

Child undernutrition in households with microbiologically safer drinking water and 'improved water' in Tanna, Vanuatu

Alexandra L. Morrison, Hanneke Lewthwaite, Lisa A. Houghton, Daniel Sum Jimmy Nasak, Katrina J. Sharples, Peter Brown, John A. Crump and Susan J. Jack

ABSTRACT

The Sustainable Development Goal drinking water indicators include microbiological safety measures, whereas the Millennium Development Goal indicator 'improved water' may be microbiologically unsafe. In rural Vanuatu, we undertook household surveys, child anthropometry, and tested stored drinking water, to investigate relationships between water and undernutrition. Using *Escherichia coli* most probable number, we categorized results according to Compartment Bag Test drinking water cutoffs: <1/100 mL (safe), 1–10/100 mL (intermediate risk), >10–100/100 mL (high risk), and >100/100 mL (very high risk). Of 201 households, 191 (95%) had microbiologically unsafe drinking water, regardless of 'improved' status. We investigated cross-sectional associations between households with microbiologically safer drinking water (≤ 10 *E. coli*/100 mL) versus 'improved water' and undernutrition among children. Of children under 5, 145 (48.8%, 95% CI: 42.8, 54.8) were stunted and 59 (19.1%, 95% CI: 14.4, 23.8) were underweight. Among households with 'improved water', the adjusted prevalence ratio (95% CI) of stunting was 0.61 (0.46, 0.80) and underweight was 0.46 (0.29, 0.73) compared with 'unimproved water'. However, we found no association between having drinking water with ≤ 10 *E. coli*/100 mL at one point in time and undernutrition. Longer-term variations in water quality and unmeasured conditions beyond water may have contributed to these associations.

Key words | improved water, stunting, undernutrition, Vanuatu, water quality, WASH

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INTRODUCTION

The Sustainable Development Goal (SDG) drinking water indicators incorporated microbiological testing to address concerns that the Millennium Development Goal's (MDG's) 'improved water' indicator did not equate with microbiological safety (Clasen 2012; Shaheed *et al.* 2014; Heitzinger *et al.* 2015). The MDGs' definition of 'improved

water' is piped water into dwelling, yard, or plot; piped water to public standpipes; tubewell or borehole; protected dug well; protected spring; or rainwater collection (Box 1). It has been suggested that the health benefits associated with 'improved water' coverage have been overestimated (Clasen 2012). In response, the Joint Monitoring Programme

Box 1 | Definitions of SDG and MDG water indicators

SDGs		MDGs
Safely managed service	A basic/improved drinking water source, located on premises, available when needed and free of fecal (<1 <i>E. coli</i> /100 mL) and priority chemical contamination	Improved drinking water source Piped water into dwelling, yard or plot; piped water to a public standpipes; tubewell or borehole; protected dug well; protected spring; or rainwater collection
Basic service	An improved water point provided collection time is <30 min for a roundtrip	
Limited service	Drinking water from unprotected springs or dug wells, carts with small tank/drum, tanker trucks or basic/improved sources with a total collection time of >30 min for a roundtrip	Unimproved drinking water source unprotected springs or dug wells, carts with small tank/drum, tanker trucks, surface water, or bottled water
No service	Drinking water coming from surface water	

Adapted from [Ps-Eau \(2016\)](#).

(JMP) for Water Supply and Sanitation of the World Health Organization (WHO) and the United Nations International Children's Emergency Fund (UNICEF) developed new indicators for measuring access to safe drinking water for SDG monitoring (SDG 6.1 Global Indicator 6.1.1) ([WHO/UNICEF 2017](#)). These SDG indicators recognize that safe drinking water should be compliant with the WHO fecal contamination standard of less than one *Escherichia coli* colony-forming unit per 100 mL (equivalent to the most probable number, MPN) and compliant with WHO chemical contamination standards ([WHO/UNICEF 2017](#)). With the SDG indicators, 'safely managed drinking water' is defined as an improved drinking water source that is located on the premises, available when needed, and free of fecal, arsenic, and fluoride contamination ([Box 1](#)). It is expected that the SDG water indicators will be more closely related to health risk ([WHO 2016](#)).

Child undernutrition is multifactorial and is a recognized consequence of poor nutrition and exposure to fecal contamination. Substandard water, sanitation, and hygiene (WASH) practices can lead to growth faltering through repeated bouts of diarrhea ([Guerrant *et al.* 2013](#)). Another proposed mechanism is the ingestion of large quantities of microbes in water contaminated with feces, which alters gut structure and function, leading to environmental enteric dysfunction (EED). EED is postulated to impair linear growth through insufficient nutrient absorption and chronic systemic inflammation that is independent of diarrhea

occurrences ([Keusch *et al.* 2014](#); [Crane *et al.* 2015](#)). Many studies have described associations between WASH shortcomings and undernutrition, in particular, stunting ([Dangour *et al.* 2013](#); [Vilcins *et al.* 2018](#)). However, although there is reasonably good evidence for an association between poor sanitation and undernutrition, the association with unsafe drinking water is unclear. Studies show differing relationships depending upon the population and water measure used ([Vilcins *et al.* 2018](#)). Water measures that accurately reflect the water risk are likely to better elucidate this relationship, such as a recent study by [Lauer *et al.* \(2018\)](#).

