Associations of Rainfall with Childhood Under-nutrition in Rwanda: An Ecological Study using the Data from Rwanda Meteorology Agency and the 2010 Demographic and Health Survey

Assumpta Mukabutera[1,*], Jamie I. Forrest[2], Laetitia Nyirazinyoye[1], Habimana Marcelin[3], Paulin Basinga[1,4]

[1]Community Health Department, School of Public Health, College of Medicine and Health Sciences, University of Rwanda, Kigali, Rwanda; [2]School of Population and Public Health, Faculty of Medicine, University of British Columbia, Vancouver, Canada; [3]Rwanda meteorology Agency, Kigali, Rwanda; [4]Rwanda Biomedical center

**Corresponding author's email: amukabutera [AT] nursph.org*

ABSTRACT— ***Seasonality of weather and climate can affect many of the complex pathways of nutrition. Methods: Using Rwanda demographic and health survey (RDHS) and precipitation measurements collected in 2009-2010; we assessed the association between rainfall and childhood malnutrition: stunting, underweight and wasting. Childhood under-nutritional status was assessed by Z-scores for weight-for-age (WAZ), weight-for-height (WHZ) and height-for-age (HAZ), as primary outcomes for this analysis.***

A total of 4176 children under five years were included in the analysis. The prevalence of underweight was 11.4%, stunting was 44% and wasting was 3%. After adjusting potential confounders (mother's BMI, mother's education, residence and wealth indices), children residing in the area with high rainfall were more likely to be stunted (OR=1.58; 95%CI=1.28,1.96; p<0.001) while children in the area with moderate and high quantity of rain were less likely to be wasted (OR=0.50; 95%CI=0.31,0.82; p=0.006 and OR=0.34; 95%CI=0.20,0.58; p<0.001 respectively).

Rainfall patterns may affect the nutritional status (under-nutrition) of children under five years of age. Estimating the effect of rainfall on malnutrition may help to better predict regions of vulnerability to under-nutrition. We suggest further study for more information about the mechanism of this association.

Keywords — Malnutrition; Underweight; Child under five; sub-Saharan Africa; Rwanda; DHS; climate; rainfall

---

1. INTRODUCTION

Malnutrition of children under five years of age remains a serious public health problem. An estimated 30% to 70% of deaths in children under five years in developing countries are directly or indirectly linked to under-nutrition (1–6). Nutritional outcomes remain an important development indicator and reflect a household's vulnerability to improved quality of life. In Rwanda, a country with a high burden of malnutrition (7), half of pediatric deaths can be attributed to malnutrition that expose children to infection due to the depressed immune function (8) .

The childhood under-nutritional status may be the result, primarily or secondarily, of an inadequate supply, relative to the body's needs, of energy and/or essential nutrients (9). Epidemiological evidence suggests that the first response to a nutritional deficiency is weight loss (wasting), followed by retardation in linear growth (stunting) (10). Wasting reflects a deficit in weight relative to height due to a deficit in tissue and fat mass (10). If malnutrition persists, children will cease to grow in height and will lose weight, thus augmenting the process and prevalence of wasting (10,11). Underweight is measured index of weight-for-age; It is a composite of stunting and wasting and takes into account both chronic and acute malnutrition. Children with Z-scores of weight-for-age (WAZ), weight-for-height (WHZ) and height-for-age (HAZ), below minus two standard deviations are classified as underweight, stunted and wasted respectively (7).

In an era of increased attention to weather variation and climate change (12), it is more important to understand the relationship between malnutrition and rainfall. This evidence can be used to plan more effective interventions for improving child nutritional status . Several studies have looked at associations between child pneumonia and climate change (13); rainfall and hand washing hygiene (14) and association between rainfall and food production(15) (16). These studies found that low rainfall is associated with an increase in childhood pneumonia and reduction of worldwide food supplies (13). However the association between rainfall and child nutritional status is not fully characterized. This study looked at the association between rainfall and childhood malnutrition in Rwanda after controlling for known factors associated with malnutrition.

2. METHODS

2.1 Study participants and study design

This study uses the data from the 2010 Rwanda Demographic Health Survey (RDHS). The RDHS is a cross-sectional study conducted by the National Institute of Statistics in collaboration with the Ministry of Health. The RDHS collected demographic, socioeconomic, health and nutritional information from a nationally representative sample of 13,671 women aged 15-49 from 12,540 households. The sample used a two-stage cluster design and had an overall response rate of 99%. In the first stage, 492 villages were selected with probability proportional to the number of households from a national listing of villages. Surveyors mapped all households in the selected villages, and in the second stage, households were systematically sampled. All women aged 15-49 present in selected households on the night before the survey were eligible. The survey questionnaires were carefully translated into Kinyarwanda, and back translated to English to ensure that the questions measured what they intended to measure. Trained enumerators using tested questionnaires collected data. The RDHS design has been described elsewhere (7).

