes to explore interactions: e.g., additive or multiplicative effects (e.g., PSNP participation and protected drinking water access on our outcome estimates) or effect modification (e.g., variations in the effect of PSNP participation on child wasting across household food insecurity levels).

Model reports and meanings

We reported main effects for between and within variations using standardized model coefficients (β) with 95% CIs: i.e., decreased model coefficients refer to increased stunting (HAZ) and wasting (WHZ).

RESULTS

Participants

Table 1 shows the baseline characteristics of the 907 study participants with complete HAZ data.

Table 1 Baseline characteristics of the study participants , rural Wolaita, Ethiopia, 2017–2018 (n=907)

Variable	# (%)*
Child sex	
Male	462 (50.9)
Female	445 (49.1)
Child age in months, mean (SD)	33.4 (11.7)
Mother's age in years, mean (SD)	29.3 (3.3)
Mother's education (grade completed)	
0-4	325 (32.8)
5–10	285 (31.4)
9–12 or higher education	297 (32.7)
Father's education (grade completed)	
0-4	452 (49.8)
5-8	277 (30.5)
9–12 or higher education	178 (19.6)
Household family size, median (Interquartile range)	6 (4-7)
Household work, any non-farming income?	
Yes (additional income)	237 (26.1)
No (exclusively farming)	670 (73.9)
Household owns latrine	
Yes	784 (86.4)
No	123 (13.6)
Household protected drinking water access	
Yes	406 (44.8)
No	501 (55.2)
Household PSNP participation	
Yes	434 (47.9)
No	473 (52.1)
Household PSNP participation and protected drinking water access (cat)	
Neither PSNP participation nor protected water access	307 (33.9)
PSNP participation (alone)	191 (21.1)
Protected water access (alone)	165 (18.2)
Both PSNP participation and protected water access	244 (26.9)

* Unless otherwise indicated. Participates in Productive Safety Net Programme (PSNP). Household PSNP participation and protected drinking water access (cat) is a categorical variable generated from two dichotomous variables (PSNP participation and protected drinking water access): 1=included households who neither had protected drinking water access nor participated in PSNP; 2= households who participated in PSNP but did not have protected drinking water access; 3= households who had protected drinking water access but that did not participate in PSNP but did not have protected drinking water access; 4=included households who had protected drinking water access and also participated in PSNP.

Summary results from repeated measurements

Table 2 summarizes prevalence rates of household food insecurity, childhood diarrhoeal illness, and stunting and wasting. The overall prevalence of child stunting was 32.1% (1145 of 3571 measurements) and that of wasting was 10.3% (360 of 3510 measurements). Child wasting rates varied across seasons (χ^2_{trend}=20.5, P=0.001), but stunting rates did not show any seasonal variations.

<u>Household food insecurity</u>

The overall prevalence of HFI was 74.2% (95% CI 72.8-75.6) during the study period study period (2651 of 3571 measurements), and HFI varied across seasons (χ^2_{trend}=29.2, P=0.001). Quantified as person-time observations, the risk of experiencing HFI in just one season was 7.5%, compared to 17.0% in at two seasons, 39.0% in three seasons and 34.8% throughout all four seasons. The median HDDS was 3 (out of the 12 food groups, interquartile range of 3–4), but the overall HDDS did not show seasonal variations. As is shown in Figure 3, dietary diversity decreased with increasing durations of household food insecurity (Z=-7.3, P=0.001).

<u>Child diarrhoeal illness</u>

The overall prevalence of child diarrhoeal illness was 26% (95% CI 24.6-27.5; 930 of 3571 measurements), and the occurrence of child diarrhoeal illness varied across seasons (χ^2_{trend}=12.0, P=0.001), with peak in the rainy (sowing) season.

Table 2 prevalence rates of household food insecurity, child diarrhoeal illness and undernutrition (stunting and wasting) rates, Wolaita, rural Ethiopia, 2017-18

		Prevalence		
Variable	Season	%	95% CI	
Household food insecurity	Sowing season (n=902)	77.2	71.6	83.2
	Main harvest season (n=904)	60.2	55.3	65.5
	Post-harvest season (n=893)	76.0	70.5	82.0
	Dry pre-harvest season (n=872)	84.0	78.1	90.4
Child diarrhoeal illness	Sowing season (n=902)	30.9	27.4	34.7
	Main harvest season (n=904)	26.5	23.3	30.1
	Post-harvest season (n=893)	22.6	19.6	26.0
	Dry pre-harvest season (n=872)	24.0	21.0	27.6
Child stunting	Sowing season (n=902)	32.2	28.7	36.2
	Main harvest season (n=904)	32.2	28.7	36.2
	Post-harvest season (n=893)	31.1	27.6	35.0
	Dry pre-harvest season (n=872)	33.6	29.9	37.7
Child wasting	Sowing season (n=894)	9.4	7.6	11.6
	Main harvest season (n=887)	8.9	7.1	11.1
	Post-harvest season (n=872)	10.0	8.1	12.3
	Dry pre-harvest season (n=857)	12.8	10.6	15.5

Outcome data distributions

Table 3 shows HAZ and WHZ data distributions by background characteristics (baseline data). Boys had lower HAZ indices than girls (t=-4.2, P=0.001). HAZ indices increased (t=11.6, P=0.001) but WHZ decreased (t=-9.4, P=0.001) with increasing maternal age. Both HAZ and WHZ increased with increasing maternal education level: HAZ (t=3.8, P=0.001) and WHZ (t=2.0, P=0.039). Children who lived in exclusively farming households had lower HAZ indices than whose households had additional income (t=-2.9, P=0.004) and WHZ decreased with decreasing household wealth (t=3.2, P=0.002).

Table 3 Distributions of height-for-age Z-score (n=907 children) and weight-for-height Z score (n=897 children) indices, by baseline factors, rural Wolaita, Ethiopia, 2017–2018

		HAZ (N=3,571)			WHZ (N=3,510)		
Variable	Categories	Mean	95% CI		Mean	95% CI	
Child sex	Female	-1.057	-1.137	-0.976	-0.638	-0.690	-0.586
	Male	-1.308	-1.385	-1.230	-0.600	-0.654	-0.545
Mother's age in years	15–24	-1.667	-1.761	-1.573	-0.434	-0.503	-0.364
	25–34	-1.191	-1.285	-1.097	-0.529	-0.589	-0.469
	>35	-0.688	-0.784	-0.593	-0.902	-0.964	-0.839
Mother's education	0-4	-1.308	-1.443	-1.173	-0.599	-0.681	-0.516
	5–8	-1.220	-1.319	-1.121	-0.669	-0.737	-0.601
	9–12 or higher	-1.161	-1.257	-1.065	-0.623	-0.690	-0.555
Father's education	0-4	-1.308	-1.443	-1.173	-0.599	-0.681	-0.516
	5–8	-1.144	-1.247	-1.042	-0.686	-0.753	-0.619
	9–12 or higher	-1.200	-1.298	-1.101	-0.592	-0.665	-0.519
Household has latrine	Yes	-1.172	-1.232	-1.112	-0.620	-0.661	-0.579
	No	-1.269	-1.427	-1.111	-0.608	-0.702	-0.514
Non-farm-related work	Yes	-1.060	-1.171	-0.950	-0.680	-0.752	-0.608
	No	-1.228	-1.293	-1.164	-0.597	-0.641	-0.553
Household wealth status	Poorest	-1.203	-1.331	-1.074	-0.649	-0.726	-0.572
	Poor	-1.101	-1.223	-0.978	-0.774	-0.861	-0.686
	Medium	-1.308	-1.436	-1.181	-0.601	-0.690	-0.513
	Rich	-1.123	-1.248	-0.997	-0.501	-0.584	-0.418
	Richest	-1.190	-1.312	-1.068	-0.565	-0.647	-0.483
Household size	<4	-1.064	-1.172	-0.956	-0.563	-0.633	-0.493
	5-7	-1.238	-1.313	-1.163	-0.667	-0.720	-0.614
	>8	-1.217	-1.349	-1.085	-0.571	-0.651	-0.490
Protected drinking water access	Yes	-1.204	-1.287	-1.121	-0.395	-0.449	-0.341
	No	-1.169	-1.245	-1.093	-0.803	-0.854	-0.752
PSNP participation	Yes	-1.051	-1.133	-0.969	-0.505	-0.560	-0.450
	No	-1.307	-1.383	-1.231	-0.723	-0.774	-0.671
PSNP participation and protected drinking water access (cat)	Neither (1)	-1.369	-1.468	-1.270	-0.842	-0.907	-0.777
	PSNP (2)	-0.893	-1.016	-0.771	-0.717	-0.801	-0.634
	Water (3)	-1.250	-1.371	-1.130	-0.486	-0.566	-0.405
	Both (4)	-1.218	-1.335	-1.102	-0.336	-0.408	-0.264

Notes. PSNP= Productive Safety Net Programme. PSNP participation and protected drinking water access (cat) is a categorical variable generated from two dichotomous variables (PSNP participation and protected drinking water access): 1=included households who neither had protected drinking water access nor participated in PSNP; 2= households who participated in PSNP but did not have protected drinking water access; 3= households who had protected drinking water access but that did not participate in PSNP but did not have protected drinking water access; 4=included households who had protected drinking water access and also participated in PSNP.

HAZ and WHZ by PSNP and drinking water access

As is shown in Table 3, both HAZ and WHZ indices were higher among children whose households had PSNP participation than whose households had no PSNP participation: mean HAZ difference=0.251 (95% CI 0.136, 0.365) and mean WHZ difference= 0.216 (95% CI 0.141, 0.291). Besides, children whose households had protected drinking water access had higher WHZ indices than whose households had no protected drinking water access: mean difference=0.399 (95% CI 0.324, 0.474). HAZ did not vary by drinking water access.

Protected drinking water access had a confounding effect on the observed association between PSNP participation and increased WHZ: mean difference = 0.136; (95% CI 0.060, 0.212). Figure 4 shows WHZ data distributions by categories for a multinomial variable disentangling PSNP participation and protected drinking water access.

Baseline factors associated with child nutritional status

Table 4 shows results of multivariable regression models for factors independently associated with HAZ and WHZ. Accordingly, PSNP participation was independently associated with increased HAZ and WHZ. Besides, protected drinking water access was associated with increased WHZ. Moreover, protected water access enhanced the association between PSNP participation and increased HAZ. On the other hand, being a boy, lower level of maternal education and lack of household latrine were associated decreased HAZ.

Table 4 Results of multivariable linear regression models for factors associated with child stunting and wasting, Wolaita, rural Ethiopia, 2017-18

	HAZ (N=3,571)			WHZ (N=3,510)		
Variables	β	95% CI		β	95% CI	
Child age in months (lnmonths)	-2.022***	-3.093	-0.951	-0.196**	-0.309	-0.083
Child sex (ref=female)	-0.327***	-0.441	-0.213	-0.034	-0.110	0.043
Mother's age in years ,continuous	-0.039	-0.079	0.002	-0.005	-0.032	0.022
Mother's education level, continuous	0.121***	0.074	0.169	0.023	-0.009	0.054
Father's education level ,continuous	-0.032	-0.084	0.019	-0.027	-0.062	0.008
Household latrine (ref=yes)	-0.175*	-0.343	-0.007	0.024	-0.088	0.137
Family size ,continuous	-0.123	-0.209	-0.037	-0.019	-0.077	0.038
Wealth index, continuous	-0.075	-0.179	0.029	0.024	-0.045	0.094
Work, non-farming income (ref=yes)	-0.182***	-0.316	-0.047	-0.043	-0.133	0.047
Drinking water access (W)	0.234	0.066	0.403	-0.363	-0.476	-0.250

PSNP participation $^{(P)}$	-0.092	-0.265	0.081	-0.172	-0.288	-0.056
Interaction term $^{(W\times P)}$	-0.367***	-0.600	-0.133	0.005	-0.152	0.162
Child diarrhoeal illness	-0.038	-0.166	0.090	0.017	-0.069	0.103
Household food insecurity	0.063	-0.066	0.192	0.020	-0.067	0.106

Notes. Our units of analysis here are HAZ (Height-for-age Z-scores) measurements on 902 children and WHZ (Weight-for-height Z-scores) measurements on 897 children in the preceding season. Drinking water access (0=Protected vs. 1=Unprotected); PSNP=Productive Safety Net Programme (0=PSNP participant or beneficiary vs. PSNP non-participants or non-beneficiary); Interaction term: included households who neither had protected drinking water access nor PSNP participation. Child age and cohort-effect: We considered child age in months in the logarithmic scale (lnmonths) to account for the observed inconsistencies in child age data distributions. All model coefficients here are adjusted for the effect of child age changes during the study period (cohort-effect). P-value: ***P≤0.001, **P≤0.01, *P<0.05

Seasonality

As is shown in Figure 5, child wasting rates varied with seasonal household food insecurity, and child wasting rates increased with increasing durations of household food insecurity (χ^2_{trend}=5.9, P=0.015). Moreover, Table 5 shows the association between seasonal household food insecurity and child WHZ indices adjusted for baseline factors, child age changes during the study period, and time series of our repeated measurements. Accordingly, seasonal household food insecurity was independently associated with decreased WHZ.