WHO recommends an integrated approach to improving child nutrition outcomes that combines both nutrition and WASH interventions. Recently, large clustered randomized control trials (RCTs), the WASH benefits studies ([Stewart *et al.* 2018](#); [Tofail *et al.* 2018](#)), and the Sanitation Hygiene Infant Nutrition Efficacy (SHINE) trial ([Prendergast *et al.* 2019](#)) concluded that WASH interventions did not improve growth without parallel nutrition interventions. However, the authors noted that uptake of WASH interventions was low and their conclusions may not be generalizable to populations where baseline characteristics differ.

In the Republic of Vanuatu, the proportion of the population with reported access to 'improved water' in rural areas is 87% ([WHO/UNICEF 2017](#)). However, groundwater in Vanuatu is frequently contaminated with *E. coli* ([Foster *et al.* 2019](#)). Despite improved water and food security

provided by subsistence agriculture (World Vision 2013), the proportion of children under 5 years of age with poor nutrition outcomes in rural Vanuatu is high. The Vanuatu (2014) Demographic and Health Survey reported that in rural populations isolated from the main centers, 32% of children under 5 years were stunted (Vanuatu Ministry of Health 2014). Concurrently, there were just 12% of households reporting child diarrheal diseases in the previous two weeks (Vanuatu Ministry of Health 2014).

We sought to investigate the microbiological status of 'improved water' compared with 'unimproved water' in Vanuatu and whether there were associations between water microbiological quality and nutrition outcomes in children under 5 years of age in the context of a food secure population with suspected widespread undernutrition concerns. A cross-sectional study was undertaken, involving household questionnaires, observations of WASH facilities, microbiologically testing of stored household drinking water, and child anthropometry in a small, rural population of Vanuatu.

MATERIALS AND METHODS

Survey setting and design

We conducted a cross-sectional survey from 19 through 29 January 2015 in an area participating in a three year World Vision Integrated WASH and Nutrition Project in southwest Tanna, an island in Tafea Province, Vanuatu (Figure 1). The overall goal of the World Vision Integrated WASH Project was to reduce child undernutrition, with short- and medium-term objectives to increase WASH infrastructure and improve caregiver WASH and nutrition knowledge and practices. Our survey took place at the end of the second year of the project when the sanitation and hygiene components of the project had been completed, but the water infrastructure component was yet to begin. The study population consisted of 28 villages with approximately 2,500 individuals in total. There was a total of 233 households with at least one child under 5 years of age, and complete enumeration of households and their children under 5 was attempted. A total of 13 households were not included: 12 were not present at the time of the survey as

they were visiting non-study communities and one refused because of sick children in the household. A total of 220 households with 320 children under 5 years of age were included in our study. Figure 2 describes the numbers of households and children involved in each component of the study and where data were missing. All households in the study population were remote and rural, and participants were estimated to be in the lowest wealth quintiles (Vanuatu Ministry of Health 2014).

Following informed consent, interviews were conducted with the primary caregiver of the child and direct observations of WASH facilities were made. All interview and observation responses were recorded directly into smartphones (Samsung Group, Seoul, South Korea) using the survey platform Fieldtask, developed by Smap Consulting (Neil Penman, VIC, Australia).

WASH facilities

'Improved water' and 'unimproved water' definitions are based on WHO/UNICEF definitions described in Box 1. In our household questionnaire, adequate water treatment was defined as a treatment method that included a step to effectively remove most pathogens, such as boiling or ceramic filtration (WHO 2013). In observations of WASH facilities, adequate drinking water storage was defined as having drinking water separate from water used for cleaning and other purposes, covered with a lid and with a narrow mouth or a spigot (WHO 2013). An improved latrine was defined as a ventilated improved pit (VIP) latrine or a simple pit latrine with a concrete slab and further defined into SDG indicators 'basic service' or 'limited service' based on shared status (United Nations Water 2016). An operational handwashing facility was defined as one which was able to be used when study observations took place.

Water sampling and microbiology

We sampled drinking water that was stored at the household in drinking water storage containers. No households had water piped directly into the dwelling. The sources of the stored water included 'improved water' from piped water to public standpipes from protected or unprotected sources,