Daily rainfall data was collected between January 2009 and December 2011 by Rwanda Meteorology Agency in the Ministry of Natural Resources and were used to estimate total rainfall and rainfall variability. We compared recent rainfall to global estimates of the 30 year (1971-2000) long-term average calculated by Famine Early Warning Systems (FEWS) Network (17). Monthly runoff and soil moisture were estimated by the US National Oceanic and Atmospheric Administration (18), in a one-layer global hydrological model using observed meteorological data.

2.2 Study variables

Data come from the 2010 RDHS, restricted to children under five years that had complete anthropometric data. Childhood malnutrition was measured by Z-scores for weight-for-age (WAZ), weight-for-height (WHZ) and height-for-age (HAZ), which are the primary outcome for this analysis. For each child under five years of age, anthropometric measurements (height and weight) were taken to evaluate nutritional status. We classified children nutritional status using a cutoff Z-score of below negative two (−2) standard deviations from the median of the reference population (Z-score<−2) according to the 2006 WHO Growth Reference Chart. WAZ Scores below −2 led to underweight children, WHZ led to stunted children and HAZ led to wasted children (7).

According to the context and our conceptual framework, we considered different aspects of rainfall that could impact the child nutritional status as our main predictors. We hypothesized that rainfall may be associated to the infectious diseases (through quantity and quality of water) and shortage of crops production (figure1). First, we hypothesized that during dry periods, people may have less water available (14,19,20) and that the quality of that water might be reduced (21–23). Secondly, we hypothesized that unusually high or low rainfall compared to long-term norms may affect hygiene practices behavior by forcing community members to alter their behavior during these periods. Underweight and wasting may be the results of insufficiency intake or infection diseases for a short period. Based on this, we considered short and long period-related rainfall variables to be associated with underweight and wasting: we considered the numbers of days with rain of 2mm, the quantity of runoff water in one month to the survey, and the quantity of annual rainfall in the year to be associated with underweight and the total rainfall in last three month to the survey, the annual rainfall, a day with heavy rainfall (with 5mm or more per day) and the quantity of rain in last six months compared to the annual mean rainfall to be associated with wasting. For stunting, we considered long-period rainfall variables including: total rainfall in the last six months, the annual rainfall and the quantity of rain in the last six months compared to the annual mean rainfall and variables included child characteristics (sex and age), mother characteristics (age and education) and household characteristics (region and number of children in the household) were considered.

A Geographic Coordinate (GPS coordinate) was collected in each village and randomly geo-displaced up to 2 kilometers in urban neighborhoods and up to 5 kilometers in rural villages. We used daily rainfall data from the closest weather station to each surveyed village. Data were spatially joined to the DHS dataset based on village location. From these data sources, we calculated four rainfall variables corresponding to the village location and date for each survey collected for the 2010 RDHS survey.

Our proposed conceptual model to describe the relationship between childhood malnutrition and rainfall is displayed in Figure 1.

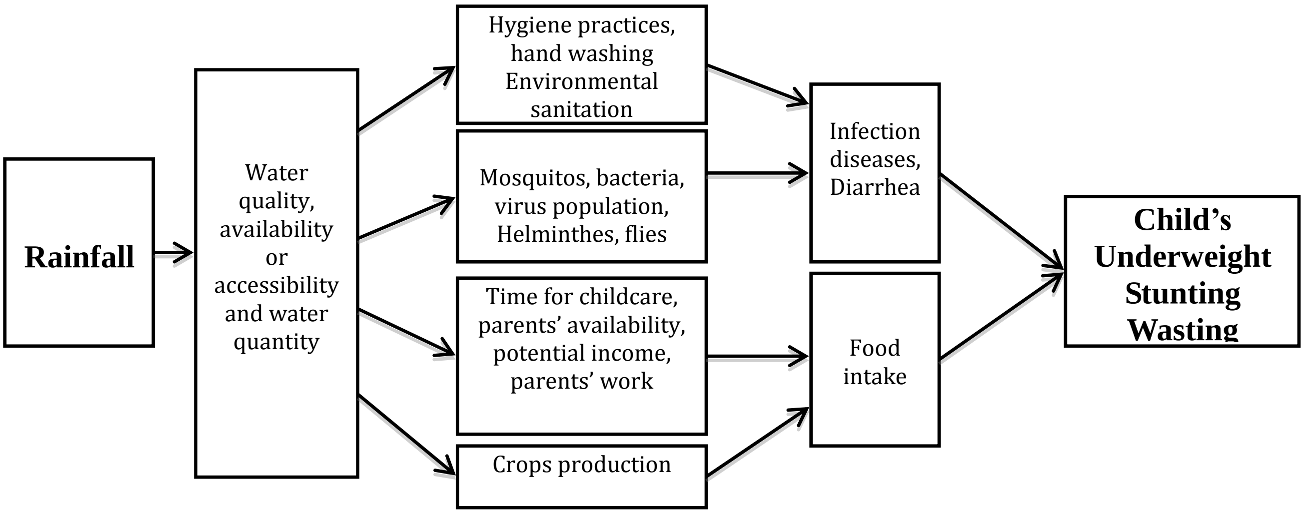

Figure 1. Conceptual framework for the proposed association between rainfall and child nutritional status

2.3 Data Analysis

Descriptive statistics were used to describe the distributions of key variables within the sample. We assessed the effect of rainfall factors on childhood malnutrition through multivariable logistic regression. We tested for confounders and only variables that changed the coefficient of the rainfall-nutrition by 10% or more were retained and controlled for in the final models. All socio-demographic variables that changed the rainfall-nutrition coefficient by 10% or more were included in the multivariable model as potential confounders of the relationship between underweight, stunting, and wasting and rainfall factors. The unadjusted model included nutrition outcomes and only all rainfall factors, then the adjusted model controlled for the potential confounders (mother's education level, BMI, residence and wealth index). Odds ratio, 95% Confidence interval and p-value were reported.