Table 5 results of multivariable linear regression models for seasonality of child wasting, Wolaita, rural Ethiopia, 2017-18 (N=3,510)

	β	95% CI	
Child age in months	-0.150**	-0.263	-0.036
Child sex (ref=female)	-0.009	-0.083	0.065
Mother's age ,continuous	0.013	-0.019	0.045
Mother's education, continuous	0.021	-0.010	0.052
Father's education ,continuous	-0.021	-0.054	0.013
Household latrine (ref=yes)	0.050	-0.059	0.159
Family size ,continuous	-0.026	-0.082	0.030
Wealth index, continuous	0.020	-0.048	0.087
Work, non-farming income (ref=yes)	-0.033	-0.120	0.055
PSNP participation	-0.122**	-0.199	-0.044
Drinking water access	-0.349 ***	-0.431	-0.267
Child diarrhoeal illness (ref=yes)	0.006	-0.081	0.093
Household food insecurity (ref=yes)	0.077	-0.058	0.211
Seasonal household food insecurity (ref=main harvest season)			
Sowing season	0.003	-0.131	0.137
Post-harvest season	-0.170*	-0.302	-0.037
Dry pre-harvest season	-0.345***	-0.481	-0.209
Child age changes during the study period (cohort)	0.638*	0.066	1.211
Child diarrhoeal illness (time series)			
At first season	-0.020	-0.133	0.092
At second season	0.004	-0.104	0.112
At third season	-0.157	-0.279	-0.034
At fourth season	0.054	-0.053	0.161
Household food insecurity (time series)			
At first season	0.167	0.071	0.263

At second season	-0.143	-0.225	-0.061
At third season	0.192	0.052	0.333
At fourth season	-0.083	-0.246	0.079

P-value: ***P≤0.001,**P≤0.01, *P<0.05

Effect modification

Table 6 shows results of further analysis of the fitted WHZ model by the durations of household food insecurity. Accordingly, seasonal household food insecurity modified the effect of PSNP participation and protected drinking water access on increased WHZ estimates.

DISCUSSION

Key results

Our cohort study suggested seasonal variations in weight-for-height Z-score (WHZ) indices among children aged 6-59 months in rural southern Ethiopia, with dose-response relationships. . Household participation in the Ethiopian government's social safety net (PSNP) and having protected drinking water access were main factors associated with increased HAZ (Height-for-age Z-score) or WHZ. Lower level of maternal education, lack of non-farming household income, and absence of household latrine were associated with decreased HAZ indices.

Limitations and strengths

This study was based on random sample of households and our units of analysis were counts of total observations compiled from four repeated measurements undertaken for one year. However, our one sample estimation could be one of the limitations of this study, especially as some background factors (e.g., household wealth, PSNP participation, and drinking water access) clustered in the lowland areas. There could be subjectivity bias in our food insecurity measurements, especially as this study was conducted in a chronically food-insecure setting [33, 34]. We used 'Household Food Insecurity Access Scale' questionnaire which had been validated in the study area [6]. To ensure accuracy of the current study data, measurements were repeated, and we used the same data collectors for the repeated data rounds; yet, it was sometimes not possible to maintain the same data collectors. We did not initially estimate separate samples for our repeated measurements, but our analytical sample (i.e., counts of observations compiled from the repeated measurements) showed adequate statistical power. We analysed HAZ and WHZ indices as composite measures of child nutritional status as continuous variables using linear regression models which enhanced accuracy of our estimates [16]. Moreover, we accounted and adjusted our estimates for the observed clustering effects at the primary sampling stage (at kebele level). We accounted for seasonality through some time-varying exposures (household food insecurity and child diarrhoeal illness). However, we did not assess other illnesses such as malaria, measles, Tuberculosis etc. [35-38]. We considered some dummy variables to account for the time series random effects beyond the scope of our time-varying exposures.

Comparative discussions

Our prevalence estimates for stunting and wasting rates are consistent with recent estimates from the Ethiopian demographic and health surveys [39]. Our study suggested household socioeconomic conditions such as low level of maternal education; lack of non-farming income; and absence of PSNP participation were associated with HAZ or WHZ indices (Table 4) which complements previous reports [27, 40-42]. The country's persistently low socio-economic status is often described as main cause for child undernutrition in Ethiopia [27, 40-42].

Our study suggested household PSNP participation could improve HAZ and WHZ (Table 4) complementing some previous studies [43, 44], but there also are other contradicting reports [45-47]. These inconsistencies could be due to variations in the study designs, participants, and data approaches. Nonetheless, a growing pool of literature suggests that PSNP improves household food security and consumptions.

Our study suggested lack of clean water access and household latrine as independent predictors for child undernutrition (Table 4) which aligns with previous reports [48, 49]. Lack of clean water access and sanitation could pre-dispose to recurrent infections such as diarrhoea and intestinal parasites [50, 51]. Improving clean water, sanitation, and hygiene are often described as priority interventions to reduce child undernutrition [52].

Our study suggested seasonal household food insecurity as an independent predictor of decreased WHZ (Table 5) complementing previous reports [53, 54]. This could be due to seasonal fluctuations in household food consumption patterns [7, 55] and some scholars describe seasonality as a grossly neglected dimension of poverty [7, 13, 56].

Meanings and possible explanations

Seasonal household food insecurity could contribute to decreased WHZ indices in rural Ethiopia, suggesting that this population is vulnerable to food insecurity [13]. Strengthening the

PSNP intervention through effective targeting of the neediest households might further enhance its impacts on child undernutrition. Yet, the criteria for household PSNP eligibility remain controversial [57]; for example, if geographic criteria prioritise the lowland areas [9], then poorer households in the midland villages (as in our study setting) could be neglected. Improving clean water access and sanitation have widely been described as nutrition-sensitive interventions [58, 59]. In our study area context, expanding the coverage of protected drinking water access in the midland villages might contribute to reducing child undernutrition. Moreover, addressing seasonal variations in household food insecurity could help prevent child undernutrition [13].

FIGURE LEGENDS

Figure 1: Conceptual framework for possible chain of relationships between seasonal food insecurity and child undernutrition, Wolaita, Ethiopia, 2017-18

Figure 2: Flow chart of child anthropometric measurements considered for this cohort study, Wolaita, rural Ethiopia, 2017-18

Figure 3: Household dietary diversity score (HDDS) by duration of household food insecurity for households who participated in Productive Safety Net Programme (PSNP) and households that did not participate in this program, Wolaita, rural Ethiopia, 2017-18

Figure 4: Mean weight-for-height Z-score indices of children aged 6-59 months by household participation in 'Productive Safety Net Programme (PSNP) and protected drinking water access, Wolaita, rural Ethiopia, 2017-18

Figure 5: Seasonal variations in child wasting rates among overall measurements and measurements within food-insecure households, Wolaita, rural Ethiopia, 2017-18

DECLARATIONS

Ethics approval and consent to participate

The institutional review committee at Hawassa University in Ethiopia (IRB/002/09) and the Regional Committee for Medical and Research Ethics in Western Norway (2016/482/REK vest) approved the study protocol. Written consent was obtained from the respondents and assent for their children's weight and height measures. Responses were anonymised using unique identification numbers.

Consent for publication

Not applicable

Availability of data and material

All data relevant to the study are included in the article or uploaded as supplementary information.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

BYK conceived the research idea, designed the study protocol, implemented the study, made major statistical analyses, and wrote the draft and final versions of the scientific report. BL conceived the research idea, made substantial contributions to the design, field methods, major statistical analyses, and writing. Both authors read and approved this manuscript for submission.

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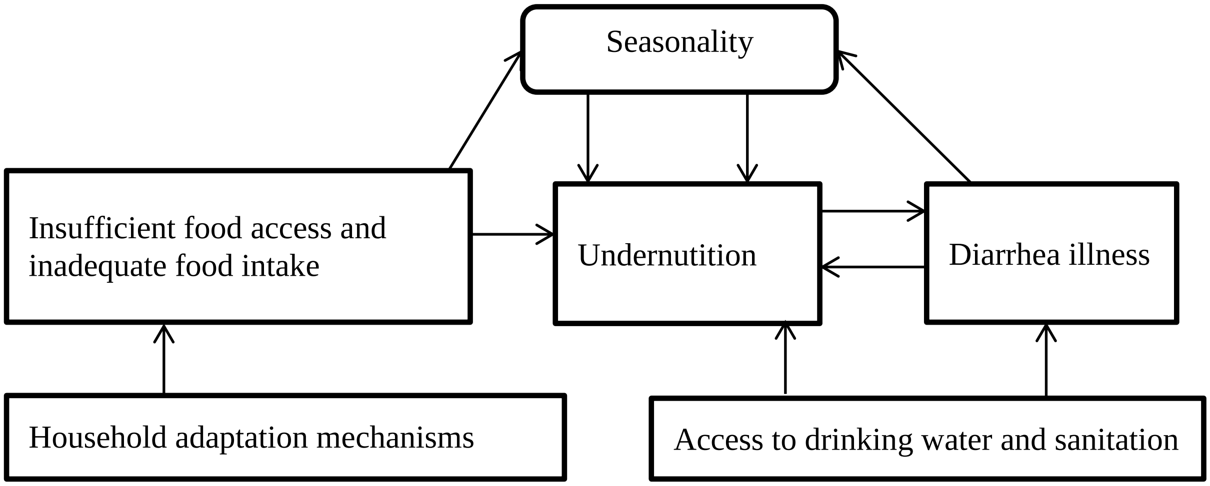

Figure 1 Conceptual framework for possible chain of relationships between seasonal food insecurity and risk for child undernutrition, Wolaita, Ethiopia, 2017-18