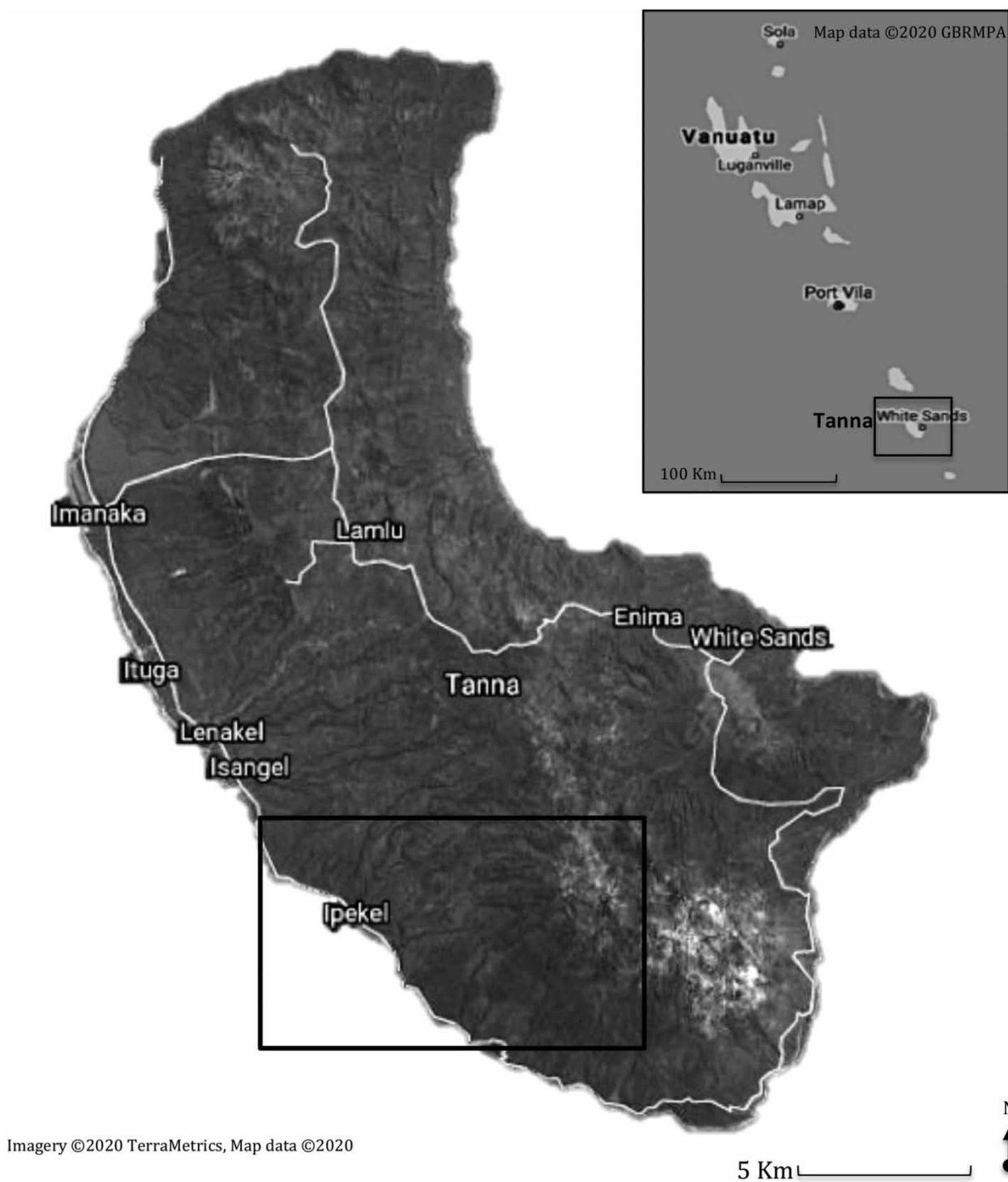


Figure 1 | Map of project area within Tanna, Vanuatu. Edited Google Maps locations: Vanuatu and Tanna, Vanuatu.

and rainwater; and ‘unimproved water’ from unprotected springs, and surface water.

At each household, we collected 100 mL of drinking water into sterile bottles. Any ornamental or other objects