Sampling weights were applied with "svyset" commands to all observations to compensate for over-sampling of urban respondents in the study design, and we accounted for clustering of children within villages. All analyses were conducted in STATA version 12.0 (StataCorp, College Station, USA).

3. RESULTS

3.1 Sample description and prevalence of child nutritional status (stunting, underweight and wasting) by socio demographic characteristics

A total of 4177 children under 5 years of age were included in the analysis. Almost one child out of two children (44.0%) was stunted, one child out of ten was found to be underweight (11.4%) and three out of ten (2.9%) were wasting. The mean age of children was 29.96 months (Standard Deviation [SD] = 17.02). The sample included 2,101 (50.3%) males under five years and 2,075 (49.7%) females under five years. Fifteen percent were born with a birth weight < 2.5 kg. A high number of mothers (54.0%) were aged 25 - 34 and the majority of the children have mothers with a primary and less level of education (91.4 %). Five percent of mothers in this sample were underweight, with BMI<18.5; almost half of the families 1,848 (44.25%) are in the class of household with poor wealth index (table note displayed).

In bivariate analysis, child nutritional status (stunting, underweight and wasting) was significantly associated with socio-demographic and household factors. Stunting and underweight status were significantly associated with child age, sex, size at birth, mother age, education, BMI, number of children under five years per household, residence and wealth index; but wasting was associated only with child age and mother's BMI (p<005) (Table 3). Stunting cases were high among children aged 24 - 35 months (464(52.3%)). Underweight among children aged 48-59 (116(13.9%)) and wasting among children aged 6 - 11 months (32(7.7%)). Stunting and underweight cases increased as the mother's age and BMI increased, and as wealth index improved (Table 1).

Table 1. Distribution of child nutritional status, by demographic and household characteristics of 4176 children under-5 years, DHS 2010 survey.

Characteristics	N (%)	p. value	N (%)	p. value	N (%)	p. value
	Stunting		**Underweight**		**Wasting**	
Child characteristics						
Child age						
<6	59(16.8)	0.000	23(6.5)	0.005	18(5.1)	0.000
6-11	93(22.2)		46(11.1)		32(7.7)	
12-23	383(48.8)		100(12.7)		27(3.5)	
24-35	464(52.3)		104(11.7)		14(1.6)	
36-47	430(51.3)		80(9.5)		10(1.2)	
48-59	382(45.7)		116(13.9)		18(2.2)	
Child sex						
Boys	987(47.7)	0.000	263(12.7)	0.010	69(3.3)	0.111
Girls	825(40.3)		206(10)		50(2.4)	
Child size at birth						
Not small (>2,500)	1477(42.5)	0.000	344(9.9)	0.000	94(2.7)	0.068
Small at birth (<2500hg)	327(52.2)		123(19.6)		25(4.0)	
Mother's age						
15-24 years	293(39.7)	0.000	51(6.9)	0.000	24(3.3)	0.208
25-34 years	946(42.5)		233(10.5)		55 (2.5)	
35-49 years	573(49.6)		186(16.1)		41(3.5)	
Mother's education level						
Primary and less	1729(45.9)	0.000	459(12.2)	0.000	106(2.8)	0.250
secondary and high	82(23.3)		10(2.8)		13(3.8)	
BMI						
<18,5 underweight	1338(45.2)	0.000	338(11.4)	0.000	85(2.9)	0.039
18,5-24,00 Normal	90(48.7)		45(24.5)		12(6.6)	
25,0-29,00 Overweight	171(32.9)		32(6.2)		14(2.7)	
>=30 Obesity	23(25)		7(7.8)		1(1.2)	
Number of under five children						
1-3 children	1037(41.4)	0.000	239(9.6)	0.000	72(2.9)	0.905
4+ child	774(48)		230(14.3)		47(2.9)	
Residence area						
Urban	131(27.5)	0.000	31(6.4)	0.000	18(3.8)	0.234
Rural	1680(46.2)		438(12)		101(2.8)	
Wealth index						
Richest	172(25.9)	0.000	34(5.1)	0.000	20(3.0)	0.209
Richer	308(38.7)		74(9.3)		18(2.3)	
Middle	378(45.1)		94(11.3)		17(2.0)	
Poorer	469(51.2)		130(14.2)		31(3.4)	
Poorest	484(53.7)		137(15.1)		32(3.6)	

3.3 Prevalence of child nutritional status (stunting, underweight and wasting) and rain variation in the last decade to the survey

As shown in table 2 below, there are more stunting and underweight cases during the high total rain in the last year, thus 1309.95mm to 1641.42 mm (51.85%; 11.95% respectively); contrary, more cases of wasting were high among children whose households were interviewed during the low rain 4.31%. Concerning the abnormality of rain, more cases of wasting were observed among children interviewed during the period with moderate abnormal rain compared to the long-term rain -319.41mm to -195.19mm 710 (49.5%) in the last six months compared to the long-term period.

