ORIGINAL ARTICLE

Determinants of diarrhoeal diseases and height-for-age *z*-scores in children under five years of age in rural central Tanzania

ELPIDIUS RUKAMBILE[1-3*], GARY MUSCATELLO[1], VITALI SINTCHENKO[2,4], PETER C. THOMSON[1], WENDE MAULAGA[3], RICHARD MMASSY[5], JULIA DE BRUYN[6], RICHARD KOCK[7], IAN DARNTON-HILL[8], ROBYN ALDERS[9-12]
[1] School of Life and Environmental Sciences, Faculty of Science, The University of Sydney, Australia; [2] Marie Bashir Institute for Infectious Diseases and Biosecurity, The University of Sydney, Australia; [3] Tanzania Veterinary Laboratory Agency, Dar es Salaam, Tanzania; [4] Centre for Infectious Diseases and Microbiology - Public Health, Westmead Hospital and New South Wales Health Pathology, Sydney, Australia; [5] University of Dar es Salaam, Dar es Salaam, Tanzania; [6] Natural Resources Institute, University of Greenwich, United Kingdom; [7] The Royal Veterinary College, University of London, United Kingdom; [8] The University of Sydney, Faculty of Medicine and Health; [9] Kyeema Foundation, Brisbane, Australia; [10] Centre for Global Health Security, Chatham House, London, United Kingdom; [11] Development Policy Centre, Australian National University, Canberra, Australia; [12]Department of Infectious Disease and Global Health, Cummings School of Veterinary Medicine, Tufts University

Keywords

Gastrointestinal infection • Linear growth • Mpwapwa • Manyoni • Stunting

Summary

Introduction. *Childhood diarrhoeal diseases and stunting are major health problems in low- and middle-income countries (LMICs). Poor water supply, sanitation services and hygiene, frequently encountered in resource-poor settings, contribute to childhood diarrhoea and stunting.*
Methods. *Data on demographic characteristics, hygiene practices, sanitation and human-animal interactions (predictors) and child height-for-age z-scores (HAZ) (outcome) were collected once, while diarrhoea incidences were collected fortnightly for 24 months (outcome).*
Results. *Drinking water from public taps (OR = 0.51, 95% CI. 0.44 - 0.61; p < 0.001) and open wells (OR = 0.46, 95% CI. 0.39 - 0.54; p < 0.001) and older age of children (OR = 0.43, 95% CI. 0.27 - 0.67; p < 0.001) were protective against diarrhoea. Inappropriate disposal of children's faeces (OR = 1.15, 95% CI. 1.02 - 1.31; p = 0.025), sharing water sources with animals in the dry season (OR = 1.48, 95% CI. 1.29 - 1.70; p < 0.001), overnight sharing of houses with cats (OR = 1.35, 95% CI. 1.16 - 1.57; p < 0.001) and keeping chickens inside the house overnight regardless of room (OR = 1.39, 95% CI. 1.20 - 1.60; p < 0.001) increased the risk of diarrhoea. The Sukuma language group (p = 0.005), washing hands in running water (p = 0.007), access of chickens to unwashed kitchen utensils (p = 0.030) and overnight sharing of the house with sheep (p = 0.020) were associated with higher HAZ in children.*
Conclusions. *Until a more precise understanding of the key risk factors is available, these findings suggest efforts towards control of diarrhoea and improved linear growth in these areas should be directed to increased access to clean and safe water, handwashing, sanitation, and improved animal husbandry practices.*

Introduction

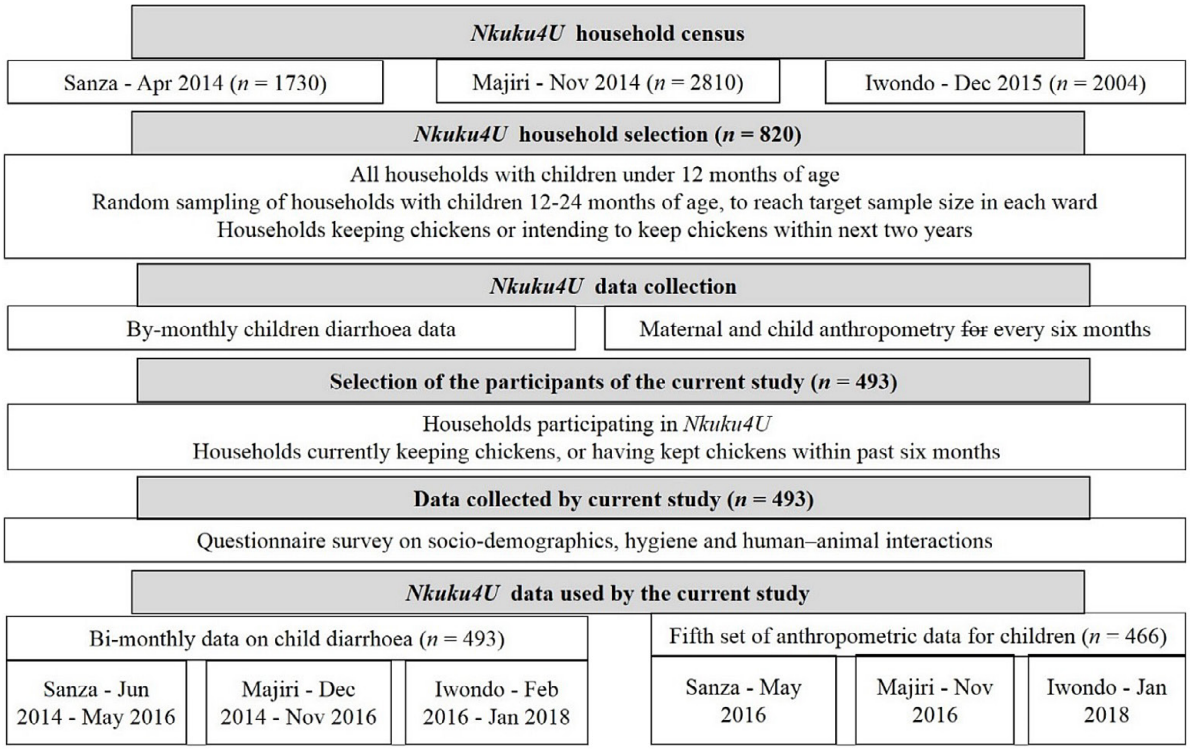
Diarrhoeal diseases and retarded linear growth are highly prevalent in children under five years old in many low- and middle-income countries (LMICs), particularly in South Asia and sub-Saharan Africa. Globally, diarrhoea and stunting are estimated to have affected 957.5 and 151 million children under five, respectively, from 2015 to 2017. Despite a 28.6% reduction in the incidence of diarrhoea in children under five between 2005 and 2015 [1], and a 10.0% decrease in stunting from 2005 to 2015, 12.0% and 34.4% of children under five in Tanzania were still affected by diarrhoea and stunting, respectively, during that period [2, 3].
Stunting or retarded linear growth in children occurs as the result of an inadequate dietary intake and repeated infections. It has immediate negative consequences such as an increased risk of death and longer term effects including increased subsequent risk of noncommunicable disease [4]. It has also been related to the increased risk of obstructed labour in women, due to the smaller pelvic size in shorter women, and to giving birth to babies with low birth weight [5]. Apart from nutritional inadequacy, chronic exposure to a variety of pathogens from human and animal faeces, as is mostly observed in children exposed to unsanitary environments, may induce pathological changes in the gastrointestinal tract that increase nutrient losses and reduce nutrient absorption [6]. Measures of growth, including wasting, low weight and stunting, have been reported to have a close association with childhood diarrhoea in children under five years old [7]. A study conducted in seven LMICs in Asia and Africa between 2000 and 2012 attributed over 30% of child mortality to persistent diarrhoea. In addition, 40% of the same population had severe undernutrition, which indicates a feasible strong relationship between the two [8].
A classification of risk factors for stunting using studies from 137 LMICs has reported that foetal growth restriction and preterm birth are the most important risk