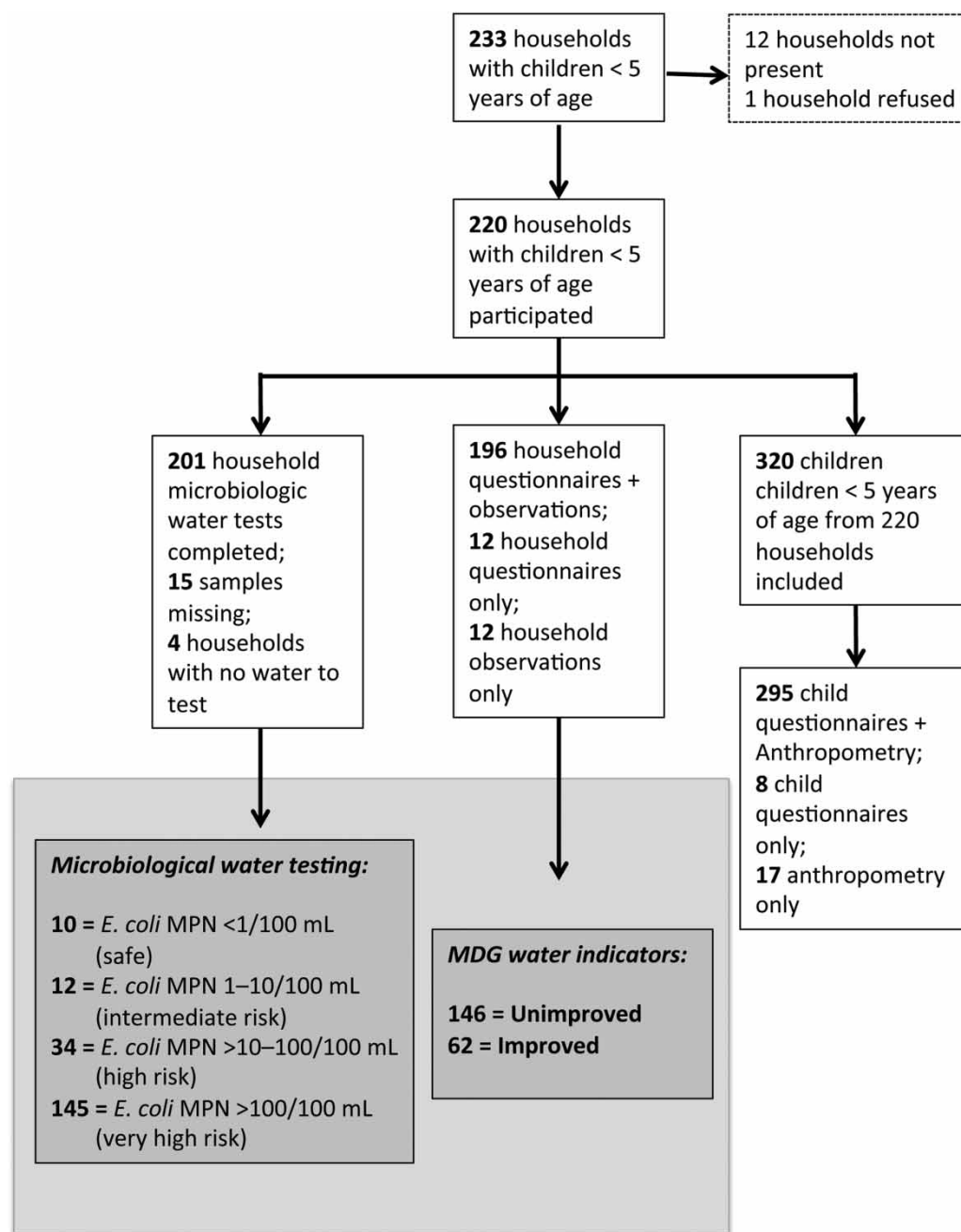


Figure 2 | Numbers of households and children involved in each of the study components in Tanna, 2015. Microbiological water categories according to the Aquagenx CBT method (Aquagenx 2013), based on WHO Guidelines for Drinking Water Quality, 4th ed.

were removed from the spigot or mouth of the container before sampling. We used the Compartment Bag Test (CBT) (Aquagenx, USA) method to estimate an MPN of *E. coli* based on color changes. We processed samples according to the manufacturer's instructions within 6 h of collection (Aquagenx 2013). We recorded color changes 48 h after

processing unless all compartments, indicating varying *E. coli* concentrations, had become positive before 48 h. Positive and negative *E. coli* controls for each batch of CBTs were tested prior to data collection. Negative controls were also tested during data collection. We categorized results according to Aquagenx CBT recommended categories (Aquagenx

2013), which are based on WHO Guidelines for Drinking Water Quality, 4th Edition (WHO 2011): MPN of <1 *E. coli*/100 mL (safe), 1–10 *E. coli*/100 mL (intermediate risk), >10 –100 *E. coli*/100 mL (high risk), and >100 *E. coli*/100 mL (very high risk).

Anthropometry

Growth measures were used as a proxy for child undernutrition. Anthropometric measurements were carried out on children under 5 years of age and their mothers. Measurements were conducted by trained personnel using calibrated equipment, standardized procedures, and conventional protocols (Cogill 2013). We used WHO recommended cutoffs: Z-score <-2 was used for stunting, wasting, and underweight; and Z-score <-3 was used for severe stunting, wasting, and underweight. Anthropometry measurements were excluded if they had missing information or if the Z-score was 5 or more standard deviations from the mean, indicating possible measurement error.

Covariates

Known confounders of the relationship between WASH and undernutrition were investigated, including child age, child gender, maternal height, and education of the primary caregiver. Maternal height was measured objectively at the household, and education was measured by self-report in the household questionnaire. We had insufficient household asset data to generate a wealth index.

Potential confounders of the relationship between water indicators and undernutrition were also investigated and included the WASH facilities described above, minimum dietary diversity (MDD), and diarrhea. Data for MDD were collected according to the WHO Infant and Young Child Feeding (IYCF) recommendation that children 6–23 months of age should be receiving food from at least four of the seven IYCF food groups. The IYCF food groups are grains, roots, and tubers; legumes and nuts; dairy products; flesh foods; eggs; vitamin-A rich fruits and vegetables; and other fruits and vegetables (WHO 2008). Caregivers were asked if each child under 5 years of age had experienced diarrhea (defined as three or more loose stools in the previous 24 h) in the past 7 days.

Statistical analysis

All data were analyzed using Stata 13.1. We used univariate and multivariate analyses to investigate any associations between households having MDG ‘improved water’ and water that tested <1 *E. coli*/100 mL or >100 *E. coli*/100 mL. For these analyses, we used a logistic model to generate odds ratios (ORs) because of symmetry with respect to outcome and exposure. We also controlled for village-level variation using clustering.

We then investigated any associations between ‘improved water’ and child undernutrition, and microbiological quality and undernutrition. Because of the low numbers of household drinking water with <1 *E. coli*/100 mL, these analyses used a dichotomous microbiological indicator of ≤ 10 *E. coli*/100 mL (safe or intermediate risk) compared to >10 *E. coli*/100 mL (high or very high risk).

We estimated unadjusted and adjusted associations using generalized estimating equation (GEE) models to obtain estimates with 95% confidence intervals and *P*-values which allowed for the clustering. As multiple children under five were surveyed at some households, two levels of data nesting, household and village, were used when any child measure was the outcome. We used independent working correlations with robust standard errors. When weight-for-height Z (WHZ) scores, height-for-age Z (HAZ) scores, or weight-for-age Z (WAZ) scores were the outcomes, we used a Gaussian GEE model to estimate the mean difference (MD) in Z-score. Where wasting, stunting, and underweight were the outcomes, we used a Poisson model (log link with Poisson errors) to generate prevalence ratios (PRs). The robust standard errors also account for the fact that the data were binary rather than Poisson.

The Zanthro Stata (StatsCorp, TX, USA) (Vidmar *et al.* 2004) module was used to generate HAZ scores (stunting), WAZ scores (underweight), and WHZ scores (wasting), based on 2006 child growth standards (WHO Multicentre Growth Reference Study Group 2006).

Known confounders of relationships were included in multivariate models regardless of significance in our univariate analysis. Potential confounders were included in the multivariate model after investigation by univariate analysis showed plausible confounding associations with *p*-values ≤ 0.1 . A *P*-value of ≤ 0.05 was considered significant in all final analyses. Complete case analysis was used, so differences

in the total numbers of children or households between tables are due to missing outcomes for some study components.