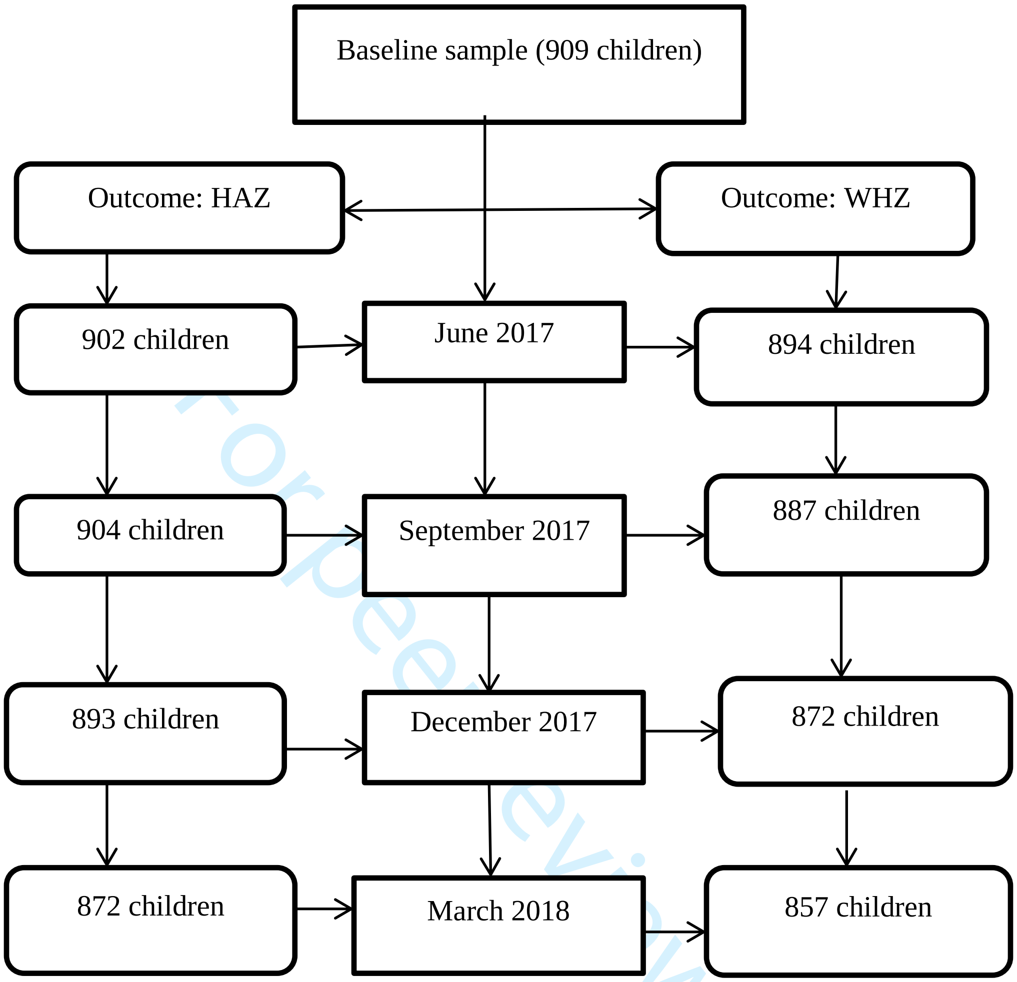

Figure 2 Height-for-age Z-scores (HAZ) and Weight-for-height Z-scores (WHZ) of children aged 6-59 months considered for this cohort study, Wolaita, rural Ethiopia, 2017-18

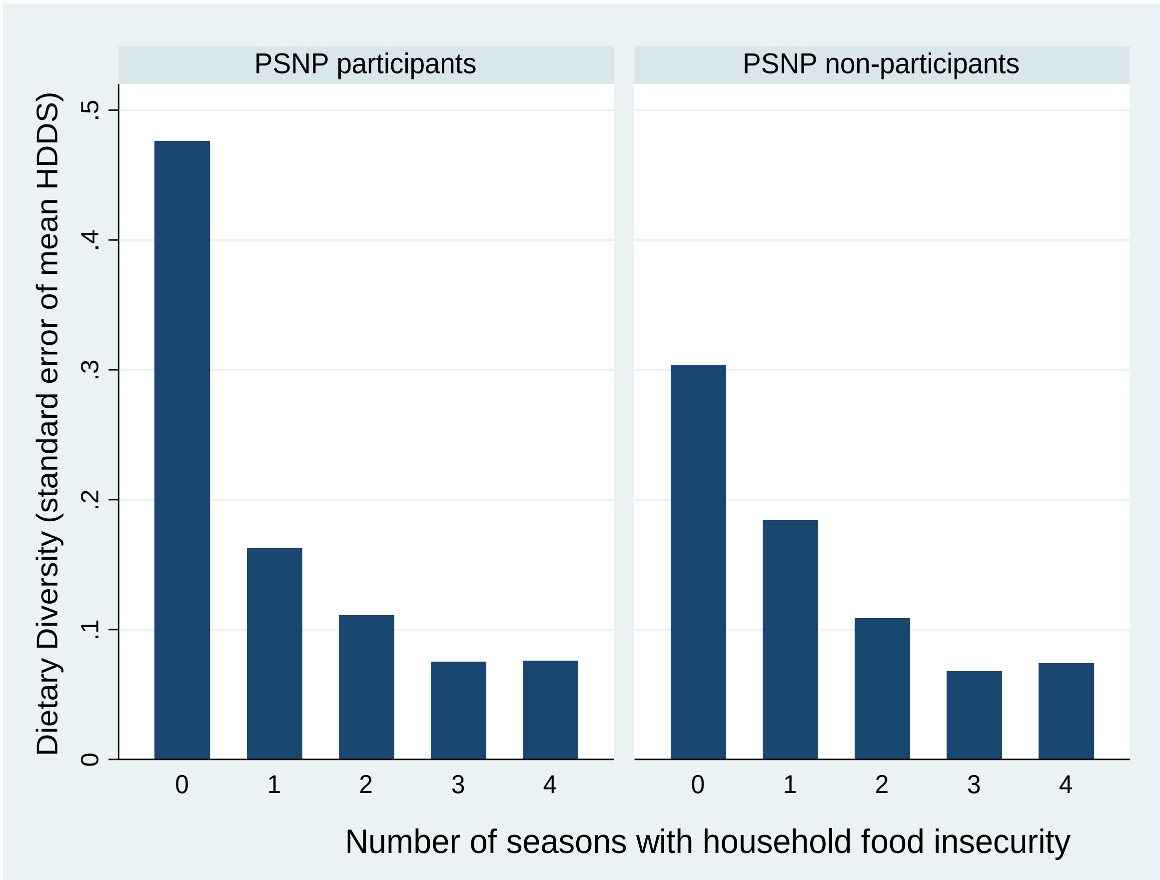

Figure 3 household dietary diversity score (HDDS) by duration of household food insecurity for households who participated in Productive Safety Net Programme (PSNP) and households that did not participate in this program, Wolaita, rural Ethiopia, 2017-18

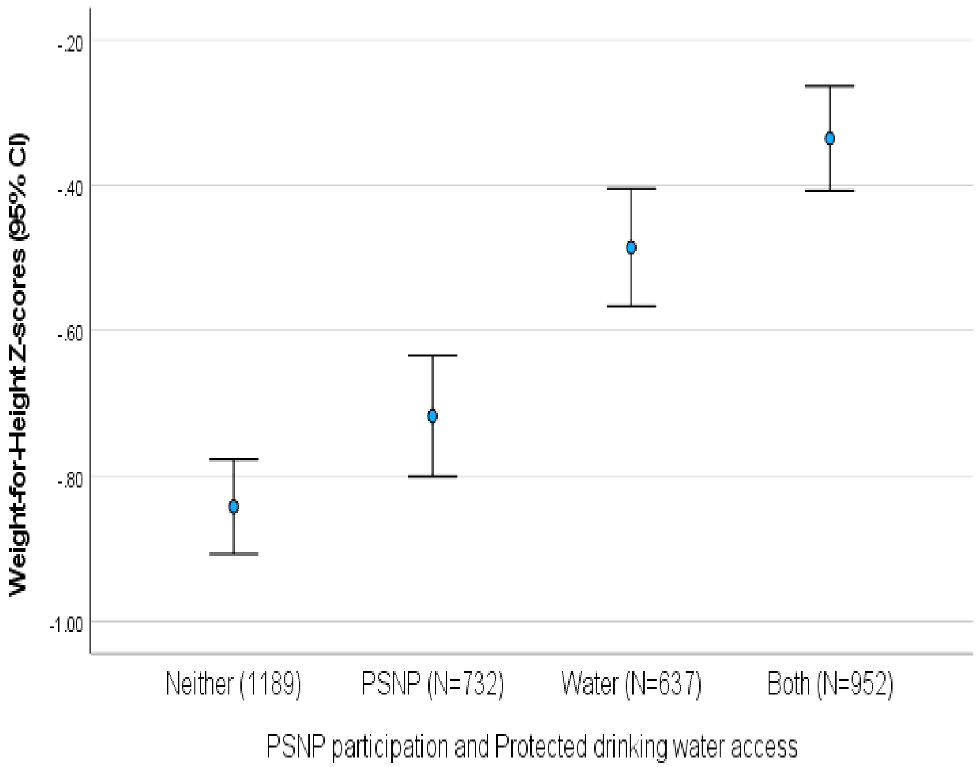

Figure 4 Weight-for-height Z-scores of children aged 6-59 months by household participation in 'Productive Safety Net Programme (PSNP)' and protected water access, Wolaita, rural Ethiopia, 2017-18

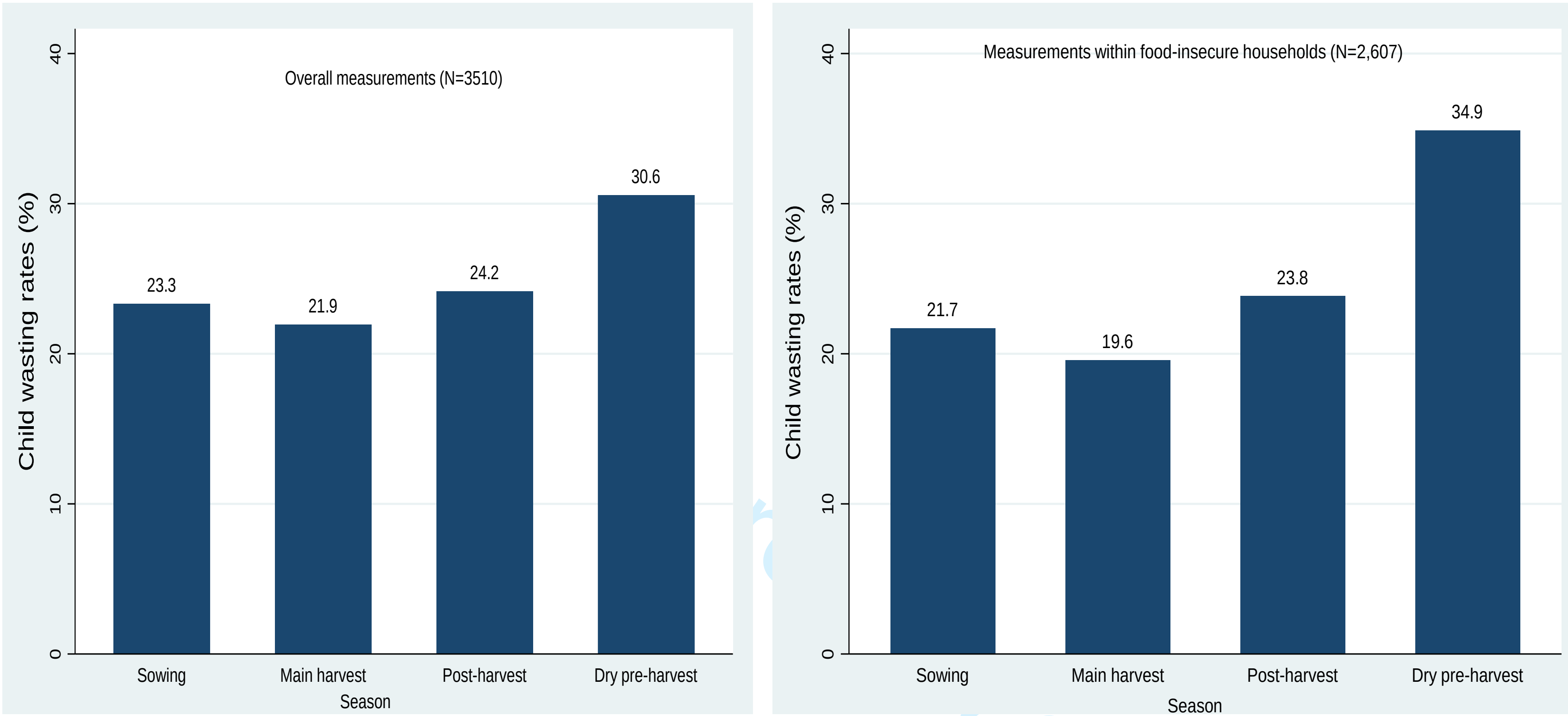

Figure 5 seasonal variations in child wasting rates among overall measurements and measurements within food-insecure households, Wolaita, rural Ethiopia, 2017-18