factors associated with stunting in children under five years of age globally. This is followed by environmental factors (e.g. unimproved water supply, unimproved sanitation and use of biomass fuel), and maternal and child nutrition and infection [9]. Poor sanitation and hygiene, including lack of access to improved toilet facilities and a failure to wash hands with soap before eating and after toilet use, significantly increase the risk of diarrhoea in children under five years of age [10].

In rural communities of LMICs, dependency on domestic animals and peridomestic wildlife for livelihood and food is often very high, which increases the level of human-animal interactions. Free-roaming animals may have access to rooms within the house during the day and are often confined within a specific part of the house at night as a physical security measure. Reports associated with this close interaction and occurrence of childhood diarrhoeal diseases have mixed results to date. Recent attention has focused on the close contact between animals and children in such settings, where exposure to livestock faeces presents a risk of children acquiring animal-associated diarrhoeal pathogens [11]. A study conducted in Kenya reported an increased incidence of diarrhoea in children under five years of age with increases in the number of sheep owned by households and with children's participation in providing drinking water to chickens [12]. In contrast, a longitudinal study that included fortnightly records of diarrhoea in children under five years of age in one of the two districts where the current study was conducted showed no significant association with chicken ownership or keeping chickens inside the house overnight with child diarrhoea [13]. Also, a study in Peru reported a higher rate of *Campylobacter*-related diarrhoea in children from households with confined chickens compared to those from households keeping chickens under an extensive system [14]. This serves as an indication that relationships between animals and people and frequency of diarrhoea are undoubtedly complex.

This quantitative study explored associations between variables related to socio-demographic characteristics, hygiene practices and human-animal interactions with the frequency of diarrhoea and height-for-age *z*-scores (HAZ) in children under five years of age in three wards of central Tanzania. Height-for-age *z*-score (HAZ) expresses linear growth, whereby low HAZ is an indication of failure to reach linear growth potential (retarded linear growth). Low HAZ does not necessarily mean stunting, which in children is a subset of retarded growth [5]. This study is a sub-study associated with a broader cluster randomised controlled trial titled 'Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia' (Nkuku4U) [15]. An understanding of factors associated with diarrhoea and HAZ is an essential step

Fig. 1. Data collected by Nkuku4U project and this study and selection criteria of the participating households, the months and years indicates the time of collection of respective data set and ***n*** indicates the number of households.



towards formulating effective strategies for diarrhoea control and for improving growth in children.

Materials and methods

Study area

Iwondo Ward in the Mpwapwa District and Sanza and Majiri Wards in the Manyoni District are situated within the Great Rift Valley in Tanzania. These areas form part of the semi-arid area of the Central Zone, experiencing low, short-lived and often erratic rainfall (approximately 600 mm per annum) in a unimodal pattern, typically from November to April, with reasonably widespread drought occurring approximately one year in four [16]. Low and unpredictable rainfall is associated with chronic food and nutritional insecurity in the study area due to water and pasture shortage, reduced crop production, livestock deaths, and the sale of livestock and crops at suboptimal prices to meet immediate household needs. Village chickens are kept by more than 50% of the households throughout the year, mostly under an extensive production system, and are the livestock least affected by these unpredictable climatic conditions in terms of feed availability [17].

Selection of participating households

The Nkuku4U project team conducted a census of all households in Sanza Ward in April 2014, Majiri Ward in October 2014, and Iwondo Ward in December 2016, as part of a staggered implementation within the broader study design, giving a total of 1730, 2810 and 2004 households, respectively. The criteria used for inclusion of households in the broader Nkuku4U study were having at least one child less than two years of age, and either currently owning chickens or expressing an intention to keep chickens within two years. Few households were excluded based on the latter criterion. Two-stage sampling was used to reach the study target of 240 households in Sanza Ward, 280 in Majiri Ward and 300 in Iwondo Ward. First, all eligible households with a child under 12 months of age were enrolled, and then random selection through lottery draw using household identification numbers deployed to select additional households with children aged 12-24 months to give a required number of children. In cases where more than one child under two years of age was present in the household, information on diarrhoea and anthropometry was collected for the younger child.

Households in the present study are a subset of those participating in the Nkuku4U project: encompassing all households either currently owning chickens or who owned chickens within the six months before administration of the questionnaire in February 2018. A total of 493 out of 711 households participating in the larger project fulfilled this criterion and were included. The number of households participating in this study from each ward was 153, 153 and 187 for Sanza, Majiri and Iwondo Wards, respectively.