Table 2. Distribution of nutritional status among under-5 years, by rainfall factors variation.

Variables	**Frequency**	**Percent**	**P.Value**
Stunting	***Stunted***		
Annual total mm rain			0.000
785.54 mm to 1031.38 mm	401	35.70	
1031.38mm to 1309.95mm	667	42.78	
1309.95mm to 1641.42 mm	744	51.85	
Difference in measured rainfall for 6 months compared to the long term rainfall			0.000
-489.58mm to -319,42mm	633	44.12	
-319,41mm to -195,19mm	710	49.05	
-195,1 mm to 44.28 mm	468	37.96	
Underweight	***Underweight***		
Annual total mm rain			0.516
785.54 mm to 1031.38 mm	117	10.39	
1031.38mm to 1309.95mm	181	11.6	
1309.95mm to 1641.42 mm	171	11.95	
Difference in measured rainfall for 6 months compared to the long term rainfall			0.051
-489.58mm to -319,42mm	119	12.48	
-319,41mm to -195,19mm	175	12.05	
-195,1 mm to 44.28 mm	115	9.35	
Wasting	***Wasted***		
Annual total mm rain			0.002
785.54 mm to 1031.38 mm	48	4.31	
1031.38mm to 1309.95mm	45	2.89	
1309.95mm to 1641.42 mm	26	1.79	
Difference in measured rainfall for 6 months compared to the long term rainfall			0.025
-489.58mm to -319,42mm	43	3.01	
-319,41mm to -195,19mm	29	1.97	
-195,1 mm to 44.28 mm	47	3.84	

3.4 Association between rainfall variation and nutritional status: underweight, wasting and stunting among children under 5 years

The stunting, underweight and wasting results of the logistic regression models are presented in Tables 5, 6 and 7. Two models (unadjusted and adjusted) are presented for the outcome to assess the effect of rainfall on childhood nutritional status. We tested for confounders; only socio-demographic variables that changed the nutrition—rainfall coefficient by 10% or more were included in the final multivariable model as potential confounders of the relationship between underweight, stunting, and wasting and rainfall factors. The unadjusted model included nutritional outcomes and only all rainfall factors, then the adjusted model controlled for the potential confounders (mother's education level, BMI, residence and wealth index).

Associations with stunting

After adjusting mother's education, residence area and wealth indices, rainfall factors were found to favor stunting among children under five years: Annual total rainfall and abnormal rain compared to the long-term rainfall (difference in measured rainfall for 6 months compared to the long-term rainfall—30 years—for the same month). The high rainfall in the last year to the survey negatively favors stunting in the same way as moderate abnormal rain. Children residing in the area with high quantity of rain were more likely to be stunted (OR=1.58; 95%CI=1.28,1.96; p<0.001) compared to children in the area with low rainfall. This is the same for the children residing in the area with abnormal rainfall for the last six months compared to the long-term rain; in moderated abnormally rainy period, the odds of stunting are 1.37 (95%CI=1.13, 1.66; p=0.001) compared to the children in the area with dry period compared to the expected rain (Table 3).

Table 3. The models of multivariable logistic regression investigating the effect of rainfall factors on stunting children under-5 years of age in Rwanda 2010

Rainfall and Potential confounders	Unadjusted model		Adjusted model	
	OR (95%CI)	p value	OR (95%CI)	p value
Annual total mm rain				
785.54 mm to 1031.38 mm	1		1	
1031.38mm to 1309.95mm	1.36 [1.12, 1.66]	0.002	1.15 [0.95, 1.40]	0.162
1309.95mm to 1641.42 mm	1.95 [1.57, 2.41]	0.000	1.58 [1.28, 1.96]	0.000
Difference in measured rainfall for six months compared to the long term rainfall				
-489.58mm to -319,42mm	1		1	
-319,41mm to -195,19mm	1.36 [1.13, 1.64]	0.001	1.37 [1.13, 1.66]	0.001
-195,1 mm to 44.28 mm	1.04 [0.83, 1.31]	0.741	1.16 [0.92, 1.46]	0.218
Mother's education level				
Primary and less			1	
Secondary and high			0.59 [0.44, 0.81]	0.001
Residence area				
Urban			1	
Rural			1.28 [0.92, 1.78]	0.142
Wealth index				
Richest				
Poorest			2.33 [1.78, 3.05]	0.000
Poorer			2.10 [1.61, 2.74]	0.000
Middle			1.66 [1.25, 2.21]	0.000
Richer			1.33 [1.02, 1.73]	0.035

Associations with underweight

Of the variables tested and after controlling for factors of potential confounders, there were no significant associations between rainfall and underweight (Table 4). Even though the relationship is not statistically significant, children in rain period are less likely to be underweight.