Table 6 variations in the effects of household PSNP participation and protected drinking water access on weight-for-height Z-scores of children aged 6-59 months by durations of household food insecurity, Wolaita, rural Ethiopia, 2017-18

	Duration of household food insecurity					
	1or 2 seasons			3 or 4 seasons		
	β	95% CI		β	95% CI	
Child age (lnmonths), continuous	1.279	-0.039	2.598	1.417	0.596	2.238
Child age changes (cmonths), continuous	-0.266	-0.461	-0.070	-0.242	-0.361	-0.124
Child sex (ref=female)	-0.141	-0.277	-0.004	0.031	-0.056	0.119
Mother's age ,continuous	-0.046	-0.097	0.005	-0.034	-0.065	-0.004
Mother's education, continuous	-0.141	-0.198	-0.083	0.068	0.032	0.105
Father's education ,continuous	0.156	0.092	0.220	-0.080	-0.120	-0.041
Household latrine (ref=yes)	-0.382	-0.592	-0.171	0.178	0.049	0.307
Family size ,continuous	-0.004	-0.112	0.105	0.004	-0.062	0.070
Wealth index, continuous	-0.099	-0.227	0.030	0.061	-0.018	0.141
Work, non-farming income	-0.273	-0.438	-0.108	0.038	-0.065	0.142
PSNP participation and protected drinking water access (cat) (ref=both)						
Neither (1)	-0.679	-0.867	-0.491	-0.395	-0.518	-0.273
PSNP (2)	-0.350	-0.556	-0.143	-0.296	-0.430	-0.162
Water (3)	-0.421	-0.616	-0.225	-0.058	-0.194	0.079
Both (4)						
Child diarrhoeal illness (ref=no)	0.015	-0.144	0.173	0.008	-0.094	0.110
Child diarrhoeal illness (1st season)	-0.066	-0.275	0.142	0.088	-0.046	0.222
Child diarrhoeal illness (2nd season)	0.077	-0.126	0.280	0.000	-0.127	0.127
Child diarrhoeal illness (3rd season)	-0.010	-0.232	0.211	-0.150	-0.296	-0.003
Child diarrhoeal illness (4th season)	-0.088	-0.286	0.110	0.143	0.016	0.270

Notes. PSNP= Productive Safety Net Programme. PSNP participation and protected drinking water access (cat) is a categorical variable generated from two dichotomous variables (PSNP participation and protected drinking water access): 1=included households who neither had protected drinking water access nor participated in PSNP; 2= households who participated in PSNP but did not have protected drinking water access; 3= households who had protected drinking water access but that did not participate in PSNP but did not have protected drinking water access; 4= households who had both protected drinking water access and PSNP participation. Decreased (β) coefficients refer to increased child wasting and vice-versa. Child age changes (cmonths) =child age in months divided by child age in the logarithmic scale; cmonths was used to account and adjust for child age changes during the study period.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*7-9*
Bias	9	Describe any efforts to address potential sources of bias	6-10
Study size	10	Explain how the study size was arrived at	6, 9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9-10
		(*b*) Describe any methods used to examine subgroups and interactions	10
		(*c*) Explain how missing data were addressed	9
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	No loss to follow-up
		(*e*) Describe any sensitivity analyses	

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	None
		(c) Consider use of a flow diagram	8-9
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11-12
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	*12*
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	13-16
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	15-16
Discussion			
Key results	18	Summarise key results with reference to study objectives	16
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	17
Generalisability	21	Discuss the generalisability (external validity) of the study results	18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	19

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Seasonality and predictors of childhood stunting and wasting in drought-prone areas in Ethiopia: A cohort study

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Seasonality and predictors of childhood stunting and wasting in drought-prone areas in Ethiopia: A cohort study

Authors:

Bereket Yohannes Kabalo (BYK) [1, 2] and Bernt Lindtjørn (BL) [1, 2]

Authors' addresses:

Bereket Yohannes Kabalo: bkabalo@gmail.com

Bernt Lindtjørn: bernt.lindtjorn@uib.no

Authors' affiliations:

[1]School of Public Health, Hawassa University, Hawassa, Ethiopia

[2]Centre for International Health, University of Bergen, Bergen, Norway

* **Corresponding author**:

Bereket Yohannes Kabalo

bkabalo@gmail.com

ABSTRACT

Background and objectives: Over centuries, Ethiopia has experienced severe famines and periods of serious drought, and malnutrition remains a major public health problem. The aims of this study were to estimate seasonal variations in child stunting and wasting, and identify factors associated with both forms of child malnutrition in drought-prone areas.
Methods: This cohort study was conducted among a random sample of 909 children in rural southern Ethiopia. The same children were followed for one year (2017 - 2018) with quarterly repeated measurements of their outcomes: height-for-age and weight-for-height indices (Z-scores). Linear regression models were used to analyse the association between both outcomes and baseline factors (e.g., household participation in a social safety net program) and water access) and some time-varying factors (e.g., household food insecurity).
Results: Child wasting rates varied with seasonal household food insecurity ($\chi^2_{trend} = 15.9$, $p = 0.001$), but stunting rates did not. Household participation in a social safety net program was associated with decreased stunting ($p = 0.001$) and wasting ($p = 0.002$). In addition to its association with decreased wasting ($p = 0.001$), protected drinking water access enhanced the association between household participation in a social safety net program and decreased stunting ($p = 0.009$). Absence of a household latrine ($p = 0.011$), lower maternal education level ($p = 0.001$), larger family size ($p = 0.004$), and lack of non-farming income ($p = 0.002$) were associated with increased child stunting.
Conclusions: Seasonal household food insecurity was associated with child undernutrition in rural Ethiopia. Strengthening community-based food security programs, such as the Ethiopian social safety net program, could help to reduce child undernutrition in drought-prone areas. Improving clean water access and sanitation could also decrease child undernutrition.

Key terms: Z-scores; Social safety net program; Water access

Limitations and strengths of this study

- This study accounted for agro-ecological strata and random selection of households; however, we did not initially estimate separate samples for the different strata (e.g., by household participation in social safety net program).
- Seasonality was accounted for in our repeated measurements using some time-varying exposure variables (e.g., household food insecurity and child diarrhoeal illness); however, we did not assess other illnesses, such as malaria, measles, tuberculosis, etc.
- We did not initially estimate separate samples for our repeated measurements, but our analytical sample (i.e., counts of observations compiled from the repeated measurements) showed adequate statistical power of estimation to meet the primary aims of the study.
- This study analysed height-for-age Z-score and weight-for-height Z-score indices as continuous measures using linear regression models; our estimates were adjusted for the observed clustering effects at the primary sampling stage (at the kebele level) and time series effects of our repeated measurements.
- As our data were analysed in a cohort design, a certain underestimated time element may exist in our repeated measurements beyond the scope of our time-varying exposures.

INTRODUCTION

Over the centuries, Ethiopia has experienced droughts and famine events, averaging once per decade [1 2]. The Intergovernmental Panel on Climate Change (IPCC) also predicts that climate change will lead to more desertification and crop failures in vulnerable areas, such as Ethiopia [3-5] where malnutrition remains one of the major public health problems [6-9].

In communities that rely on subsistence agriculture, food insecurity often peaks seasonally in pre-harvest periods [10 11]. Affected households adapt by: reducing the frequency and size of daily meals; selling livestock or dairy products; borrowing food or money from merchants or local social networks; selling wood, charcoal, or grass; engaging in paid labour; and renting out farm land [12]. However, such coping mechanisms are often insufficient, leading to a vicious cycle of poverty and food insecurity.

Following many years of food provision for famine-prone populations, the Ethiopian government launched the Productive Safety Net Program (PSNP) in 2005 [13]. PSNP's stated aims are to prevent household asset depletion and strengthen communities [13]. This program provides cash or food payments in exchange for labour to produce public works, local infrastructure, and environmental projects, or direct payments for households that are unable to provide labour [14].

Researchers use several methods to assess the impact of food scarcity on populations. One common outcome is the level of household food insecurity and occurrence of malnutrition among vulnerable populations (e.g.., young children), and both these outcomes are subjected to the impacts of climate change [15 16]. Recent literature has emphasised the importance of understanding seasonal variations in nutrition status among young children as an indicator of vulnerability to food insecurity [17]. Population's vulnerability in this context could be described as the level of susceptibility to food insecurity challenges due to lack of capacity to cope and adapt to those challenges [18].

Since the 1970s, undernutrition has been classified in two major ways: wasting (i.e., low weight-for-height or small mid-upper arm circumference) and stunting (i.e., low height-for-age) [19]. However, this categorical classification neglects many children with borderline measurements who are undernourished [20]. Height-for-age and weight-for-height indices (Z-scores) as continuous outcome measures could reflect shared factors and pathophysiological processes that should be viewed as composite measures of undernutrition [21].

Wolaita, a densely populated area in southern Ethiopia, has experienced severe droughts and famines [2 10]. As such, the population's experiences and coping mechanisms related to severe food insecurity are relevant for other famine-prone areas in the country and across Africa. The aims of this study were to estimate seasonal variations in child stunting and wasting, and identify factors associated with both these forms of child malnutrition in drought-prone areas.

METHODS

Study design and setting

We conducted a prospective cohort study using a random sample of 909 households in the rural Wolaita area in southern Ethiopia. We recruited one child per household at the start of the study (in June 2017), and followed the same children by measuring their outcomes, i.e., height-for-age and weight-for-height indices, every three months for one year (June 2017 to June 2018). Our exposure variables included background factors (measured at baseline) and some time-varying factors (measured each season). Quarterly repeated measurements were performed in the first month of each season (i.e., June, September, December, and March) [10].

Wolaita is located between the Great Rift Valley and the Omo Valley in southern Ethiopia. Rural villages in this area mainly represent two agro-ecological areas: the hot and semi-dry 'lowlands' and the relatively cooler and sub-humid 'midlands' [3 22]. Mean annual rainfall ranges from 800 mm in the lowlands to 1,200 mm in the midlands, with a bimodal distribution [10]. Farming of staple crops, such as maize, occurs during the *Belg* rains from approximately March to early May [10 23]. Root crops, such as taro and sweet potato, are farmed in both seasons and help to bridge seasonal gaps in food security [3 10].

Outcomes

The main outcome measures were height-for-age and weight-for-height indices (Z-scores), measured each season for one year and defined based on the World Health Organization (WHO) 2006 child growth standards [24]. Stunting and wasting were defined as HAZ (height-for-age Z-scores) and WHZ (weight-for-height Z-scores) of -2 standard deviations below the respective WHO standard median.

Exposures

Our exposure variables included background factors (baseline data) and some time-varying factors (measured each season). Baseline factors comprised the following: (1) child age and sex; (2) parent age and education; (3) household socio-economic conditions, such as family size, source of income, wealth index, and participation in the food security program (PSNP); (4) household latrine ownership; and (5) drinking water access. We considered household food insecurity, dietary diversity, and child diarrhoeal illness as time-varying exposures, for which we carried out repeated measurements.

Repeated measurements

Our repeated measurements were performed during the four seasons based on agricultural cycles: *Kiremt* is the sowing season in June, July, and August; *Belg* is the main harvest season in September, October, and November; *Bega* is the post-harvest season in December, January, and February; and *Tsedey* is the dry pre-harvest season in March, April, and May [10]. These quarterly repeated measurements were carried out at the same time for outcomes and time-varying exposures.