Data collection

Information on parental reports of diarrhoea in children was collected twice per month by trained male and female community members ('Community Assistants') over 24 months, starting in June 2014, December 2014 and February 2016 in Sanza, Majiri and Iwondo Wards, respectively. Community Assistants visited each household to record the occurrence of diarrhoea within the preceding fortnight, based on information provided by the mother or primary caretaker of the enrolled child. Diarrhoea was defined as the passage of loose or liquid stools three or more times per day [18]. At each household visit, children reported as having diarrhoea for one or more days during the preceding two weeks were documented as a single positive count. A questionnaire that was initially tested and validated using the sub-population from the same study population was administered in February 2018 to 493 mothers or caregivers of enrolled children in participating households by trained male and female enumerators recruited from within each ward. Survey questions were in Swahili, but enumerators were encouraged to make use of the languages of the two predominant language groups (Gogo and Sukuma) where appropriate to aid in communication. Information collected spanned three key areas: socio-demographic characteristics, hygiene practices and human-animal interactions. Anthropometric data were taken at six-monthly intervals during the Nkuku4U project by trained personnel from the Tanzania Food and Nutrition Centre, Ministry of Health and respective district hospitals. Recumbent length was recorded for children up to 24 months of age, and standing height for children aged 24 months of age or above, using UNICEF portable baby/child length-height measuring boards. Measurements were recorded to the nearest 1 mm. The weights of the mother and child were measured to the nearest 0.1 kg using TANITA HD355 digital scales. Mother/caregiver and child were weighed together and maternal weight subtracted from the combined weight to give the weight of the child; this method eliminated the difficulties of handling children alone on a digital scale. The fifth anthropometry data set in May 2016, November 2016 and January 2018 for Sanza, Majiri and Iwondo, respectively, were used in this study (Fig. 1). Anthropometry was recorded for 466 children (out of the total number of 493 children enrolled in this study) as 27 children (12 boys, 15 girls) were not available for measurements, therefore, *z*-scores were calculated for 466 children, 223 boys and 243 girls.

Defining variables

These particular diarrhoea and anthropometry data sets were selected for analysis because they were collected during the time when all enrolled children were less than five years of age and data collection was the closest to the time of the questionnaire survey conducted in February 2018. HAZ were calculated from children's measurements using the Emergency Nutrition Assessment for SMART software (http://www.nutrisurvey.net/ena/ena.html) and WHO child growth standards [19]. A HAZ of less than -2 was classified as stunting. Longitudinal diar-

rhoea data (episodes) were collected fortnightly for 24 months (48 trials) through household visits. The number of successful visits (i.e. household informant present and able to provide information on the occurrence of diarrhoea in the enrolled child) was taken as the binomial event. For each successful visit, the enrolled child was recorded as having (yes) or not having (no) diarrhoea in the previous fortnight. The incidence of diarrhoea was calculated as a proportion i.e. the numbers of positive diarrhoea records divided by number of successful visits. The dependent and independent variables evaluated by this study are described in Table I.

Data analysis

Descriptive statistics

Data was first entered into an Excel 2007 spreadsheets and then transferred to STATA® software version 14.2

Tab. I. Description of the variables evaluated in the study categorised into socio-demographic characteristics, hygiene practices and human-animal interactions.

Variable	Definition or description of categories
Socio-demographic characteristics	
Height-for-age ***z***-score (HAZ)	Calculated based on WHO child growth standards [19]
Incidence of diarrhoea	Positive records of diarrhoea in the number of successful fortnightly visits collected over 24 months
Sex of enrolled child	Male or female
Age of enrolled child	Months as a continuous variable
Age group of enrolled child	Months grouped as 24-34, 35-45 and 46-56
Number of children under five in household	≤ 2 children or > 2 children
Maternal age	Years as a continuous variable
Maternal level of education	None, some primary school, or post-primary school
Sex of the head of the household	Male or female
Language group of the head of household	Gogo, Sukuma or others
Type of house floor	Unimproved (sand/soil) or improved (cement, concrete, tiles etc.)
Primary sources of drinking water in dry or rainy seasons	Stream, river, pond or dam, open well or public tap; separate variables for dry season and rainy season
Time spent fetching water	≤ 1 hour or > 1 hour, separate variables for dry season and rainy season
Hygiene practices	
Storage of kitchen utensils (unwashed, washed and with food)	On the floor, raised surface (e.g. table, shelf etc.) or hanging by a rope
Treatment of drinking water	Daily, occasionally (e.g. during gastrointestinal disease outbreaks, in the dry or rainy season) or never
Method of hand washing before child feeding	All household members in the same container, or one at a time using running water
Use of dried utensils for serving food*	Yes or No
Sharing latrine facilities among households	Yes or No
Handwashing with soap before feeding the child	Yes or No
Maternal handwashing with soap after toilet use	Yes or No
Latrine disposal of child faeces	Yes or No
Access of chickens to human faeces	Yes or No
Received hygiene education	Yes or No
Human-animal interactions	
Water source sharing with animals	Yes or No, separate variables for dry season and rainy season
Access of chickens to drinking water container	Yes or No
Chicken roosting locations	Inside (any room in house) or outside (chicken house or outside with no specific area)
Chicken roosting locations	Kitchen, bedroom, chicken house, outside with no specific place, or in separate room in the house
Frequency of cleaning chicken roosting location	Daily or occasional
Access of chickens to house during the day	Yes or No
Access of chickens to dirty and washed kitchen utensils	Yes or No
Keeping cattle inside the house overnight	Yes or no
Keeping goats inside the house overnight	Yes or no
Keeping sheep inside the house overnight	Yes or no
Keeping dogs inside the house overnight	Yes or no
Keeping cats inside the house overnight	Yes or no

*The utensils used while wet after washing or the washed utensils are rinsed and used while wet

for analysis [20]. Descriptive statistics were used to characterise the study population and explore differences in explanatory variables among the three study wards. Proportions were used to present categorical variables, and means, range and standard deviations for quantitative variables. Differences between wards and groups were determined by using *t*-tests and chi-square tests for continuous and categorical variables, respectively, and the variables were considered statistically significant at $p \leq 0.05$.