Research ethics

Free and informed consent of the participants or their legal representatives was obtained, and the study protocol was approved by the Human Ethics Committee (Health), University of Otago, New Zealand, Number 14/224, January 2015. We also obtained consent from the Ministry of Health, Vanuatu.

RESULTS

Demographics and WASH

Participation in the study components is summarized in Figure 2. Of the 233 households in the study population with children under 5 years of age, 220 (94.4%) were eligible and agreed to participate. The 220 households included 320 children under 5 years of age. Of the 208 household questionnaires completed, the mother was the main caregiver respondent and the median age (range) was 28 (16–69) years. Half of the caregivers reported that they had not received any schooling (Table 1).

Of the 208 households participating in the household survey, 63 (30.3%) self-reported adequate treatment of drinking water, with boiling water being the only adequate treatment method reported (Table 1). Of the 208 households participating in the WASH observation survey, 11 (5.3%) had adequate water storage; 106 (51.0%) had operational handwashing facilities, consisting of tippy tap variations using plastic containers or bamboo shoots to hold water; and 202 (97.1%) had improved latrines in the form of VIP latrines or improved simple pit latrines. When information from both observations and questionnaires were combined, 116 (59.2%) of 196 met the SDG sanitation definition of 'basic service', based on shared status.

Drinking water microbiological quality and relationship to water indicators

Of the 201 households that had stored water tested, 10 (5.0%) had water that met WHO fecal contamination

standards for drinking water, <1 *E. coli*/100 mL (Figure 2). A further 12 (6.0%) households had drinking water with 1–10 *E. coli*/100 mL; 34 (16.9%) with >10 –100 *E. coli*/100 mL; and 145 (72.1%) with >100 *E. coli*/100 mL.

Of 208 households, 62 (29.8%) reported collecting drinking water from 'improved water' sources, which consisted of 46 (74.2%) gravity fed systems to public standpipes and 16 (25.8%) rainwater catchments (Table 1). When we classified household drinking water according to SDG indicators (Box 1), 37 (17.8%) of the 208 households met the requirements for 'basic drinking water', and 5 (2.4%) met the requirements for 'safely managed drinking water'.

Table 2 compares MDG 'improved water' with microbiological quality. Of the 57 households with improved water in this analysis, 50 (87.7%) had >1 *E. coli*/100 mL. In our univariate analysis, the odds of having drinking water <1 *E. coli*/100 mL was higher in households with 'improved water' (unadjusted OR: 6.02, 95% CI: 1.25, 29.10) than households with unimproved water. However, this was no longer significant when other WASH factors were adjusted for, including water treatment. The odds of having water with >100 *E. coli*/100 mL was lower in households with 'improved water', and this association remained significant when adjusted for WASH factors (adjusted OR: 0.22, 95% CI: 0.08, 0.65).

Variables associated with household drinking water ≤ 10 *E. coli*/100 included the caregiver having any primary or above education ($P = 0.001$), secondary education ($P = 0.02$), and self-reported adequate water treatment ($P = 0.021$) (Table 1). Household drinking water ≤ 10 *E. coli*/100 was also associated with having rainwater as the main drinking water source ($P = 0.011$) but not water from public standpipes ($P = 0.479$) (Table 1).

Variables associated with households using 'improved water' were having primary or above education ($P = 0.003$), secondary education ($P = 0.048$), and adequate water storage ($P = 0.048$) (Table 1).

Child anthropometry indicators

A total of 312 children under 5 years of age were available to have anthropometry measurements taken. The numbers in the analyses vary due to missing information (height/

Table 1 | Participant, caregiver, and WASH characteristics by improved water status and household drinking water *E. coli* MPN in Tanna, 2015

	Improved status				Household water <i>E. coli</i> MPN					
	Improved		Unimproved		P-value ^a	≤10/100 mL		>10/100 mL		P-value ^a
	<i>n</i>	(%)	<i>n</i>	(%)		<i>n</i>	(%)	<i>n</i>	(%)	
Children	(N = 101)		(N = 213)			(N = 37)		(N = 253)		
Under 2 years of age	50	(49.5)	97	(45.5)		17	(46.0)	118	(46.6)	
Age in months: Medium (range)	26.7	(0.3–59.1)	26.3	(0.1–59.9)	0.894	27.7	(0.3–53.6)	25.4	(0.1–59.9)	0.749
Gender, female	48	(47.5)	110	(51.6)	0.528	20	(54.1)	117	(47.6)	0.367
Diarrhea ^c , yes	14/95	(14.7)	21	(10.1)	0.239	7	(18.9)	26/235	(11.1)	0.187
Child MDD ^b (ages 6–23 months only)	16/30	(53.3)	43/65	(66.2)	0.882	5/12	(41.7)	48/73	(65.8)	0.447
Primary caregiver	(N = 62)		(N = 146)			(N = 22)		(N = 167)		
Mother was respondent	59	(95.2)	136	(93.2)		22	(100)	157	(94.0)	
Education										
Any primary or above	47	(75.8)	54	(37.0)	0.003	18	(81.8)	74	(44.3)	0.001
Secondary	13	(21.0)	16	(11.0)	0.048	8	(36.4)	19	(11.4)	0.020
Height in cm: Median (range)	158.9	(147.6–186.7)	155.7	(146.2–167.7)	0.608	156.2	(147.6–186.7)	157.0	(147.4–170.9)	0.291
Age in years: Median (range)	27	(18–49)	28	(16–69)	0.318	25.5	(16–42)	28	(17–69)	0.251
WASH indicators^d										
<i>Self reported from household questionnaire</i>	(N = 62)		(N = 146)			(N = 22)		(N = 167)		
Improved water	62	(100.0)	0	(0.0)		13	(59.1)	44	(26.4)	0.004
Pubic standpipe	46	(74.2)				6	(27.3)	35	(21.0)	0.479
Rainwater catchment	16	(25.8)				7	(31.8)	9	(5.4)	0.011
Adequate water treatment self-report	20	(32.3)	43	(29.5)	0.693	11	(50.0)	48	(28.9)	0.021
<i>Observed</i>	(N = 61)		(N = 135)			(N = 22)		(N = 174)		
Water storage adequate	6	(9.8)	5	(3.8)	0.048	1	(4.5)	9	(5.2)	0.861
Latrine improved (total)	57	(93.4)	133	(98.5)	0.081	21	(95.5)	157/162	(96.9)	0.540
Basic service (<i>not shared</i>)	34	(55.7)	82	(60.7)	0.078	11	(50.0)	98/162	(60.5)	0.522
Limited service (<i>shared</i>)	23	(37.7)	51	(37.8)		10	(45.5)	59/162	(36.4)	
Operational handwashing facility	31	(50.8)	72	(53.3)	0.787	9	(40.9)	89	(51.2)	0.462