Participants

A multistage random selection of households was conducted. First, we selected two rural districts, or Woredas, representing the two agro-ecological strata in Wolaita: the Humbo district in the lowlands and Soddo Zuria district in the midland area, with the assumption that household food insecurity would be more prevalent in the lowland areas [25 26]. Population density was higher in the midland villages than in the lowland villages in the study area. As such, we selected three kebeles (the smallest administrative unit) from the lowland district and two kebeles from the midland district using the complex samples selection feature in SPSS version 25.0 (IBM). Finally, we selected households with children under five years-old and enrolled one child aged 6 - 59 months per household.

To estimate the sample size, we followed an earlier cohort study assessing seasonal variations in wasting prevalence [27]. The estimated sample size to estimate differences in prevalence rates of wasting 6.6% and 13%, with a 95% level of confidence and 80% power, was 820 children (OpenEpi software). Our study included 909 children.

Patient and public involvement

No subject involvement.

Outcome measurements

Height and weight measurements were performed each season. We trained four data collectors on standard techniques for height and weight measurements. After the training, we validated the consistency of their measurements by recruiting 10 children aged below 5 years from another rural village and having all four data collectors (observers) measure each child's height twice. The overall measurements showed approximately 92% average internal consistency. These four observers recorded height and weight measurements for the actual study. Height (or recumbent length for children younger than 24 months) was measured to the nearest 0.1 cm using a local wooden length board. Weight was measured to the nearest 0.1 kg using a Seca weight scale (*Seca* GmbH & Co. Kg, Hamburg, Germany).

Exposure measurements

Time-invariant factors (baseline)

Children's age in months, mothers' age in years, and highest grade of school completed by both parents were recorded. We also recorded family size (number of household members), source of income (exclusively farming vs. generates other additional income), possession of common household assets, and participation in the food security program (data collectors observed PSNP beneficiary cards during household visits). In addition, we recorded household latrine ownership (yes vs. no) and drinking water access (protected vs. unprotected), and only water piped via public tap was as a protected source [28]. We used principal component analysis to construct a wealth index based on common household assets: (1) housing material of the roof, interior ceilings, floors, and walls; (2) number of livestock owned by the household; (3) land size in hectares; and (4) possession of common assets, such as a radio, mobile telephone, bed and mattress, kerosene lamp, watch, electric or solar panels, chairs and tables, wooden boxes, and donkey carts [10 29].

Time-varying factors (measured each season)

The time-varying variable, i.e., household food insecurity (HFI), was measured using nine questions in the Household Food Insecurity Access Scale, which has been validated in the study area [10]. Household dietary diversity was scored using 24-hour recall measurements. Household members were asked about the 12 common food groups in Ethiopia: (1) cereals and breads; (2) potatoes and other roots or tubers; (3) vegetables; (4) fruits; (5) eggs; (6) dairy products; (7) pulses; (8) fish; (9) meat; (10) oil, fat, or butter; (11) sugar or honey; and (12) other foods or condiments (e.g., coffee, tea, other spices, etc.). The responses for the 12 food-groups were used to generate a scale of food intake diversity, i.e., the household dietary diversity score (HDDS) [30]. The occurrence of childhood diarrhoeal illness was also assessed, which was defined as the passage of three or more loose or watery stools in the preceding 24-hours [31 32], and was assessed during the two weeks prior to the survey dates [33].

We generated two categorical variables from the actual HFI observations in our dataset and the time series of our repeated measurements. Quantified as person-time observations, an ordinal HFI measure (i.e., number of seasons with HFI) was generated as an exposure variable to explore dose-response relationships (e.g., between child wasting and HFI). Quantified also as person-time observations, we generated a multinomial HFI measure summarising incidence rates of HFI by the four seasons (0 = food-secure; 1 = HFI in the sowing season; 2 = HFI in the main harvest season; 3 = HFI in the post-harvest season; and 4 = HFI in the dry pre-harvest season) as an exposure variable in our main analysis (i.e., multivariable models). As household food security and dietary diversity are highly correlated entities, we accounted for HDDS as the null category for HFI multinomial measure (i.e., 0 = food-secure) as an exposure variable in our main analysis. Moreover, child diarrhoeal illness was considered as a covariate for the effect of the other time-varying exposures (e.g., seasonal HFI).

Conceptual framework

Based on a systematic review paper, Phalkey and colleagues suggested complex pathways from climate variability to undernutrition in subsistence communities [34]. Our current work used their work, but we adapted it to the scope of our study, and we focused on human nutrition (Figure 1).

Data and measurements

Data entry and cleaning

Data were double-entered in EpiData software version 3.1 (EpiData Association 2000 - 2021, Aarhus, Denmark) and corrected for entry errors. First, we entered our baseline data by unique identification numbers for the subjects (ID). We then entered repeated measurements by the subject ID and recorded each round of measurement with different variable names for each variable. After cleaning our data in the short format (by ID), we reshaped the dataset into long format for statistical analysis, with which a new variable (season) was generated to specify the discrete time series of our repeated measurements. We generated nutritional indices (HAZ and WHZ) from anthropometric data using ENA and WHO Anthro software 3.2.2 (WHO, Geneva, Switzerland).

Units of analysis

As we measured each child in each of the four seasons, we compiled counts of observations totalling 3636 HAZ and WHZ measurements at the end of the study period. However, we excluded 46 HAZ and 126 WHZ observations that had incomplete data or that were severe outliers [35]. Accordingly, our units of analysis were counts of measurements totalling 3571 HAZ estimates and 3510 WHZ estimates (Figure 2). We analysed complete WHZ data (n = 3510) of 897 children and complete HAZ data (n = 3571) of 907 children.

Time-varying data considerations

As we measured the same children in each season, age changes during the study period could lead to certain deviations in outcome estimates (i.e., cohort effects). As such, we generated a separate variable (age in months divided by age in the logarithmic scale) to account for cohort effects. Time-varying effects could also be due to external factors (e.g., seasonality). Accordingly, we considered HFI as a multinomial variable to estimate the seasonally variable effect of household food insecurity on child undernutrition. Furthermore, we accounted for the time series of our repeated measurements using some dummy variables as measurement components of time-varying exposures.

Statistical methods

We used Stata version 15 (Stata Corp LLC, College Station, TX, U.S.A.) for our statistical works. To explore our data distributions (bivariate analysis), we used parametric tests, such as t-tests to compare two means, ANOVA tests to compare more than two means, and correlation tests to assess the associations between two continuous variables. We analysed our normally distributed data for both outcomes with background factors (baseline data) and some time-varying factors (repeated measurements) using hierarchical linear regression models. Our data comprised two categories: (1) clustering effects at the primary sampling stage (at the kebele level) or (2) time-varying effects within our repeated measurements.

Multivariable analysis

We first estimated between-variations as main effects of baseline factors on our outcome measures, and then analysed within-variations as main effects to explore time-varying exposure effects on outcome estimates (additional details are provided under separate subheadings hereafter).

Between-variation models

HAZ data were analysed using a multivariable linear regression model with adjustment for the clustering effect of stunting at the primary sampling stage, but we ignored observed insignificant clustering when analysing the WHZ data [36 37]. HAZ and WHZ estimates in the preceding season were considered to control for cohort effects when analysing baseline factors associated with stunting and wasting.

Within-variation models

At this stage, we aimed to estimate the time-varying exposure effects on outcome estimates, and further analysed the fit between-variation models to account for an exposure-season interaction effect (e.g., household food insecurity by the four seasons as a multinomial exposure variable) to estimate seasonally variable effects of relevant exposure variables on outcome estimates. Time-varying exposure effects were estimated as main effects with adjustment for other time-varying effects (i.e., cohort and time series effects) and main effects of all baseline factors included in the fitted models for between-variations.

Further analysis

We further analysed the fitted models for both outcomes to explore interactions, e.g., additive, or multiplicative effects (e.g., PSNP participation and protected drinking water access on our outcome estimates) or effect modification (e.g., variations in the effect of PSNP participation on child wasting across household food insecurity levels).

<u>Model reports and meanings</u>

We reported main effects for between- and within-variations using standardized model coefficients (β) with 95% CIs. Decreased model coefficients refer to increased stunting (HAZ) and wasting (WHZ).

RESULTS

Participants

Table 1 presents the baseline characteristics of the 907 study participants with complete HAZ data.

Table 1. Baseline characteristics of the study participants in rural Wolaita, Ethiopia, 2017 - 2018 (n = 907).

Variable	**# (%)***
Child's sex	
Male	462 (50.9)
Female	445 (49.1)
Child's age in months, mean (SD)	33.4 (11.7)
Mother's age in years, mean (SD)	29.3 (3.3)
Mother's education (grade completed)	
0-4	325 (32.8)
5–8	285 (31.4)
9–12 or higher education	297 (32.7)
Father's education (grade completed)	
0-4	452 (49.8)
5-8	277 (30.5)
9–12 or higher education	178 (19.6)
Household family size, median (interquartile range)	6 (4-7)
Household work, any non-farming income?	
Yes (additional income)	237 (26.1)
No (exclusively farming)	670 (73.9)
Household owns a latrine	
Yes	784 (86.4)
No	123 (13.6)
Household has protected drinking water access	
Yes	406 (44.8)
No	501 (55.2)
Household PSNP participation	
Yes	434 (47.9)
No	473 (52.1)
Household PSNP participation and protected drinking water access (cat)	
Neither PSNP participation nor protected water access	307 (33.9)
PSNP participation (alone)	191 (21.1)
Protected water access (alone)	165 (18.2)
Both PSNP participation and protected water access	244 (26.9)

* Unless otherwise indicated. Participates in the Productive Safety Net Program (PSNP). Household PSNP participation and protected drinking water access [(cat)] is a categorical variable generated from two dichotomous variables (PSNP participation and protected drinking water access): 1 = households who neither had protected drinking water access nor participated in PSNP; 2 = households who participated in PSNP, but did not have protected drinking water access; 3 = households who had protected drinking water access, but did not participate in PSNP; 4 = households who had protected drinking water access and also participated in PSNP.

Summary results from repeated measurements

Table 2 summarizes prevalence rates of household food insecurity, childhood diarrhoeal illness, and stunting and wasting. The overall prevalence of child stunting was 32.1% (1,145 of 3,571 measurements) and that of wasting was 10.3% (360 of 3,510 measurements). Child wasting rates varied across seasons (χ^2_{trend} = 20.5, p = 0.001), but stunting rates did not exhibit any seasonal variations.

Household food insecurity

The overall prevalence of HFI was 74.2% (95% CI 72.8-75.6) during the study period (2,651 of 3,571 measurements), and HFI varied across seasons (χ^2_{trend} = 29.2, p = 0.001). Quantified as person-time observations, the risk of experiencing HFI in just one season was 7.5%, compared to 17.0% in two seasons, 39.0% in three seasons, and 34.8% throughout all four seasons. The median HDDS was 3 (out of the 12 food groups, interquartile range of 3–4), but the overall HDDS did not show seasonal variations. As shown in Figure 3, dietary diversity decreased with increasing durations of household food insecurity (Z = -7.3, p = 0.001).

Child diarrhoeal illness

The overall prevalence of child diarrhoeal illness was 26% (95% CI 24.6-27.5; 930 of 3,571 measurements), and the occurrence of child diarrhoeal illness varied across seasons (χ^2_{trend} = 12.0, p = 0.001), with a peak in the rainy (sowing) season.

Table 2. Prevalence rates of household food insecurity, child diarrhoeal illness, and undernutrition (stunting and wasting) rates (Wolaita, rural Ethiopia, 2017 - 2018).