Table 4. The models of multivariable logistic regression investigating the effect of rainfall factors on underweight children under-5 years of age in Rwanda 2010

Rainfall and Potential confounders	Unadjusted model		Adjusted model	
	OR (95%CI)	p value	OR (95%CI)	p value
Annual total mm rain				
785.54 mm to 1031.38 mm	1		1	
1031.38mm to 1309.95mm	0.99 [0.73, 1.35]	0.973	0.86 [0.64,1.15]	0.302
1309.95mm to 1641.42 mm	1.00 [0.72, 1.37]	0.978	0.82 [0.60,1.12]	0.208
Difference in measured rainfall for six months compared to the long term rainfall				
-489.58mm to -319,42mm	1		1	
-319,41mm to -195,19mm	0.96 [0.75, 1.24]	0.748	0.96 [0.75,1.24]	0.761
-195,1 mm to 44.28 mm	0.72 [0.51, 1.01]	0.058	0.80 [0.58,1.11]	0.185
Mother's education level				
Primary and less			1	
Secondary and high			0.31 [0.17,0.58]	0.000
Residence area				
Urban			1	
Rural			1.17 [0.74,1.83]	0.505
Wealth index				

Richest		
Poorest	2.39 [1.53,3.75]	0.000
Poorer	2.18 [1.38,3.44]	0.001
Middle	1.71 [1.07,2.73]	0.026
Richer	1.42 [0.88,2.28]	0.147

Associations with wasting

After controlling for potential confounders (household wealth and mother's BMI), rainfall factors were found to be associated with wasting among the children under five (Table 5). Wasting was positively associated with total rainfall in the last year to the survey, and abnormal rain compared to the long-term rainfall (difference in measured rainfall for 6 months compared to the long-term rainfall—30 years—for the same month). The cases of wasting decease, as the quantity of annual rain increases. Children residing in wetter areas with high total rainfall in the last year to the survey were less likely to be wasted compared to children in areas with low rain in last year: children in the areas with high quantity of rain (1031.38mm to 1309.95mm) and (1309.95mm to 1641.42 mm) in the last year to the survey are less likely to be wasted (OR=0.50; 95%CI=0.31,0.82; p=0.006, OR=0.34; 95%CI=0.20,0.58; p<0.001 respectively) compared to the area with row rain (785.54 mm to 1031.38 mm). Children in the area with moderately abnormal rainfall for the last six months compared to the long-term rain for the same months are less likely to be wasted compared to those in highly dry abnormal time (OR=0.52; 95%CI=0.30,0.91; p=0.023).

Table 5. The models of multivariable logistic regression investigating the effect of rainfall factors on wasting children under-5 years of age in Rwanda 2010

Rainfall and Potential confounders	Unadjusted model		Adjusted model	
	OR (95%CI)	p value	OR (95%CI)	p value
Annual total mm rain				
785.54 mm to 1031.38 mm	1		1	
1031.38mm to 1309.95mm	0.60 [0.37, 0.99]	0.045	0.50 [0.31,0.82]	0.006
1309.95mm to 1641.42 mm	0.37 [0.22, 0.62]	0.000	0.34[0.20, 0.58]	0.000
Difference in measured rainfall for six months compared to the long term rainfall				
-489.58mm to -319,42mm	1		1	
-319,41mm to -195,19mm	0.53 [0.31, 0.89]	0.017	0.52 [0.30,0.91]	0.023
-195,1 mm to 44.28 mm	0.80 [0.49, 1.32]	0.385	0.84 [0.51,1.40]	0.507
Wealth index				
Richest			1	
Poorest			1.65[0.89, 3.05]	0.110
Poorer			1.54 [0.84,2.81]	0.159
Middle			0.77 [0.39,1.52]	0.448
Richer			0.95[0.44, 2.03]	0.107
BMI				
<18,5 underweight			2.00 [0.97,4.14]	0.061
18,5-24,00 Normal			1	
25,0-29,00 Overweight			0.96 [0.55,1.69]	0.895
>=30 Obesity			0.37 [0.05,3.00]	0.354

4. DISCUSSION

This study investigated the association of rainfall factors with the three forms of malnutrition (underweight, stunting and wasting) among children under 5 years in Rwanda. Heavy rainfall and flooding can interrupt fieldwork activities or make farmers have to work longer hours. The hypothesis was that more rainfall is affecting the food production and relates to water availability that increase hygiene practices for water-borne diseases prevention, and that the increase of rain pushes people, mostly farmers to a busy time, which leads to less time for childcare or make people inactive due to heavy rainfall which prevents people to go out to get stove for cooking. Also, we hypothesized that the abnormal rain may affect the population hygiene practices, but also the infection development depending on the bacterial, virus development cycle and mechanism: neither a very dry period nor a very heavy rainfall may not facilitate the survival and development of those pathogens, which causes more infection mostly water-borne diseases.