Univariable and multivariable models

Univariable linear regression and logistic regression models were fitted to determine the independent variables unconditionally associated with HAZ and diarrhoea outcome variables, respectively. Independent variables that showed suggestive associations ($p \leq 0.2$) were retained for construction of multivariable models. Candidate variables for multivariable models were categorised into three groups associated with: (1) socio-demographic characteristics, (2) hygiene practices and (3) human-animal interactions. The individual multivariable linear regression model (HAZ outcome variable) and logistic regression model (diarrhoea outcome variable) were run to test the association of independent variables significantly and suggestively associated with the outcomes in univariable models from each category and the outcomes variables under this study. The variables that were significant associated with the outcomes in each multivariable model were run in a single model to generate a final multivariable model. Stepwise backward elimination was used to eliminate the variables with *p*-values higher than 0.05 to reach the final model in each of the three multivariable models and in final combined multivariable models. The models were fitted by R studio software version 3.6.0 using data stored in the STATA® spreadsheets [21].

Ethical approval

The study design, protocols and research tools for this program were approved by the National Institute for Medical Research ethics committee (NIMR/HQ/R.8a/Vol.IX/1690) in Tanzania, and The University of Sydney Human Research Ethics Committee (2014/209). Informed consent was obtained from all questionnaire survey respondents via signature or thumb print, with the assurance of confidentiality, anonymity and voluntary participation.

Results

Demographic characteristics

The mean maternal and children's age in this study was 32 ± 7.5 years and 32.5 ± 5.3 months, respectively. The percentage of mothers with education above primary school level ranged from 1.1% in Iwondo to 9.8% in Sanza, and the variation in the level of education across the three wards was significant ($p < 0.001$). Gogo was the predominant language spoken by more than 80% of the heads of households, whereas Sukuma speakers ranged from 13.0% of households in Majiri to 1.1% of households in Iwondo. The mean number of diarrhoea incidents collected fortnightly for 24 months were 2.3, 1.7, 2.8 and 2.4 over 24 months for the overall sample, Sanza, Majiri and Iwondo wards, respectively. The difference in mean diarrhoea incidence between Gogo and Sukuma language group households was not significant ($p = 0.29$). The prevalence of stunting was 46.9% (CI. 42.3-51.6), 49.8% (CI. 43.0-56.5) and 44.4% (CI. 38.1-50.9) in the overall sample, boys and girls, respectively, with no significant difference between sex ($p = 0.25$) and among wards ($p = 0.13$). The proportion of stunted children among the 24-34, 35-45 and 46-56 month age groups was 47.3% (CI. 41.8-52.8), 48.3% (CI. 38.9-57.7) and 33.3% (CI. 13.3-59.0), respectively. Stunting rates in Gogo, Sukuma and other language groups were 47.9% (CI. 43.1-52.7), 32.1% (CI. 15.9 -52.3) and 45.5% (CI. 16.7-76.6) respectively with no significant difference ($p = 0.27$); however, the height-for-age *z*-scores were significantly different in children from the Gogo (-1.9) and Sukuma (-1.1) language groups ($p = 0.004$). The details of the demographic characteristics in this study are in Table II.

Univariable and multivariable models

Diarrhoea

Due to the relatively large number of predictive variables tested, individual multivariable models (i.e. socio-demographic characteristics, hygiene practices, human-animal interactions) and final models were fitted to test their association with diarrhoea. The variables suggestive and significant associated diarrhoea in the univariable model are presented in Tables III, IV and V. In a univariable model, age of children as a continuous variable ($p < 0.001$), maternal education ($p = 0.008$), time spent fetching water ($p = 0.007$) and age of children ($p = 0.007$) were significantly associated with diarrhoea but not significant in the final socio-demographic characteristic multivariable model (Tab. III). Male children (OR = 1.17, 95% CI. 1.04-1.32; $p = 0.001$) were associated with increased diarrhoea incidence in the socio-demographic characteristics multivariable model. The older age of children (OR = 0.21, 95% CI. 0.07-0.67; $p < 0.004$), use of open wells (OR = 0.41, 95% CI. 0.35-0.48; $p < 0.001$) and public taps (OR = 0.47, 95% CI. 0.40-0.55; $p < 0.001$) in the dry season and public taps (OR = 0.70, 95% CI. 0.53-0.93; $p = 0.025$) in the rainy season as the household's primary source of drinking water were associated with low risk of childhood diarrhoea in the socio-demographic characteristic multivariable model.

Storage of washed utensils on raised surfaces reduced the risk of diarrhoea in children in the hygiene practices multivariable model (OR = 0.80, 95% CI. 0.68-0.93; $p = 0.004$), whereas inappropriate disposal of child faeces (OR = 1.17, 95% CI. 1.03-1.32; $p = 0.015$), access of chickens to human faeces (OR = 1.16, 95% CI. 1.02-1.32; $p = 0.026$) and respondents untrained in hygiene

Tab. II. Demographic characteristics of the studied populations expressed in percentage, mean, range and standard deviation (SD) depending on the type of variable presented.

Variable	Sanza (*n* = 153)	Majiri (*n* = 153)	Iwondo (*n* = 187)	Overall study sample (*n* = 493)
Age of children (months)				
Mean (SD)	34.6 (6.5)	31.0 (4.0)	31.8 (4.6)	32.4 (5.3)
Range	25.7-52.5	24.3-46.0	25.2-47.5	24.3-52.5
Age group of children (%)				
24-34 months	58.2	82.4	72.2	71.0
35-45 months	33.3	15.7	25.7	24.9
46-56 months	8.5	1.31	1.6	3.65
Age unknown	0	0.65	0.53	0.41
Sex of the enrolled children (%)				
Male	53.6	46.4	43.9	47.7
Female	46.4	53.6	56.2	52.3
Number of children under five years				
Mean (SD)	1.7 (0.7)	1.7 (0.6)	1.5 (0.6)	1.7 (0.70
Range	1–4	1–4	1–4	1-4
Number of diarrhoea incidents				
Mean (SD)	1.7 (1.6)	2.8 (3.0)	2.4 (2.8)	2.3 (2.6)
Range	0-8	0-16	0-14	0-16
Height-for-age *z*-scores (HAZ)				
Mean (SD)	-1.8 (1.0)	-1.9 (0.9)	-1.9 (1.1)	-1.9 (1.0)
Range	-4.4-0.4	-4.0-0.6	-4.7-1.5	-4.7-1.5
Missing	4	18	5	27
Maternal age (years)				
Mean (SD)	33.9 (7.4)	31.5 (8.1)	30.9 (7.0)	32.0 (7.5)
Range	18-56	17–54	18–53	17 - 56
Maternal level of education (%)				
Primary school	75.8	66.7	71.7	71.4
Above primary school	9.8	3.9	1.1	4.7
None	14.4	29.4	27.3	23.9
Sex of head of household (%)				
Male	74.5	80.4	86.6	80.9
Female	25.5	19.6	13.4	19.1
Language of head of household (%)				
Gogo	88.9	84.3	97.9	90.9
Sukuma	7.2	13.1	1.1	6.7
Other	3.9	2.6	0.5	2.2
Unspecified	0.0	0.0	0.5	0.2