		Prevalence		
Variable	**Season**	**%**	**95% CI**	
Household food insecurity	Sowing season (n = 902)	77.2	71.6	83.2
	Main harvest season (n = 904)	60.2	55.3	65.5
	Post-harvest season (n = 893)	76.0	70.5	82.0
	Dry pre-harvest season (n = 872)	84.0	78.1	90.4
Child diarrhoeal illness	Sowing season (n = 902)	30.9	27.4	34.7
	Main harvest season (n = 904)	26.5	23.3	30.1
	Post-harvest season (n = 893)	22.6	19.6	26.0
	Dry pre-harvest season (n = 872)	24.0	21.0	27.6
Child stunting	Sowing season (n = 902)	32.2	28.7	36.2
	Main harvest season (n = 904)	32.2	28.7	36.2

	Post-harvest season (n = 893)	31.1	27.6	35.0
	Dry pre-harvest season (n = 872)	33.6	29.9	37.7
Child wasting	Sowing season (n = 894)	9.4	7.6	11.6
	Main harvest season (n = 887)	8.9	7.1	11.1
	Post-harvest season (n = 872)	10.0	8.1	12.3
	Dry pre-harvest season (n = 857)	12.8	10.6	15.5

Outcome data distributions

Table 3 shows HAZ and WHZ data distributions by background characteristics (baseline data). Boys had lower HAZ indices than girls (t = -4.2, p = 0.001). HAZ indices increased (t = 11.6, p = 0.001), but WHZ decreased (t = -9.4, p = 0.001), with increasing maternal age. Both HAZ and WHZ increased with increasing maternal education level: HAZ (t = 3.8, p = 0.001) and WHZ (t = 2.0, p = 0.039). Children who lived in exclusively farming households had lower HAZ indices than those who lived in households with additional income (t = -2.9, p = 0.004), and WHZ decreased with decreasing household wealth (t = 3.2, p = 0.002).

Table 3. Distributions of height-for-age Z-score (n = 907 children) and weight-for-height Z-score (n = 897 children) indices by baseline factors (rural Wolaita, Ethiopia, 2017 - 2018).

		HAZ (n = 3,571)			**WHZ (n = 3,510)**		
Variable	**Categories**	**Mean**	**95% CI**		**Mean**	**95% CI**	
Child's sex	Female	-1.057	-1.137	-0.976	-0.638	-0.690	-0.586
	Male	-1.308	-1.385	-1.230	-0.600	-0.654	-0.545
Mother's age in years	15–24	-1.667	-1.761	-1.573	-0.434	-0.503	-0.364
	25–34	-1.191	-1.285	-1.097	-0.529	-0.589	-0.469
	>35	-0.688	-0.784	-0.593	-0.902	-0.964	-0.839
Mother's education	0-4	-1.308	-1.443	-1.173	-0.599	-0.681	-0.516
	5–8	-1.220	-1.319	-1.121	-0.669	-0.737	-0.601
	9–12 or higher	-1.161	-1.257	-1.065	-0.623	-0.690	-0.555
Father's education	0-4	-1.308	-1.443	-1.173	-0.599	-0.681	-0.516
	5–8	-1.144	-1.247	-1.042	-0.686	-0.753	-0.619
	9–12 or higher	-1.200	-1.298	-1.101	-0.592	-0.665	-0.519
Household has a latrine	Yes	-1.172	-1.232	-1.112	-0.620	-0.661	-0.579
	No	-1.269	-1.427	-1.111	-0.608	-0.702	-0.514
Non-farm-related work	Yes	-1.060	-1.171	-0.950	-0.680	-0.752	-0.608
	No	-1.228	-1.293	-1.164	-0.597	-0.641	-0.553
Household wealth status	Poorest	-1.203	-1.331	-1.074	-0.649	-0.726	-0.572
	Poor	-1.101	-1.223	-0.978	-0.774	-0.861	-0.686
	Medium	-1.308	-1.436	-1.181	-0.601	-0.690	-0.513
	Rich	-1.123	-1.248	-0.997	-0.501	-0.584	-0.418
	Richest	-1.190	-1.312	-1.068	-0.565	-0.647	-0.483
Household size	≤4	-1.064	-1.172	-0.956	-0.563	-0.633	-0.493
	5-7	-1.238	-1.313	-1.163	-0.667	-0.720	-0.614
	>8	-1.217	-1.349	-1.085	-0.571	-0.651	-0.490
Protected drinking water	Yes	-1.204	-1.287	-1.121	-0.395	-0.449	-0.341

access	No	-1.169	-1.245	-1.093	-0.803	-0.854	-0.752
PSNP participation	Yes	-1.051	-1.133	-0.969	-0.505	-0.560	-0.450
	No	-1.307	-1.383	-1.231	-0.723	-0.774	-0.671
PSNP participation and protected drinking water access (cat)	Neither (1)	-1.369	-1.468	-1.270	-0.842	-0.907	-0.777
	PSNP (2)	-0.893	-1.016	-0.771	-0.717	-0.801	-0.634
	Water (3)	-1.250	-1.371	-1.130	-0.486	-0.566	-0.405
	Both (4)	-1.218	-1.335	-1.102	-0.336	-0.408	-0.264

Notes. PSNP = Productive Safety Net Program. PSNP participation and protected drinking water access (cat) is a categorical variable generated from two dichotomous variables (PSNP participation and protected drinking water access): 1 = households who neither had protected drinking water access nor participated in PSNP; 2 = households who participated in PSNP, but did not have protected drinking water access; 3 = households who had protected drinking water access, but did not participate in PSNP; 4 = households who had protected drinking water access and also participated in PSNP.

HAZ and WHZ by PSNP and drinking water access

As shown in Table 3, both HAZ and WHZ indices were higher among children whose households participated in PSNP than those whose households did not participate in PSNP: mean HAZ difference = 0.251 (95% CI 0.136, 0.365) and mean WHZ difference = 0.216 (95% CI 0.141, 0.291). Moreover, children whose households had protected drinking water access had higher WHZ indices than those whose households had no protected drinking water access: mean difference = 0.399 (95% CI 0.324, 0.474). HAZ did not vary by drinking water access.

Protected drinking water access had a confounding effect on the observed association between PSNP participation and increased WHZ: mean difference = 0.136; (95% CI 0.060, 0.212). Figure 4 shows WHZ data distributions by categories for a multinomial variable that disentangles PSNP participation and protected drinking water access.

Baseline factors associated with child nutritional status

Table 4 presents results of multivariable regression models for factors independently associated with HAZ and WHZ. PSNP participation was found to be independently associated with increased HAZ and WHZ. In addition, protected drinking water access was associated with increased WHZ. Furthermore, protected water access enhanced the association between PSNP participation and increased HAZ. Being a boy, a lower level of maternal education, and a lack of a household latrine were associated with decreased HAZ.

Table 4. Results of multivariable linear regression models for factors associated with child stunting and wasting (Wolaita, rural Ethiopia, 2017 - 2018).

	HAZ (n = 3,571)			WHZ (n = 3,510)		
Variables	**β**	**95% CI**		**β**	**95% CI**	
Child's age in months (ln)	-2.022***	-3.093	-0.951	-0.196**	-0.309	-0.083
Child's sex (ref = female)	-0.327***	-0.441	-0.213	-0.034	-0.110	0.043

Mother's age in years, continuous	-0.039	-0.079	0.002	-0.005	-0.032	0.022
Mother's education level, continuous	0.121***	0.074	0.169	0.023	-0.009	0.054
Father's education level, continuous	-0.032	-0.084	0.019	-0.027	-0.062	0.008
Household latrine (ref = yes)	-0.175*	-0.343	-0.007	0.024	-0.088	0.137
Family size, continuous	-0.123	-0.209	-0.037	-0.019	-0.077	0.038
Wealth index, continuous	-0.075	-0.179	0.029	0.024	-0.045	0.094
Work, non-farming income (ref = yes)	-0.182***	-0.316	-0.047	-0.043	-0.133	0.047
Drinking water access $^{(W)}$	0.234	0.066	0.403	-0.363	-0.476	-0.250
PSNP participation $^{(P)}$	-0.092	-0.265	0.081	-0.172	-0.288	-0.056
Interaction term $^{(W\times P)}$	-0.367***	-0.600	-0.133	0.005	-0.152	0.162
Child diarrhoeal illness	-0.038	-0.166	0.090	0.017	-0.069	0.103
Household food insecurity	0.063	-0.066	0.192	0.020	-0.067	0.106

Notes. Our units of analysis here are HAZ (height-for-age Z-scores) measurements on 902 children and WHZ (weight-for-height Z-scores) measurements on 897 children in the preceding season. Drinking water access (0 = protected vs. 1 = unprotected); PSNP = Productive Safety Net Program (0 = PSNP participant or beneficiary vs. PSNP non-participant or non-beneficiary); interaction term: included households who neither had protected drinking water access nor PSNP participation. Child age and cohort-effect: we considered the child's age in months in the logarithmic scale (ln) to account for the observed inconsistencies in child age data distributions. All model coefficients here are adjusted for the effect of child age changes during the study period (cohort-effect). *p*-value: *** $p \leq 0.001$; ** $p \leq 0.01$; * $p < 0.05$.

Seasonality

As shown in Figure 5, child wasting rates varied with seasonal household food insecurity, and child wasting rates increased with increasing duration of household food insecurity ($\chi^2_{trend} = 5.9$, $p = 0.015$). Moreover, Table 5 presents the association between seasonal household food insecurity and child WHZ indices adjusted for baseline factors, child age changes during the study period, and time series of our repeated measurements. It was found that seasonal household food insecurity was independently associated with decreased WHZ.

Table 5. Results of multivariable linear regression models for seasonality of child wasting, Wolaita, rural Ethiopia, 2017 - 2018 (n = 3,510).

Variables	**β**	**95% CI**	
Child's age in months	-0.150**	-0.263	-0.036
Child's sex (ref = female)	-0.009	-0.083	0.065
Mother's age, continuous	0.013	-0.019	0.045
Mother's education, continuous	0.021	-0.010	0.052
Father's education, continuous	-0.021	-0.054	0.013
Household latrine (ref = yes)	0.050	-0.059	0.159
Family size, continuous	-0.026	-0.082	0.030
Wealth index, continuous	0.020	-0.048	0.087
Work, non-farming income (ref = yes)	-0.033	-0.120	0.055
PSNP participation	-0.122**	-0.199	-0.044
Drinking water access	-0.349 ***	-0.431	-0.267
Child diarrhoeal illness (ref = yes)	0.006	-0.081	0.093
Household food insecurity (ref = yes)	0.077	-0.058	0.211
Seasonal household food insecurity (ref = main harvest season)			
Sowing season	0.003	-0.131	0.137

Post-harvest season	-0.170*	-0.302	-0.037
Dry pre-harvest season	-0.345***	-0.481	-0.209
Child age changes during the study period (cohort)	0.638*	0.066	1.211
Child diarrhoeal illness (time series)			
At first season	-0.020	-0.133	0.092
At second season	0.004	-0.104	0.112
At third season	-0.157	-0.279	-0.034
At fourth season	0.054	-0.053	0.161
Household food insecurity (time series)			
At first season	0.167	0.071	0.263
At second season	-0.143	-0.225	-0.061
At third season	0.192	0.052	0.333
At fourth season	-0.083	-0.246	0.079

p-value: *** $p \leq 0.001$; ** $p \leq 0.01$; * $p < 0.05$.

Effect modification

Table 6 presents the results of further analysis of the fitted WHZ model by duration of household food insecurity. The results showed that seasonal household food insecurity modified the effect of PSNP participation and protected drinking water access on increased WHZ estimates.