Our study found that a number of rainfall factors are associated with stunting and wasting, but not associated with underweight among children under five years in Rwanda. High rainfall in the last year and moderately abnormal rainfall (difference in measured rainfall for 6 months compared to the long-term rainfall—30 year—for the same month) negatively favors stunting but positively favors wasting. Children residing in areas with high rain were more likely to be stunted and were less likely to be wasting. Children in areas with moderately abnormal rainfall for the last six months compared to the long-term rain for the same month were less likely to be wasted compared to those in highly dry abnormal time, but were more likely to be stunted. These associations may be related to the availability, accessibility of water and favorable climate for pathogens development and propagation, hygiene practices, which may lead to water-borne diseases and infection due to the availability of parents to care for their children.

The majority of the population in Rwanda are famers (90%) (7), the annual quantity of rainfall may indicate the level of food production during the last year to the survey; being busy with farming activities during moderately rainy season may lead to poor childcare, thereafter child get malnutrition problems. Also, in periods of high crop yield due to increased rainfall, less food is available to be retained for the household. Additionally, the availability of water may increase hygiene practices for diseases prevention. Stunting is the chronic malnutrition issue among children. A child may be stunted due to lack of enough food intakes, long episode of infectious diseases, which leads to under-nutrition, or low birth weight, which may be due to family wealth status.

In our study, we found that more rainfall in the last year to the survey and moderately abnormal rain during the last six months compared to the long-term rain were associated with the increased cases of stunting. This may be due to the parents' availability for caring for their children and water-borne diseases infections, which leads to stunting among children under five years. The important association of rainfall data with stunting has been revealed in other studies and corroborates our findings (14,19,24–31).

Children who don't get enough food, with low nutrients intake, may lose weight and be underweight in a short period of time, and this may be resolved if the child is well fed (11,32). The hypothesis was that more rainfall in the year would lead to greater availability of food and increased hygiene practices for diseases prevention. Also we hypothesize that the abnormal rain may lead to change in hygiene practices, which may be associated with water-borne diseases or infection. After controlling for potential confounders characteristics, we found that there is no significant association between the quantity of annual rainfall and abnormal rain in the last six months compared to the long-term rain.

Children in areas with more rainfall in the period of the survey were less likely to be wasted than children in the areas with low quantity of rainfall. This is the same with children interviewed in the period with moderately abnormal rainfall. Rainfall produces abundant water in the ground, improves the quantity of water available from safe sources, and even the quality of this water. Also, variation of rainfall influences the sanitation practice that may lead to different infections like diarrhea that may cause the malnutrition. We suggest this may be due to the infection from poor hygiene, which parents may face during the dry period due to low availability of water. During rainy periods, water may be available and improves the hygiene. People who are using the surface water that may be contaminated during rainy periods use rainwater which may prevent water-borne diseases if it is well collected and kept. This may be the same as what was found in a study published by Carleton et al., showing that heavy rainfall events were associated with increased diarrhea incidence among villagers in Ecuador (20).

Greater availability of water may enable households to adopt more hygienic practices such as hand washing. Suggesting that general conditions of household put children at risk of acute under-nutrition, improved sanitary conditions are protective against wasting by preventing vectors of infectious diseases, thereby reducing episodes of illness such as diarrhea which compromises the body's ability to convert food into energy (10). These results were consistent with other studies which found that providing children with better overall sanitary conditions prevents diarrhea and other risk factors for under-nutrition (3,33–35).

The strengths of this study include our nationally representative sample of children with extensive data about social, economic, and demographic characteristics as well as standardized measures of height and weight. Despite the breadth of this dataset, there were some important factors that were not measured, such as household food insecurity and political conditions that might affect food availability in the community. Although household wealth may serve as a proxy for food security, we recognize it as an imperfect measure.

Limitations

Despite the breadth of this dataset, there were some important factors that were not measured, such as household food insecurity and political conditions that might affect food availability in the community. Although household wealth may serve as a proxy for food security, we recognize it as an imperfect measure. Our data being all cross-sectional, we can only perform correlation analysis allowing us to generate additional hypothesis; we are therefore unable to draw any conclusive causal relationship between rainfall and childhood under-nutrition.

5. CONCLUSION

Rainfall patterns found to be associated with under five children nutritional status (under-nutrition). Estimating the effect of rainfall on malnutrition may help to better predict regions of vulnerability to under-nutrition. Child malnutrition remains a serious problem in Rwanda and further studies are needed to explore in depth the effect of rainfall on childhood malnutrition. We recommend an in-depth causal effect evaluation of the effect of rainfall on nutritional outcomes for more information about the mechanism of this association.

6. ACKNOWLEDGEMENTS

The authors would like to thank the Rwanda Meteorology Agency for access to rainfall and temperature data. We also would like to express our gratitude to Prof. Megan Murray, Dana Thomson, and Sidney for their support in rainfall data creation.