(OR = 1.35, 95% CI. 1.19-1.53; $p < 0.001$) were associated with higher risk of childhood diarrhoea. Overnight sharing of housing with sheep (OR = 1.30, 95% CI. 1.02-1.66; $p = 0.034$) and cats (OR = 1.13, 95% CI. 1.12-1.52; $p < 0.001$), keeping the chickens inside the house overnight regardless of which room (OR = 1.49, 95% CI. 0.77-1.72; $p < 0.001$) or outside as compared to kitchen (OR = 1.50, 95% CI. 1.09-2.05; $p = 0.012$) and sharing water sources with animals in the dry season (OR = 1.55, 95% CI. 1.37-1.75; $p < 0.001$) were significantly associated with increased diarrhoea incidence in the human-animal interactions model (Tab. VI).

In the final multivariable model, children from the households depending on open wells (OR = 0.46, 95% CI. 0.39-0.54; $p < 0.001$) and public tap (OR = 0.51, 95% CI. 0.44-0.61; $p < 0.001$) as their primary source of drinking water in the dry season were less likely to report diarrhoea, as compared to those from households using water from a stream, river, pond or dam. Male children (OR = 1.24, 95% CI. 1.09-1.39; $p < 0.001$), not disposing of child faeces in latrines (OR = 1.15, 95% CI. 1.02-1.31; $p = 0.025$), sharing water sources with animals in the dry season (OR=1.48, 95% CI. 1.29-1.70; $p < 0.001$), overnight sharing of houses with cats (OR = 1.35, 95% CI. 1.16-1.57; $p < 0.001$) and chickens roosting in house regardless of the room (OR = 1.39, 95% CI. 1.20-1.60; $p < 0.001$) were associated with an increase in diarrhoea incidence in children. Older children (46-56 months)

Tab. III. Univariable models evaluating the significance of socio-demographic characteristic related independent variables showing *p*-values of all suggestive ($p \leq 0.2$) and significant ($p \leq 0.05$) variables associated with diarrhoea and height-for-age *z*-scores and the coefficient of association.

	Diarrhoea[a]			Height-for-age *z*-scores[b]		
Variable	Coef.*	*p*-value	Overall *p*-value	Coef.*	*p*-value	Overall *p*-value
Children age group (months)			< 0.001			0.314
24-34	Ref.*					
35-45	-0.08	0.236		0.10	0.456	
46-56	-0.83	< 0.001		-0.06	0.643	
Age of children (months)	-0.03	< 0.001	< 0.001	-0.00	0.662	0.661
Sex of child, male	0.16	0.007	0.007	-0.14	0.126	0.125
Number of children under 5 years			0.197			0.168
≤ 2 children	Ref.					
> 2 children	0.14	0.19		0.24	0.169	
Age of mothers (years)	0.00	0.441	0.442	-0.00	0.659	0.658
Maternal education			0.008			0.483
At most primary school	Ref.					
Above primary school	-0.28	0.095		0.26	0.248	
Never attended school	0.17	0.017		0.05	0.640	
Sex of head of household, male	-0.17	0.024	0.026	-0.05	0.694	0.693
Children diarrhoea incidence	NA	NA	NA	-1.34	0.78	0.088
Language group of head of household			0.577			0.010
Gogo	Ref.					
Sukuma	0.08	0.480		0.52	0.007	
Other	0.16	0.407		0.45	0.135	
Type of house floor			0.511			0.627
Unimproved	Ref.					
Improved	-0.06	0.514		0.05	0.627	
Source of drinking water						
Dry season			< 0.001			0.136
Stream/river/pond/dam	Ref.					
Open wells	-0.91	< 0.001		0.22	0.047	
Public tap	-0.84	< 0.001		0.12	0.297	
Rainy season			< 0.001			0.989
Stream/river/pond/dam	Ref.					
Open wells	-0.35	0.002		0.00	0.978	
Public tap	-0.63	< 0.001		-0.02	0.886	
Time spent to fetch water						
Dry season			0.007			0.322
≤ 1 hour	Ref.					
> 1 hour	0.17	0.007		-0.10	0.323	
Rainy season			0.571			0.959
≤ 1 hour	Ref.					
> 1 hour	0.06	0.568		0.01	0.959	

Coef.* = Regression coefficient; Ref.* = Reference category; [a] Logistic Regression Model; [b] Linear Regression Model

were less likely to have diarrhoea compared to younger children (24-34 months) (OR = 0.43, 95% CI. 0.27-0.67; $p < 0.001$) (Tab. VI).

Height-for-age z-score

In the multivariable model based on socio-demographic characteristics, only language group ($p = 0.019$) and house floor ($p = 0.028$) were significantly associated with HAZ, and in the final combined model, only the language group remained significant. Of variables relating to hygiene practices, handwashing with running water ($p = 0.009$) and storing washed utensils by hanging ($p = 0.007$) were positively and negatively associated with HAZ, respectively. Human-animal interaction-related variables significantly associated with HAZ were access of chickens to unwashed utensils ($p = 0.033$) and keeping sheep inside the house overnight ($p = 0.015$) which remained significant even in the final combined model (Tab. VII). The final combined multivariable model indicated that children from households headed

Tab. IV. Univariable models evaluating the significance of hygiene practices related independent variables showing *p*-values of all suggestive ($p \leq 0.2$) and significant (≤ 0.05) variables associated with diarrhoea and height-for-age *z*-scores and the coefficient of association.