Table 6. Variations in the effects of household PSNP participation and protected drinking water access on weight-for-height Z-scores of children aged 6 - 59 months by durations of household food insecurity, Wolaita, rural Ethiopia, 2017-18

	Duration of household food insecurity					
	1or 2 seasons			3 or 4 seasons		
	β	95% CI		β	95% CI	
Child age (lnmonths), continuous	1.279	-0.039	2.598	1.417	0.596	2.238
Child age changes (cmonths), continuous	-0.266	-0.461	-0.070	-0.242	-0.361	-0.124
Child sex (ref=female)	-0.141	-0.277	-0.004	0.031	-0.056	0.119
Mother's age, continuous	-0.046	-0.097	0.005	-0.034	-0.065	-0.004
Mother's education, continuous	-0.141	-0.198	-0.083	0.068	0.032	0.105
Father's education, continuous	0.156	0.092	0.220	-0.080	-0.120	-0.041
Household latrine (ref=yes)	-0.382	-0.592	-0.171	0.178	0.049	0.307
Family size, continuous	-0.004	-0.112	0.105	0.004	-0.062	0.070
Wealth index, continuous	-0.099	-0.227	0.030	0.061	-0.018	0.141
Work, non-farming income	-0.273	-0.438	-0.108	0.038	-0.065	0.142
PSNP participation and protected drinking water access (cat) (ref=both)						
Neither (1)	-0.679	-0.867	-0.491	-0.395	-0.518	-0.273
PSNP (2)	-0.350	-0.556	-0.143	-0.296	-0.430	-0.162
Water (3)	-0.421	-0.616	-0.225	-0.058	-0.194	0.079
Both (4)						
Child diarrhoeal illness (ref=no)	0.015	-0.144	0.173	0.008	-0.094	0.110
Child diarrhoeal illness (1st season)	-0.066	-0.275	0.142	0.088	-0.046	0.222
Child diarrhoeal illness (2nd season)	0.077	-0.126	0.280	0.000	-0.127	0.127
Child diarrhoeal illness (3rd season)	-0.010	-0.232	0.211	-0.150	-0.296	-0.003
Child diarrhoeal illness (4th season)	-0.088	-0.286	0.110	0.143	0.016	0.270

Notes. PSNP = Productive Safety Net Program. PSNP participation and protected drinking water access (cat) is a categorical variable generated from two dichotomous variables (PSNP participation and protected drinking water access):

1 = households who neither had protected drinking water access nor participated in PSNP; 2 = households who participated in PSNP, but did not have protected drinking water access; 3 = households who had protected drinking water access, but did not participate in PSNP; 4 = households who had protected drinking water access and also participated in PSNP. Decreased (β) coefficients refer to increased child wasting and vice-versa. Child age changes (cmonths) =child age in months divided by child age in the logarithmic scale; cmonths was used to account and adjust for child age changes during the study period.

DISCUSSION

Key results

Our cohort study suggested seasonal variations in weight-for-height Z-score (WHZ) indices among children aged 6 - 59 months in rural southern Ethiopia, with dose-response relationships. Household participation in the Ethiopian government's social safety net (PSNP) and having protected drinking water access were main factors associated with increased height-for-age Z-score (HAZ) or WHZ. Lower level of maternal education, lack of non-farming household income, and absence of a household latrine were associated with decreased HAZ indices.

Limitations and strengths

This study was based on a random sample of households, and our units of analysis were counts of total observations compiled from four repeated measurements undertaken for one year. However, our one sample estimation could constitute a limitation of this study, especially as certain background factors (e.g., household wealth, PSNP participation, and drinking water access) clustered in the lowland areas. Subjectivity bias could also exist in our food insecurity measurements, especially as this study was conducted in a chronically food-insecure setting [38 39]. We used the Household Food Insecurity Access Scale questionnaire, which had been validated in the study area [10]. To ensure accuracy of the current study data, measurements were repeated and, although we used the same data collectors for the repeated data rounds, it was sometimes not possible to maintain the same data collectors. We did not initially estimate separate samples for our repeated measurements, but our analytical sample (i.e., counts of observations compiled from the repeated measurements) showed adequate statistical power. We analysed HAZ and WHZ indices as composite measures of child nutritional status as continuous variables using linear regression models which enhanced the accuracy of our estimates [21]. Moreover, we accounted and adjusted our estimates for the observed clustering effects at the primary sampling stage (at the kebele level). We accounted for seasonality through some time-varying exposures (household food insecurity and child diarrhoeal illness), but we did not assess other illnesses, such as malaria, measles, tuberculosis, etc. [40-43]. We considered some dummy variables to account for the time series random effects beyond the scope of our time-varying exposures.

Comparative discussions

Our prevalence estimates for stunting and wasting rates are consistent with recent estimates from Ethiopian demographic and health surveys [44]. Our study indicated that household socioeconomic conditions, such as low level of maternal education, lack of non-farming income, and absence of PSNP participation were associated with HAZ or WHZ indices (Table 4), which complements previous reports [32 45-47]. The country's persistently low socio-economic status is often described as a main cause for child undernutrition in Ethiopia [32 45-47].

Our study suggested that household PSNP participation could improve HAZ and WHZ (Table 4), which complements some extant literature [48 49], but contradictory reports also exist [50-52]. These inconsistencies could be due to variations in the study designs, participants, and data approaches. Nonetheless, a growing body of literature indicates that PSNP improves household food security and consumption.

Our study points to the lack of clean water access and a household latrine as independent predictors for child undernutrition (Table 4), which aligns with previous reports [6 53]. The lack of clean water access and sanitation could predispose populations to recurrent infections, such as diarrhoea and intestinal parasites [54 55]. Indeed, improving clean water, sanitation, and hygiene are frequently identified as priority interventions to reduce child undernutrition [56].

Our study suggested seasonal household food insecurity as an independent predictor of decreased WHZ (Table 5), which is in accordance with previous investigations [57 58]. This could be attributable to seasonal fluctuations in household food consumption patterns [11 59], and some scholars describe seasonality as a grossly neglected dimension of poverty [11 17 60].

Meanings and possible explanations

Seasonal household food insecurity could contribute to decreased WHZ indices in rural Ethiopia, suggesting that this population is vulnerable to food insecurity [17]. Strengthening the PSNP intervention through effective targeting of the neediest households might further enhance its impacts on child undernutrition. Yet, the criteria for household PSNP eligibility remain controversial [61]; for example, if geographic criteria prioritise the lowland areas [13], then poorer households in the midland villages (as in our study setting) could be neglected. Improving clean water access and sanitation have widely been described as nutrition-sensitive interventions [62 63]. In our study area context, expanding the coverage of protected drinking water access in the midland villages might contribute to reducing child undernutrition. Moreover, addressing seasonal variations in household food insecurity could help decrease child undernutrition [17].

FIGURE LEGENDS

Figure 1. Conceptual framework for a possible chain of relationships between seasonal food insecurity and child undernutrition, Wolaita, rural Ethiopia, 2017 - 2018.

Figure 2. Flow chart of child anthropometric measurements considered for this cohort study, Wolaita, rural Ethiopia, 2017 - 2018.

Figure 3. Household dietary diversity score (HDDS) by duration of household food insecurity for households who participated in the Productive Safety Net Program (PSNP) and households that did not participate in the program, Wolaita, rural Ethiopia, 2017 - 2018.

Figure 4. Mean weight-for-height Z-score indices of children aged 6 - 59 months by household participation in the Productive Safety Net Program (PSNP) and protected drinking water access, Wolaita, rural Ethiopia, 2017 - 2018.

Figure 5. Seasonal variations in child wasting rates among overall measurements and measurements within food-insecure households, Wolaita, rural Ethiopia, 2017 - 2018.

DECLARATIONS

Ethics approval and consent to participate

The Institutional Review Committee at Hawassa University in Ethiopia (IRB/002/09) and the Regional Committee for Medical and Research Ethics in Western Norway (2016/482/REK vest) approved the study protocol. Written consent was obtained from the respondents, as well as assent for their children's weight and height measures. Responses were anonymised using unique identification numbers.

Consent for publication

Not applicable.

Availability of data and material

All data relevant to the study are included in the article or uploaded as supplementary information.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

BYK conceived the research idea, designed the study protocol, implemented the study, made major statistical analyses, and wrote the draft and final versions of the scientific report. BL conceived the research idea, and made substantial contributions to the design, field methods, major statistical analyses, and writing. Both authors read and approved this manuscript for submission.

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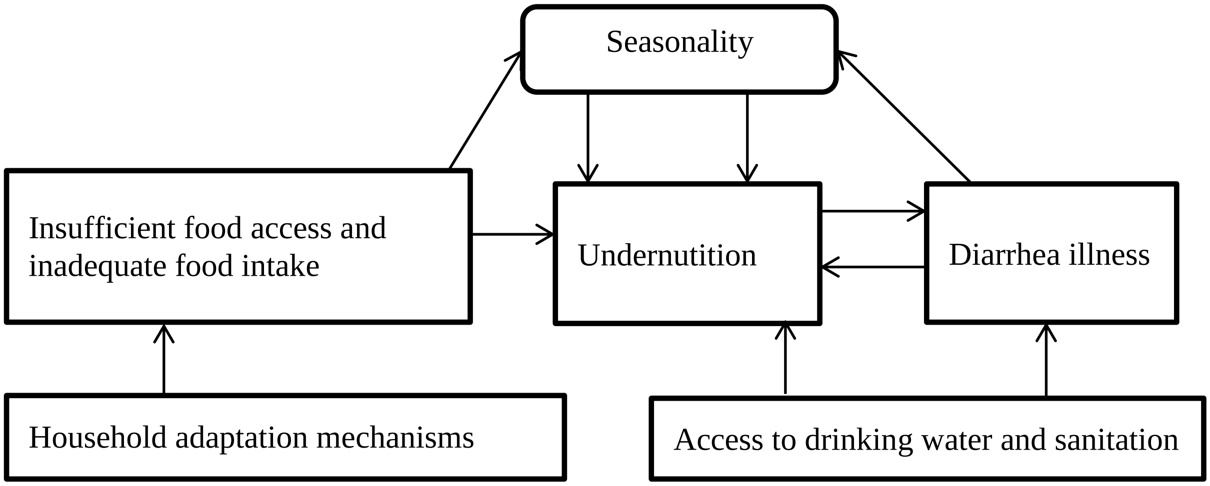

Figure 1 Conceptual framework for possible chain of relationships between seasonal food insecurity and risk for child undernutrition, Wolaita, Ethiopia, 2017-18

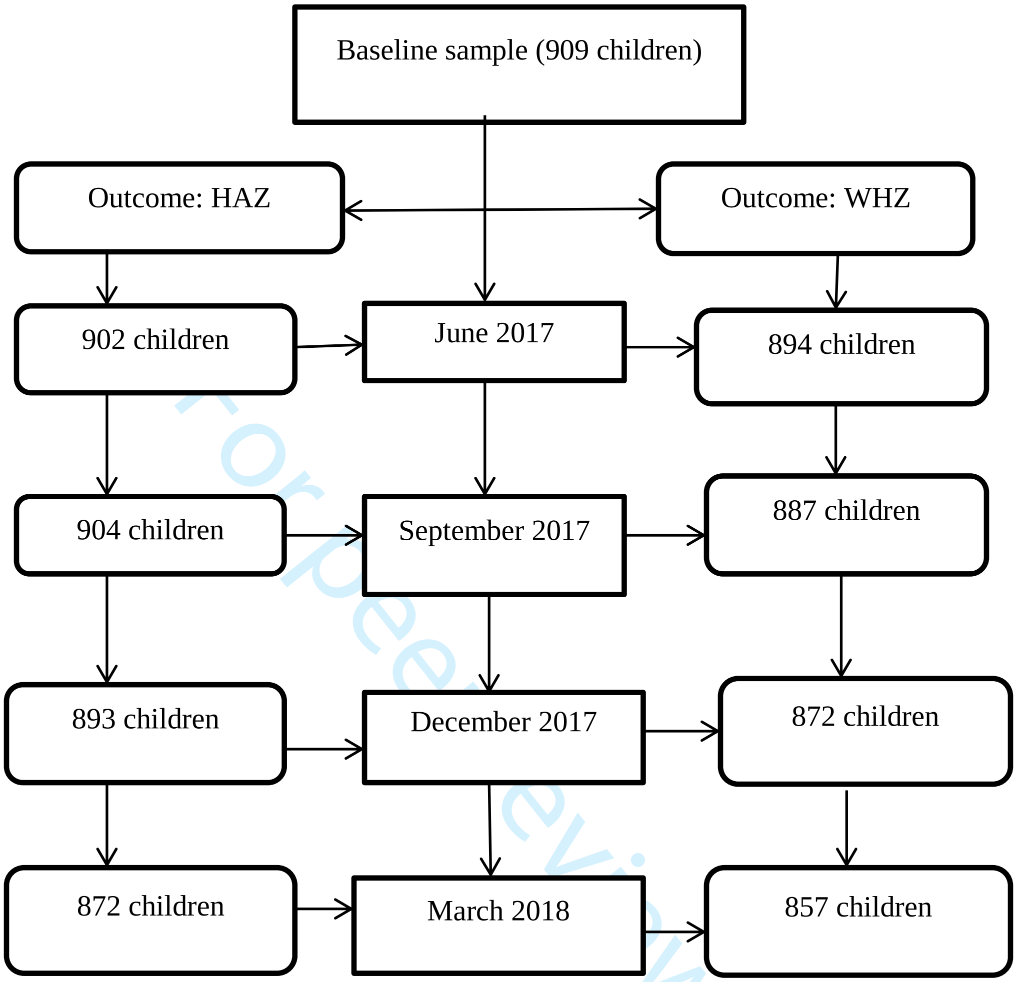

Figure 2 Height-for-age Z-scores (HAZ) and Weight-for-height Z-scores (WHZ) of children aged 6-59 months considered for this cohort study, Wolaita, rural Ethiopia, 2017-18