Conflict of Interest: the authors declare no conflict of interest.
Funding: none
Ethical considerations
The Rwandan National Ethics Committee granted ethics review for the RDHS data collection. Informed consent from each respondent was obtained before asking questions, and the Rwandan National Ethical Committee approved the study.
Author contribution Statement
Assumpta Mukabutera conceived, designed the protocol, implemented data analysis and drafted the manuscript writing; Jamie I. Forrest contributed to data analysis and manuscript writing and review; Marcelin Habimana contributed to data meteorological data collection and manuscript review; Laetitia Nyirazinyoye and Paulin Basinga guided the writing and revised the manuscript.

7. REFERENCES

1. Liu L, Johnson HL, Cousens S, Perin J, Scott S, Lawn JE, et al. Global, regional, and national causes of child mortality: an updated systematic analysis for 2010 with time trends since 2000. Lancet [Internet]. Elsevier Ltd; 2012 Jun 9 [cited 2012 Nov 5];379(9832):2151–61. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22579125
2. Black RE, Allen LH, Bhutta Z a, Caulfield LE, de Onis M, Ezzati M, et al. Maternal and child undernutrition: global and regional exposures and health consequences. Lancet [Internet]. 2008 Jan 19 [cited 2012 Nov 2];371(9608):243–60. Available from: http://www.ncbi.nlm.nih.gov/pubmed/18207566
3. Siddiqi M, Haque M, Goni M. Malnutrition of under-five children: evidence from Bangladesh. Asian J Med Sci [Internet]. 2011 [cited 2014 Jan 29];2:113–9. Available from: http://www.nepjol.info/index.php/AJMS/article/view/3662
4. Amsalu S, Tigabu Z. Risk factors for ever acute malnutrition inchildren under the age of five: a case-control study. Ethiop J Heal Dev [Internet]. 2008 [cited 2014 Jan 29]; Available from: http://www.ajol.info/index.php/ejhd/article/view/10058/31332
5. Wardlaw T, Salama P, Brocklehurst C. Diarrhoea: why children are still dying and what can be done. Lancet [Internet]. 2010 [cited 2014 Jan 29]; Available from: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Diarrhoea:+Why+children+are+still+dying+and+what+can+be+done#0
6. Nahar B, Ahmed T, Brown KH, Hossain MI. Risk factors associated with severe underweight among young children reporting to a diarrhoea treatment facility in Bangladesh. J Heal Popul Nutr [Internet]. 2010 [cited 2014 Jan 29];28(5):476–83. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2963770/
7. National Institute of Statistics of Rwanda (NISR) [Rwanda], Ministry of Health (MOH) [Rwanda] and II.

Rwanda Demographic and Health Survey 2010. 2011.

8. Binagwaho A, Condo J, Wagner C, Ngabo F, Karema C, Kanters S, et al. Impact of implementing performance-based financing on childhood malnutrition in Rwanda. BMC Public Health [Internet]. 2014 Jan;14(1):1132. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4237787&tool=pmcentrez&rendertype=abstract

9. Cheah W, Muda W, Zamh Z. A structural equation model of the determinants of malnutrition among children in rural Kelantan, Malaysia. Rural Remote Health [Internet]. 2010 [cited 2013 Jan 15];(10):1–12. Available from: http://www.rrh.org.au/articles/subviewnew.asp?articleid=1248

10. Samuel Oyekale A. Factors explaining acute malnutrition among under-five children in Sub-Sahara Africa (SSA). Life Sci J [Internet]. 2012 [cited 2013 Jan 16];9(4):2101–7. Available from: http://www.lifesciencesite.com/lsj/life0904/314_11976life0904_2101_2107.pdf

11. de Onis M, Blössner M, Borghi E. Prevalence and trends of stunting among pre-school children, 1990-2020. Public Health Nutr [Internet]. 2011 Jul 14 [cited 2012 Nov 11];1–7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21752311

12. Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R, et al. Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. Lancet. 2009;373(9676):1693–733.

13. Paynter S, Ware RS, Weinstein P, Williams G, Sly PD. Childhood pneumonia: A neglected, climate-sensitive disease? The Lancet. 2010. p. 1804–5.

14. Bandyopadhyay S, Kanji S, Wang L. The impact of rainfall and temperature variation on diarrheal prevalence in Sub-Saharan Africa. Appl Geogr [Internet]. Elsevier Ltd; 2012 Apr [cited 2012 Mar 30];33:63–72. Available from: http://linkinghub.elsevier.com/retrieve/pii/S014362281100155X

15. Kumar RH; Venkaiah K; Arlappa N; Kumar S; Brahmam GN. Diet and nutritional situation of the population in the severely drought affected areas of Gujarat. J Hum Ecol [Internet]. 2005;18(4):319–26. Available from: http://www.krepublishers.com/KRE-New-J/index.html

16. Obioha EE. Climate Variability and Food Production Nexus in Lesotho, 2001-2007. J Hum Ecol [Internet]. Kamla-Raj Enterprises, Delhi India; 2010;32(3):149–60. Available from: http://search.proquest.com/docview/853211076?accountid=13042\nhttp://oxfordsfx.hosted.exlibrisgroup.com/oxford?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&genre=article&sid=ProQ:ProQ:ibssshell&atitle=Climate+variability+and+food+production+nexus+in+Lesotho,+2001-+2007&title=Journal+of+human+ecology&issn=09709274&date=2010-12-01&volume=32&issue=3&spage=149&au=Obioha,+Emeka+E&isbn=&jtitle=Journal+of+human+ecology&btitle=&rft_id=info:eric/&rft_id=info:doi/\nhttp://search.proquest.c