Differing *N*s for differing survey components are specified (child questionnaire, household questionnaire, observations). *n* (%) may not add to final *N* because of missing values. Missing <5% unless denominator specified.

^aP-values adjusted for clustering by household and village (child indicators) or village (household indicators).

^bYCF MDD – World Health Organization Infant and Young Child Feeding Minimum Dietary Diversity.

^cDiarrhea in last 7 days.

^dWASH – water, sanitation, and hygiene.

Table 2 | Household water MPN and improved water status in Tanna, 2015**Household improved drinking water source**

	Improved		Unimproved		Unadjusted OR	(95% CI)	P-value	Adjusted ^b OR	(95% CI)	P-value
	n	(%)	n	(%)						
Household water MPN ^a	(N = 57)		(N = 132)							
<1 <i>E. coli</i> /100 mL	7	(12.3)	3	(2.3)	6.02	(1.25, 29.10)	0.025	2.80	(0.55, 16.08)	0.205
1–10 <i>E. coli</i> /100 mL	6	(10.5)	6	(4.6)						
>10–100 <i>E. coli</i> /100 mL	18	(31.6)	14	(10.6)						
>100 <i>E. coli</i> /100 mL	26	(45.6)	109	(82.6)	0.18	(0.06, 0.49)	0.001	0.22	(0.08, 0.65)	0.006

^aAquagenx CBT categories, based on WHO Guidelines for Drinking Water Quality, 4th ed.^bAdjusted for water treatment, water storage, and having an improved latrine.

length, weight, or age) or data excluded for suspected measurement error. Of the 297 children in the height-for-age (HAZ) analysis, 145 (48.8%, 95% CI: 42.8, 54.8) were stunted ($<-2z$), including 52 (17.5%) severely stunted ($<-3z$). Of the 309 children in the weight-for-age (WAZ) analysis, 59 (19.1%, 95% CI: 14.4, 23.8) were underweight ($<-2z$), including 19 (6.2%) severely underweight ($<-3z$). Of the 303 children in the weight-for-height (WHZ) analysis, 12 (4.0%, 95% CI: 1.8, 6.1) were wasted ($<-2z$), including 2 (0.7%) severely wasted ($<-3z$).

Associations between water indicators and undernutrition

Table 3 describes the proportion of child nutrition outcomes according to household drinking water microbiological quality (≤ 10 *E. coli*/100 mL or >10 *E. coli*/100 mL) and household drinking water status ('improved water' or 'unimproved'). Table 4 shows our investigation of associations between drinking water microbiological quality and child undernutrition using univariate and multivariate analysis. We found no association between having drinking water with ≤ 10 *E. coli*/100 mL and HAZ, WAZ, WHZ, stunting, or underweight in our analyses. No children in households with drinking water ≤ 10 *E. coli*/100 mL were wasted, therefore this could not be investigated in our model.

Table 5 shows our investigation of associations between having 'improved water' and child undernutrition. In multivariate analysis, the adjusted MD in child HAZ and WAZ was 0.43 (95% CI: 0.20, 0.67) and 0.36 (95% CI: 0.12, 0.59) higher, respectively, in households using 'improved

water' compared to 'unimproved water'. We found no association between WHZ and households with 'improved water'.

In multivariable analysis, the adjusted prevalence of stunted children was 39% lower in households using 'improved water' compared with those using 'unimproved water' (PR: 0.61, 95% CI 0.46, 0.80), and the prevalence of severe stunting was 59% lower (PR: 0.41, 95% CI 0.19, 0.90). The prevalence of underweight children was 54% lower in households using 'improved water' than households using 'unimproved water' (PR: 0.46, 95% CI 0.29, 0.73) in multivariate analysis. There was no statistical difference in the prevalence of wasted children among households with 'improved water' compared to 'unimproved water' although no children from households with 'improved water' were severely wasted or severely underweight.