	Diarrhoea[a]			Height-for-age *z*-scores[b]		
Variable	Coef.*	*p*-value	Overall *p*-value	Coef.*	*p*-value	Overall *p*-value
Maternal handwashing methods			0.780			0.017
All in the same container	Ref.					
One at time in running water	-0.02	0.780		0.24	0.017	
Handwashing with soap before feeding the child, Yes	0.19	0.031	0.034	0.05	0.723	0.722
Use of dry utensils for serving food, Yes	-0.16	0.041	0.044	0.08	0.573	0.572
Storage of utensils before washing			0.141			0.150
On the floor	Ref.					
On raised surface	0.15	0.058		0.00	0.979	
Hanging	0.08	0.274		-0.22	0.060	
Storage of utensils after washing			< 0.001			0.042
On the floor	Ref.					
On raised surface	-0.24	0.002		-0.12	0.314	
Hanging	0.04	0.597		-0.28	0.013	
Storage of utensils with food			0.003			0.080
On the floor	Ref.					
On raised surface	-0.24	0.005		0.22	0.076	
Hanging	0.00	0.999		-0.02	0.888	
Treatment of drinking water			0.135			0.634
Boiling always	Ref.					
Occasional boiling	-0.28	0.086		-0.10	0.679	
No treatment	-0.05	0.662		-0.17	0.370	
Latrine shared among households, Yes	0.07	0.277	0.277	-0.16	0.092	0.091
Disposal of child faeces in latrine, No	0.18	0.004	0.005	-0.08	0.404	0.403
Access of chicken to human faeces, Yes	0.12	0.066	0.065	0.01	0.878	0.878
Maternal handwashing with soap after toilet use, No	-0.07	0.261	0.2608	-0.15	0.098	0.097
Received hygiene education, No	0.31	< 0.001	< 0.001	-0.03	0.731	0.731

Coef.* = Regression coefficient; Ref.* = Reference category; [a] Logistic Regression Model; [b] Linear Regression Model.

by Sukuma speaking individuals have higher HAZ as compared to the Gogo headed households ($p = 0.005$). Washing hands in running water ($p = 0.007$), chickens gaining access to unwashed utensils ($p = 0.031$) and keeping sheep inside the house ($p = 0.020$) overnight were associated with higher HAZ.

Discussion

In this study we found that the rate of stunting in children under five was relative high in all three wards regardless of language group and gender of the children under study compared to the current national stunting rate which is at 34% [3]. This finding reflects the challenging agro-ecological conditions in the project area. The proportion of stunted children slightly decreased with increase in child age in contrast with other studies [22, 23]. The difference may be accounted for by the effects of diarrhoea, which was negatively related to age in the univariable model in the present study. Demographic and Health Survey data from Bangladesh indicates that stunting in children aged 0-59 months increases rapidly between 12 and 23 months of age, after which it levels out with minor variations [24]. An extrapolation of these data into the current study means that the minimum age of enrolled children in the current study was at the peak of the stunting prevalence, which may be the reason for the observed results of stunting rate of 47.3%, 48.3% and 33.3% at age groups 24-34, 35-45 and 46-56 months, respectively. On the other hand, the decrease in prevalence of stunting observed in the current study amongst children in the oldest age may be reflecting recovery, which has been reported to be as high as 45% in a recent longitudinal study in Kenyan children, especially those becoming stunted at less than 18 months of age [25]. Although anthropometry was conducted at different times in the three wards (May 2016 in Sanza, November 2016 in Majiri and January 2017 in Iwondo), the variation in stunting rate among wards did not vary significantly between wards.

It has been reported that the incidence of diarrhoea in children under five year of age decreases with increasing age [26]. The probability of developing diarrhoea in

Tab. V. Univariable models evaluating the significance of human-animal interactions related independent variables showing *p*-values of all suggestive ($p \leq 0.2$) and significant (≤ 0.05) variables associated with diarrhoea and height-for-age *z*-scores and the coefficient of association.

	Diarrhoea[a]			Height-for-age *z*-scores[b]		
Variable	Coef.*	*p*-value	Overall *p*-value	Coef.*	*p*-value	Overall *p*-value
Water source sharing with animals			< 0.001		0.534	
Dry season, Yes	0.47	< 0.001		-0.06		0.533
Rainy season, Yes	0.02	0.765	0.765	0.09	0.421	0.420
Access of chickens to water containers, Yes	-0.13	0.031	0.031	0.07	0.451	0.450
Chicken roosting location			0.003			0.116
Kitchen	Ref.*					
Bedroom	0.12	0.283		0.09	0.589	
Chicken house	-0.10	0.531		0.34	0.029	
Outside, no specific place	0.47	0.003		-0.11	0.712	
Separate room in the house	-0.07	0.409		0.25	0.054	
Chicken roosting location, Inside	0.31	< 0.001	< 0.001	0.15	0.192	0.190
Frequency of cleaning chicken roosting location			0.010			0.883
Daily	Ref.					
Occasional	0.24	0.008		-0.02	0.883	
Access of chickens to house during day, Yes	-0.07	0.356	0.359	0.13	0.254	0.253
Access of chickens to kitchen utensils						
Before washing, Yes	0.06	0.347	0.345	0.22	0.032	0.031
After washing, Yes	-0.03	0.604	0.6038	0.03	0.715	0.714
Other animals kept inside house overnight						
Cattle, Yes	0.21	0.10	0.109	0.11	0.600	0.599
Goat, Yes	0.06	0.601	0.604	0.39	0.031	0.030
Sheep, Yes	0.31	0.008	0.011	0.51	0.015	0.014
Dogs, Yes	0.02	0.932	0.932	0.09	0.449	0.448
Cats, Yes	0.29	< 0.001	< 0.001	0.07	0.581	0.580

Coef.* = Regression coefficient; Ref.* = Reference category; [a] Logistic Regression Model; [b] Linear Regression Model.

this study was lower in children aged between 46 and 56 months compared with those aged between 24 and 34 months, which is consistent with the literature. A higher incidence of diarrhoea in children aged between 6 and 11 months was reported compared to children aged 48-59 months [27]. This was attributed to declining levels of maternal immunity, introduction of complementary foods and mouthing of potentially contaminated objects by young children, and to strengthened immunity and environmental adaptation in older children.