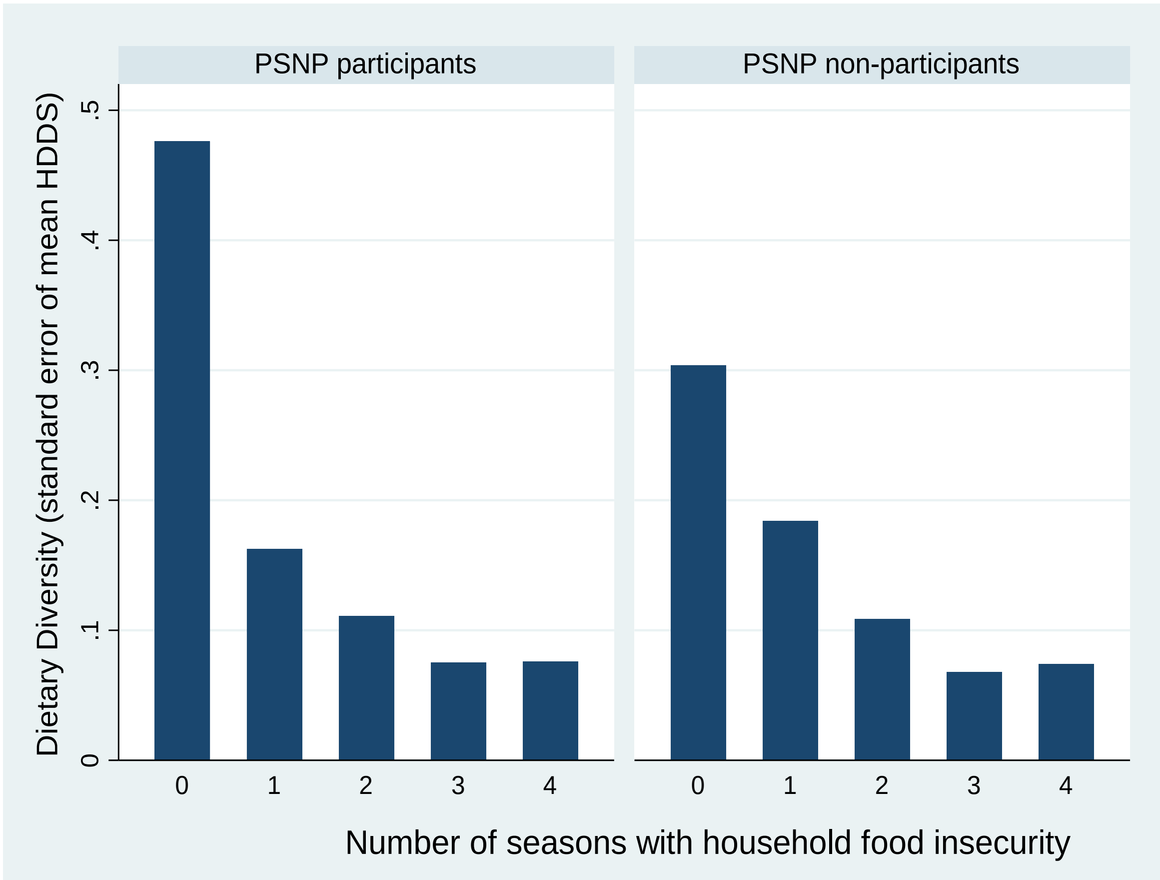

Figure 3 household dietary diversity score (HDDS) by duration of household food insecurity for households who participated in Productive Safety Net Programme (PSNP) and households that did not participate in this program, Wolaita, rural Ethiopia, 2017-18

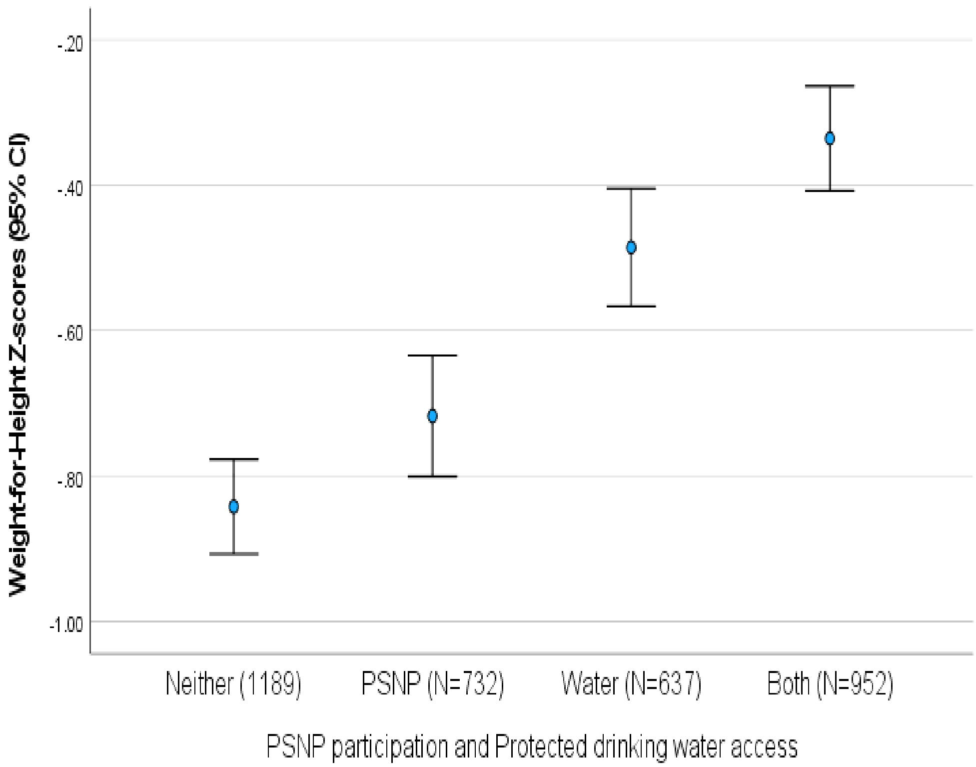

Figure 4 Weight-for-height Z-scores of children aged 6-59 months by household participation in 'Productive Safety Net Programme (PSNP)' and protected water access, Wolaita, rural Ethiopia, 2017-18

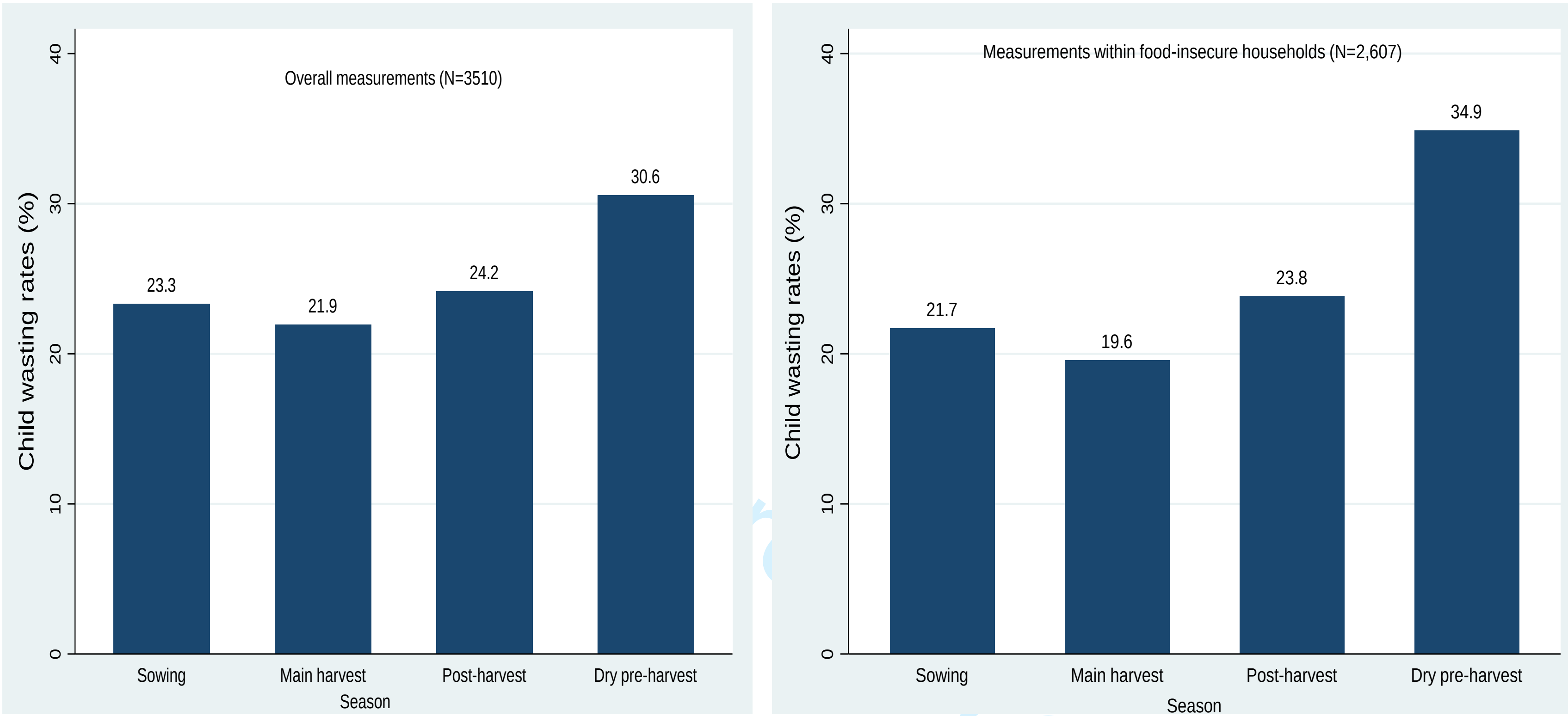

Figure 5 seasonal variations in child wasting rates among overall measurements and measurements within food-insecure households, Wolaita, rural Ethiopia, 2017-18

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*7-9*
Bias	9	Describe any efforts to address potential sources of bias	6-10
Study size	10	Explain how the study size was arrived at	6, 9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9-10
		(*b*) Describe any methods used to examine subgroups and interactions	10
		(*c*) Explain how missing data were addressed	9
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	No loss to follow-up
		(*e*) Describe any sensitivity analyses	

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	None
		(c) Consider use of a flow diagram	8-9
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11-12
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	*12*
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	13-16
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	15-16
Discussion			
Key results	18	Summarise key results with reference to study objectives	16
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	17
Generalisability	21	Discuss the generalisability (external validity) of the study results	18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	19

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.