DISCUSSION

We found that the majority of stored water in southwest Tanna, Vanuatu, at this single point in time had microbiological contamination, regardless of MDG 'improved water' status. Concurrently, according to WHO classifications, the population had a very high prevalence of stunted children and a medium prevalence of underweight children (WHO/UNICEF 2019). Compared with households with MDG 'unimproved water', those households with 'improved water' were likely to have fewer children being stunted and severely stunted, and underweight. However, there was no association

Table 3 | Undernutrition among children under 5 years of age by improved water status and household drinking water *E. coli* MPN in Tanna, 2015

	Improved status				Household water <i>E. coli</i> MPN			
	Improved		Unimproved		≤10/100 mL		>10/100 mL	
	<i>n</i>	(%)	<i>n</i>	(%)	<i>n</i>	(%)	<i>n</i>	(%)
Stunting	(N = 96)		(N = 196)		(N = 34)		(N = 232)	
Normal (≥−2z)	65	(67.7)	83	(42.4)	20	(58.8)	116	(50.0)
Stunted (<−2z)	31	(32.3)	113	(57.7)	14	(41.2)	72	(31.0)
Severely stunted (<−3z)	8	(8.3)	44	(22.5)	5	(14.7)	44	(19.0)
HAZ ^a score (Median (range))	−1.62	(−4.47, 4.50)	−2.19	(−4.96, 1.79)	−1.73	(−4.23, 4.50)	−2.02	(−4.96, 2.46)
Underweight	(N = 100)		(N = 203)		(N = 37)		(N = 239)	
Normal (≥−2z)	90	(90.0)	154	(75.9)	31	(83.8)	191	(79.9)
Underweight (<−2z)	10	(10.0)	49	(24.1)	6	(16.2)	30	(12.6)
Severely Underweight (<−3z)	0	(0.0)	19	(9.4)	0	(0.0)	18	(7.5)
WAZ ^a score (Median (range))	−0.71	(−2.95, 2.26)	−1.09	(−4.87, 3.51)	−1.20	(−2.82, 3.51)	0.95	(−4.86, 2.82)
Wasting	(N = 96)		(N = 202)		(N = 35)		(N = 235)	
Normal (≥−2z)	95	(99.0)	191	(94.6)	35	(100.0)	224	(95.3)
Wasted (<−2z)	1	(1.0)	11	(5.5)	0	(0.0)	9	(3.8)
Severely wasted (<−3z)	0	(0.0)	2	(1.0)	0	(0.0)	2	(0.85)
WHZ ^a score (Median (range))	0.25	(−2.32, 2.26)	0.03	(−4.14, 2.71)	−0.19	(−1.88, 1.41)	0.15	(−4.14, 2.71)

^aWHZ – weight-for-height Z-score, HAZ – height-for-age Z-score, and WAZ – weight-for-age Z-score.

Table 4 | Unadjusted and adjusted estimations of associations between undernutrition and water with an *E. coli* MPN ≤10/100 mL in Tanna, 2015

	Household water MPN ≤10/100 mL ^a					
	Unadjusted MD ^b	(95% CI)	P-value	Adjusted ^c MD	(95% CI)	P-value
HAZ-score	0.20	(−0.32, 0.72)	0.437	0.07	(−0.42, 0.56)	0.770
WAZ-score	0.10	(−0.27, 0.47)	0.586	−0.09	(−0.45, 0.27)	0.625
WHZ-score	−0.25	(−0.02, −0.47)	0.033	−0.33	(−0.67, −0.01)	0.057
	Unadjusted PR ^b	(95% CI)	P-value	Adjusted ^c PR	(95% CI)	P-value
Stunting (<−2z)	1.02	(0.53, 1.95)	0.959	0.96	(0.49, 1.90)	0.904
Severe stunting (<−3z)	0.92	(0.40, 2.14)	0.849	1.04	(0.48, 2.24)	0.929
Underweight (<−2z)	1.13	(0.63, 2.02)	0.682	1.19	(0.58, 2.45)	0.642

^aMicrobiological groupings are amalgamated Aquagenx CBT categories: ≤10 *E. coli*/100 mL (safe and intermediate risk) compared to >10/100 mL (high and very high risk).

^bMD – mean difference and PR – prevalence ratio.

^cAssociations adjusted for child age, child gender, maternal height, and caregiver education.

between having lower drinking water contamination (≤10 *E. coli*/100 mL) at the household and undernutrition.

Although we found that ‘improved water’ was less likely to have >100 *E. coli*/100 mL compared with ‘unimproved water’, the majority of ‘improved water’ had microbiological

contamination at the time of testing. This finding is consistent with other studies (Clasen 2012; Shaheed *et al.* 2014; Heitzinger *et al.* 2015). Despite ‘improved water’ not equating to having water <1 *E. coli*/100 mL, we cannot rule out that ‘improved water’ may have lower microbiological

Table 5 | Unadjusted and adjusted estimations of associations between undernutrition and improved water in Tanna, 2015

	Unadjusted MD ^a	(95% CI)	P-value	Adjusted ^b MD	(95% CI)	P-value
HAZ-score	0.60	(0.27, 0.94)	0.001	0.43	(0.20, 0.67)	0.001
WAZ-score	0.52	(0.20, 0.84)	0.002	0.36	(0.12, 0.59)	0.004
WHZ-score	0.23	(0.02, 0.45)	0.036	0.17	(−0.17, 0.50)	0.313
	Unadjusted PR ^a	(95% CI)	P-value	Adjusted ^b PR	(95% CI)	P-value
Stunting (< −2z)	0.55	(0.43, 0.70)	<0.001	0.61	(0.46, 0.80)	<0.001
Severe stunting (< −3z)	0.37	(0.19, 0.72)	0.003	0.41	(0.19, 0.90)	0.025
Underweight (< −2z)	0.43	(0.24, 0.78)	0.006	0.46	(0.29, 0.73)	0.001
Wasting (< −2z)	0.17	(0.02, 1.58)	0.119	0.20	(0.03, 1.51)	0.119