Drinking water from open wells and public taps appeared to be protective against diarrhoea in children in the dry season. The scarcity of water sources and the time-intensive nature of sourcing water in the study area settings often led to close proximity between water accessed by livestock and that collected for household use, exposing humans to microbial contamination by animal faeces. The likelihood of animal faecal contamination of water sources was suggested by the results of the current study, which reported increases in the risk of developing diarrhoea in children from households sharing water sources with animals in the dry period. Poor microbial quality of drinking water is well documented as a cause of diarrhoea, sometimes in the form of a disease outbreaks [28]. Although water treatment was not a significant variable in the current study, boiling [29] and use of sodium hypochlorite (liquid bleach) [30] have been proven successful in lowering childhood diarrhoea in other studies. However, the latter method may be difficult to implement in the study area settings due to financial constraints. Treatment of drinking water should be accompanied by proper handling and storage to prevent in-house re-contamination from the users as has been reported in other studies [31-33].

Improper disposal of child faeces including discarding it in the field, leaving in open spaces to dry or covering with soil, was associated with an increased risk of diarrhoea in children, compared with latrine disposal. Similar results were reported in a study conducted in children under five years of age in Iraq, in which children from households leaving children's faeces on the ground were more likely to develop diarrhoea compared to those from households disposing of children's faeces in latrines [34]. In resource-poor settings, poor faecal disposal may result in direct contamination of already-prepared food and indirect contamination of kitchen utensils, particularly if the household is keeping chickens under an extensive production system with free access to every part of the house. Nonetheless, in the current study, access of chickens to human faeces was

Tab. VI. Socio-demographic characteristics, hygiene practices and human-animal interactions multivariable models[a] built using variables showing significant ($p \leq 0.05$) or suggestive association ($p \leq 0.2$) with diarrhoea incidence in univariable models, and final combined model[a] fitted using combination of significant variables from all three multivariable models.

Variable	Odd ratio	Odd ratio 95% Conf. Interval*		*p*-value	Overall *p*-value
Socio-demographic characteristics					
Sex of child, Male	1.17	1.04	1.32	0.001	0.001
Child age group	Ref.				0.004
24-34					
35-45	0.83	0.69	1.00	0.671	
46-56	0.21	0.07	0.67	0.005	
Source of drinking water					
Dry season					< 0.001
Stream/river/pond/dam	Ref.				
Open wells	0.41	0.35	0.48	< 0.001	
Public tap	0.47	0.40	0.55	< 0.001	
Rainy season					0.045
Stream/river/pond/dam	Ref.				
Open wells	1.10	0.85	1.42	0.363	
Public tap	0.70	0.53	0.93	0.025	
Hygiene practices					
Storage of washed utensils					0.004
On the floor	Ref.				
On raised surface	0.80	0.68	0.93	0.004	
Hanging	0.99	0.85	1.14	0.862	
Latrine disposal of children faeces, No	1.17	1.03	1.32	0.015	0.015
Access of chickens to human faeces, Yes	1.16	1.02	1.32	0.026	0.026
Training on hygiene, No	1.35	1.19	1.53	< 0.001	< 0.001
Human-animal interactions					
Sharing water source with animal in dry season, Yes	1.55	1.37	1.75	< 0.001	< 0.001
Chicken roosting location					
Kitchen	Ref.				
Bedroom	1.15	0.93	1.72	0.208	0.005
Chicken house	0.90	0.73	1.43	0.324	
Outside, no specific place	1.50	1.09	1.11	0.012	
Separate room in the house	0.91	0.77	2.05	0.308	
Chicken roosting location, Inside	1.49	1.29	1.09	< 0.001	< 0.001
Sheep inside house overnight, Yes	1.30	1.02	1.66	0.034	0.039
Cats inside house during night, Yes	1.31	1.12	1.52	< 0.001	< 0.001
Final model					
Drinking water source in dry season					< 0.001
Stream/river/pond/dam	Ref.				
Open wells	0.46	0.39	0.54	< 0.001	
Public tap	0.51	0.44	0.61	< 0.001	
Sex of child, male	1.24	1.09	1.39	< 0.001	< 0.001
Child age group (months)					< 0.001
24-34	Ref.				
35-45	0.97	0.84	1.12	0.666	
46-56	0.43	0.27	0.67	< 0.001	
Latrine disposal of child faeces, No	1.15	1.02	1.31	0.025	0.026
Training on hygiene, No	1.16	1.01	1.33	0.030	0.030
Sharing water source with animals in dry season, Yes	1.48	1.29	1.70	< 0.001	< 0.001
Chicken roosting location, Inside	1.39	1.20	1.60	< 0.001	< 0.001
Cats inside house overnight, Yes	1.35	1.16	1.57	< 0.001	< 0.001

OR = Odd ratio ; 95% Conf. Interval.* = 95% Confidence interval for odd ratio; Ref.* = Reference category; [a] Logistic Regression Model.

Tab. VII. Socio-demographic characteristics, hygiene practices and human-animal interactions multivariable models[b] built using variables showing significant ($p \leq 0.05$) or suggestive association ($p \leq 0.2$) with age-for-age *z*-scores in univariable models, and final combined model[b] built from combination of significant variables from all three multivariable models.

Variable	Coef.*	Std. error*	*p*-value	Overall *p*-value	95% Conf. Interval*	
Socio-demographic characteristics						
Language group				0.019		
Gogo	Ref.					
Sukuma	0.53	0.19	0.006		0.15	0.91
Others	0.22	0.32	0.495		-0.41	0.85
House floor, Improved	0.33	0.15	0.028	0.028	0.04	0.62
Hygiene practices						
Handwashing				0.009		
All on the same container	Ref.					
One at a time in running water	0.26	0.10	0.009		0.07	0.46
Storage of washed utensils				0.025		
On the floor	Ref.					
Raised surface	-0.13	-0.13	0.256		-0.35	0.09
Hanging	-0.30	-0.30	0.007		-0.53	-0.08
Human-animal interactions						
Chickens access to unwashed utensils, Yes	0.22	0.10	0.033	0.033	0.02	0.42
Sheep inside house overnight, Yes	0.51	0.21	0.015	0.015	0.10	0.91
Combined model						
Language group				0.011		
Gogo	Ref.					
Sukuma	0.54	0.19	0.005		0.16	0.91
Others	0.34	0.30	0.261		-0.25	0.93
Handwashing				0.007		
All in the same container	Ref.					
One at a time in flowing water	0.27	0.10	0.007		0.07	0.47
Chickens access to unwashed utensils, Yes	0.22	0.10	0.031	0.031	0.02	0.42
Sheep inside house overnight, Yes	0.48	0.21	0.020	0.020	0.08	0.89

Coef.* = Regression coefficient; Std. Err.* = Standard error; 95% Conf. Interval* = 95% Confidence interval; Ref.* = Reference category; [b] Linear Regression Model.

significantly associated with increased incidence of diarrhoea in the hygiene practices model but non-significant in the final combined multivariable model.