17. Network Famine Early Warning Systems F. Satellite Image/Data. [Internet]. 2012. Available from: http://earlywarning.usgs.gov/fews/africa/web/datatheme.php?imgtype=nd&extent=e&cachekiller=250000

18. (NOAA). NO and AA. Global Land Surface Monitoring and Prediction [Internet]. 2012. Available from: http://www.cpc.ncep.noaa.gov/soilmst/leaky_glb.htm

19. Alexander KA, Carzolio M, Goodin D, Vance E. Climate Change is Likely to Worsen the Public Health Threat of Diarrheal Disease in Botswana. Int J Environ Res Public Health [Internet]. 2013;10(4):1202–30. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23531489

20. Carlton EJ, Eisenberg JNS, Goldstick J, Cevallos W, Trostle J, Levy K. Original Contribution Heavy Rainfall Events and Diarrhea Incidence : The Role of Social and Environmental Factors. 2014;179(3):344–52.

21. Jagai JS, Sarkar R, Castronovo D, Kattula D, McEntee J, Ward H, et al. Seasonality of rotavirus in south asia: A meta-analysis approach assessing associations with temperature, precipitation, and vegetation index. PLoS One. 2012;7(5).

22. Palma P, Alvarenga P, Palma V, Matos C, Fernandes RM, Soares A, et al. Evaluation of surface water quality using an ecotoxicological approach: a case study of the Alqueva Reservoir (Portugal). Environ Sci Pollut Res. 2010;17(3):703–16.

23. Xu Z, Etzel R a., Su H, Huang C, Guo Y, Tong S. Impact of ambient temperature on children's health: A systematic review. Environ Res. 2012;117:120–31.

24. WMO. Atlas of Health and climate. 2012. 1-68 p.

25. Thompson AA, Matamale L, Kharidza SD. Impact of Climate Change on Children's Health in Limpopo Province, South Africa. Int J Environ Res Public Health [Internet]. 2012;9(3):831–54. Available from: http://www.mdpi.com/1660-4601/9/3/831/

26. Skoufias E, Vinha K. Climate variability and child height in rural Mexico. Econ Hum Biol [Internet]. Elsevier B.V.; 2012 Jan [cited 2012 Mar 29];10(1):54–73. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21840273

27. Moreland S. Modeling Climate Change , Food Security , and Population Pilot-Testing the Model in Ethiopia. Group. 2012;(March).

28. Drayna P, McLellan SL, Simpson P, Li S-H, Gorelick MH. Association between Rainfall and Pediatric Emergency Department Visits for Acute Gastrointestinal Illness. Environ Health Perspect [Internet]. National Institute of Environmental Health Sciences; 2010;118(10):1439–43. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20515725

29. Grundmann R, Stehr N. Climate Change: What Role for Sociology?: A Response to Constance Lever-Tracy. Curr Sociol [Internet]. 2010 Nov 18 [cited 2013 Jan 29];58(6):897–910. Available from: http://csi.sagepub.com/cgi/doi/10.1177/0011392110376031

30. Yuan CT, Dembry LM, Higa B, Fu M, Wang H, Bradley EH. Perceptions of hand hygiene practices in China. J Hosp Infect [Internet]. The Hospital Infection Society; 2009 Feb [cited 2013 Jan 14];71(2):157–62. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19013685

31. Levy K, Hubbard AE, Eisenberg JNS. Seasonality of rotavirus disease in the tropics: a systematic review and meta-analysis. Int J Epidemiol [Internet]. Oxford University Press; 2009;38(6):1487–96. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2800782&tool=pmcentrez&rendertype=abstract

32. Linnemayr S, Alderman H, Ka A. Determinants of malnutrition in Senegal: individual, household, community variables, and their interaction. Econ Hum Biol [Internet]. 2008 Jul;6(2):252–63. Available from: http://www.ncbi.nlm.nih.gov/pubmed/18603490

33. Hien N, Hoa N. Nutritional status and determinants of malnutrition in children under three years of age in Nghean, Vietnam. Pakistan J Nutr [Internet]. 2009 [cited 2013 Jan 13];8(7):958–64. Available from: http://docsdrive.com/pdfs/ansinet/pjn/2009/958-964.pdf

34. Kanjilal B, Mazumdar PG, Mukherjee M, Rahman MH. Nutritional status of children in India: household socio-economic condition as the contextual determinant. Int J Equity Health [Internet]. 2010 Jan;9(1):19. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2931515&tool=pmcentrez&rendertype=abstract

35. Kabubo-Mariara J, Ndenge G, Mwabu D. Determinants of children's nutritional status in Kenya: Evidence from demographic and health surveys. J Afr Econ [Internet]. 2009 [cited 2014 Jan 29];18(3):363–87. Available from: http://jae.oxfordjournals.org/content/18/3/363.short