^aMD – mean difference and PR – prevalence ratio.^bAssociations adjusted for: child age, child gender, maternal height, caregiver education, adequate water storage, and having an improved latrine (VIP latrine or improved pit latrine).

contamination over the long term rather than a single time point tested here, as, by the nature of their design and construction, they offer some protection from external contamination (WHO/UNICEF 2017). Our finding of an association between ‘improved water’ and fewer poor nutrition outcomes supports this hypothesis, particularly for stunting which occurs over long exposure periods (Prendergast & Humphrey 2014).

Microbiologically testing drinking water at one point in time may not reflect long-term exposure to contaminated drinking water and may not provide an accurate representation of long-term water quality because of fluctuation in response to environmental conditions (Csuros 1994; WHO 2011). This is supported by Geen *et al.* (2011), who reported that fecal contamination varied by up to 50% from season to season in Bangladesh. In Tanna, variation in microbiological water quality is likely driven by heavy rainfall and flooding in the wet season, when our study took place, and turbidity from volcanic ash (Nath *et al.* 2006).

To our knowledge, no previous studies have directly compared MDG ‘improved water’ and microbiological quality to undernutrition outcomes in the same population. Previous studies have reported associations between drinking water and child undernutrition (Huttly *et al.* 1990; Esrey 1996; Merchant *et al.* 2003; Ellis & Schoenberger 2017; Lauer *et al.* 2018). However, a 2018 systematic review concluded that the evidence of a casual association was inconclusive because the simplified water indicators did not take into account household water storage and handling, and a lack of studies testing the actual water quality

(Vilcins *et al.* 2018). A recent study also using the CBT method found that microbiologically unsafe drinking water at one point in time was related to both EED and stunting in Uganda (Lauer *et al.* 2018), supporting the proposed mechanism between water, EED, and growth (Ngure *et al.* 2014). However, recently published large RCTs have emphasized that WASH interventions, as they are currently delivered, may be limited in their impact on child growth (Stewart *et al.* 2018; Tofail *et al.* 2018; Prendergast *et al.* 2019).

Using CBTs to measure water contamination was a strength of our study as it has high sensitivity and specificity when compared with membrane filtration (Stauber *et al.* 2013), did not require laboratory staff or equipment, and was relatively inexpensive. The increasing accessibility of water microbiological quality testing kits that can be used in field situations has the potential to greatly enhance community water development projects. Regular water testing by communities would allow for community awareness of water risk and ownership of interventions to mitigate risk where necessary as well as making SDG monitoring more reliable. However, WHO and UNICEF have recognized that attaining water microbiological quality results that are truly representative is a challenge for SDG monitoring (WHO/UNICEF 2012).

There are a number of limitations in our study. Although our population of south-west Tanna represents a distinct population, the results of recent RCT studies encourage us to be cautious with our findings, as they may be influenced in part by the cross-sectional nature of our study. In particular, causality cannot be inferred because poor nutritional

status may have preceded water source use, as it was unknown exactly how long households had been using the water sources. In addition, unknown confounders were not able to be controlled for in our multivariate analyses. For example, we lacked sufficient information to generate a wealth index, so could not examine this potential confounder between wealth, 'improved water', and health. As all households in our study were homogeneously in the lowest wealth quintile of Vanuatu and geographically isolated from main centers (World Vision 2013), we do not believe this affected our conclusions. Our study may also have lacked power to detect relevant associations. Low numbers of household with drinking water <1 *E. coli*/100 mL meant we could not investigate this category for associations with child undernutrition. At the time of the study, food security was reported to be achieved via self-subsistence agriculture (World Vision 2013). Although a variety of fruits, vegetables, and fish are available all year round in Vanuatu, we cannot be certain that children's dietary requirements were always upheld, and thus, poor diets prior to survey may be influencing our results. Self-report is also known to be unreliable in surveys, due to social desirability bias. To mitigate this, whenever possible in our study, WASH facilities were observed. Furthermore, our results may not be generalizable to other populations where water sources and environmental conditions differ, or to food insecure populations.

CONCLUSION

Our study sought to investigate the relationship between MDG 'improved water', microbiological water quality, and child undernutrition in a rural Vanuatu population underrepresented in the literature. The finding of extensive water contamination, regardless of improved status, and a high prevalence of child undernutrition emphasizes the need for continued community-led projects to address these problems. We found that 'improved water' was associated with a lower prevalence of undernutrition, whereas having drinking water with ≤ 10 *E. coli*/100 mL, measured at one point in time, was not. It is possible that long-term variations in water microbiological quality and unmeasured conditions beyond water quality drove these associations. Therefore, it would be beneficial for future studies to tease out the true nature of these

relationships by looking at microbiological water quality and undernutrition over time in a population. Future studies should also aim to evaluate the SDG 'safely managed drinking water' indicator that combines the 'improved water' outcome with water microbiological quality and accessibility, as very few households in our study met these requirements. Establishing water indicators that can reflect health consequences is important for identifying whether poor drinking water is a risk factor for child morbidity in a population, and for monitoring interventions more efficiently.

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DISCLOSURE

The findings and conclusions in this report are that of the authors alone, and do not necessarily represent the position of the University of Otago, World Vision, or the New Zealand Aid Programme.

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