Children from the Sukuma language group households had significantly higher HAZ compared with children from the Gogo language group households. Similar results were reported in another study involving Sukuma and Pimbwe language groups conducted in the Southern Highland Zone of Tanzania [35]. People belonging to the Sukuma language group have been reported as having greater asset accumulation and practising sound agricultural and livestock production, all regarded as important predictors of food security. This may explain the better growth rates of Sukuma children compared to those of other ethnic groups in Tanzania including Gogo speakers [36]. Associations of poor growth with low wealth index have been reported in a number of studies indicating its importance in determining childhood nutrition and growth performance [23, 37-39].

Maternal handwashing during critical times, including before feeding children and after toilet use, is important in the control of gastrointestinal infections [40, 41] and stunting [42, 43]; however, handwashing should be properly executed. The current study shows that handwashing one at a time with running water was associated with increased HAZ in children, compared to one or more persons washing hands in a shared bowl of water. Improper handwashing, including submerging hands in a bowl of water used by multiple people or on multiple occasions, should be discouraged as it increases the risk of pathogen transfer [44]. Establishment of dedicated areas for handwashing within a house, providing water and soap, and availability of locally-made handwashing facilities may promote proper handwashing in resources-poor settings. Wood ash has been proven to have antimicrobial activities, therefore it can be used as an alternative for hand washing in the households that cannot afford to have soap constantly available [45].

We did not find any significant association between sanitation, water source and hygiene variables with HAZ in children under five years of age, which contradicts observations in other studies [46, 47]. The lack of a true control group, having participating households with similar characteristics (all from resource-poor settings), and a relatively small sample size of the current study make it more difficult to assess such associations, com-

pared to those involving socio-economically diverse study populations and larger sample sizes [48, 49]. Use of a small sample size from a localised area has been mentioned as a potential reason for non-significant results from improved toilet and water sources, compared to other studies that used larger sample size and more than one population from different settings [37].

The practice of keeping cats and chickens inside the house overnight was associated with an increased risk of child diarrhoea. Domestic animals including cats and chickens have been implicated in harbouring gastrointestinal pathogens that may also infect humans [50]. Similar strains of pathogens have been isolated in asymptomatic animals and symptomatic humans, highlighting the potential importance of animal-derived pathogens to public health [51, 52]. However, a clonal difference of *Salmonella* isolated in humans and animals in high human-animal interaction settings was reported, indicating that not every infected animal presents a risk to humans [53]. Unexpectedly, keeping sheep inside the house overnight and allowing chickens to access unwashed kitchen utensils for leftover food were associated with increased HAZ in children. Pre- and postnatal exposure to pet animals (dogs and cats) have been associated with increased abundance of beneficial gut microbiota in children, reducing pathogenic bacteria population in the gut [54], which may diminish any negative impact on child growth. A study from Ethiopia that involved poultry production as an intervention to improve nutrition in children aged at 0-36 months reported increasing HAZ and weight for age *z*-score (WAZ). Also, there was no statistically significant association between the intervention and anaemia, fever, vomiting or diarrhoea in children – even in households keeping the chickens in their house overnight [55].

In the current study, overnight sharing of the house with chickens and cats was found to be associated with an increased risk of child diarrhoea, while overnight sharing of the house with sheep and allowing chickens access to unwashed kitchen utensils was associated with higher HAZ; this presents a complex picture. The significance and direction of associations between human-animal interactions and child health and growth outcomes therefore warrants further investigation. Screening for gastrointestinal pathogens in children and all animal species kept in the study areas accompanied by genomic analysis may help to clarify the public health risks that may emerge from extensive human-animal interactions.

Proper handwashing during critical times has been proven effective in different studies in controlling diarrhoea and improving HAZ in children. Therefore, the importance of effective handwashing should be emphasised and introduced to the community through evidence- and theory-based, user- and resource-friendly interventions in relation to the community being targeted [56]. Safe water supplies are lacking in the study areas and may remain a challenge for quite some time due to inadequate community and local government resources. Home drinking water treatment by boiling, using chlorine tablets or some emerging simple, effective and cheap technologies including use of a bio-sand water filter [57] are the only immediate and effective interventions in controlling diarrhoea in children under five years of age in areas using unsafe sources of water. Sharing the house with animals, especially chickens, to overcome predation and theft, is commonly practised in the area. Building chicken houses close to the home, or having a designated room within the main house for keeping chickens overnight, which is cleaned before being accessed by children and other household members, may reduce the health impacts resulting from a shared dwelling, while still reducing chicken theft and predation risks. Childhood diarrhoea and stunting is determined by a complex array of risk factors that vary from one community to another, requiring collective action to be properly addressed. The nature and extent of interventions to address childhood diarrhoea and stunting in this study setting, and in similarly resource-limited communities, can be guided by findings from this and other similar studies. The present study highlights the complexity of associations between humans and domestic animals, in which potential positive contributions of livestock ownership and inter-species variation in the risk of zoonotic disease, requires further investigation. In this setting, results suggest that access to safe and clean water, improved sanitation and proper hand washing should be the first priority in improving the nutrition and health of young children.

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Conflict of interest statement

The authors declare no conflict of interest.

Authors' contribution

Conceptualization: ER, GM, RA, RK; VS; Data curation: ER, WM, and RM; Formal analysis: ER, PCT and RM; Funding acquisition: GM, R; Investigation: ER, GM; Methodology: ER, GM, ID-H and PCT; Project administration: ER, WM; Supervision: RA, GM; Validation: WM, ER and ID-H; Visualization: ER and RK; Writing original draft: ER; Writing, review & editing: ER, GM, CT, PCT, WM, RM, JdB, RK, ID-H, RA.

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Correspondence: Elpidius Rukambile, School of Life and Environmental Sciences, Faculty of Science, The University of Sydney, Australia - E-mail: erukambile@gmail.com

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