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TECHNICAL NOTE

Household and community variations and nested risk factors for diarrhoea prevalence in southern Malawi: a binary logistic multi-level analysis

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This paper examines household and community-level influences on diarrhoeal prevalence in southern Malawi. A Bayesian multi-level modelling technique is used in the estimation of hierarchically built data from a survey of individuals nested within households nested within communities. Households have strong unobserved influence on diarrhoeal illness ($\sigma_u^2 = 4.476$; 95% CI: 2.081, 6.871). A joint Wald test of significance shows that an individual's age [$\chi_4^2 = 55.921, p = 0.000$] and school [$\chi_2^2 = 18.203, p = 0.000$] have strong influence on an individual's diarrhoeal prevalence. An individual's history of malarial-like illness also has a strong positive relationship with diarrhoeal prevalence [$\beta = 0.606$, $p = 0.000$]. Household factors that influence diarrhoea include employment status of head of household [$\beta = -0.619$, $p < 0.021$], maternal age [$\beta = -0.013$, $p < 0.003$], and size of household [$\beta = -0.669$, $p = 0.000$]. The positive relationship between diarrhoea and malaria-like episodes highlights common risk factors hence the need for common approaches to combat the diseases. Significant household effects underline the importance of household considerations in policy issues.

Keywords: Bayesian estimation; diarrhoeal prevalence; multi-level analysis; Malawi

Introduction

It is well documented that diarrhoea is among the major causes of morbidity and mortality in all age groups in the world (Kosek et al. 2003). In the developing world including sub-Saharan Africa, a child experiences four to five episodes of diarrhoea per year (Shivoga and Moturi 2009). About 6% of deaths in developing countries are attributable to diarrhoea mainly as a result of the consumption of water derived from unsafe water sources, poor sanitation, overcrowding, and poor behavioural and food hygiene practices (Kosek et al. 2003; Morse et al. 2007; Taulo et al. 2008).

Statistics in Malawi show that 18% of children under the age of five had diarrhoea in 2000 and the proportion increased to 22% in 2004 (National Statistical Office [NSO] 2001, 2005). Most studies on diarrhoeal diseases in Malawi have

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concentrated on national data mostly from the national demographic health surveys whose classifications are at regional, district or sub-district levels (Kandala et al. 2006; Kazembe et al. 2007). We are not aware of any epidemiological studies that have considered the heterogeneity existing within small-area levels such as villages. Ignoring such analysis would be an overstatement or overstep of the sort of infection that may exist in nested observations (Beale et al. 2008).

This paper analyses data from a survey conducted within a district of Chikwawa in Malawi with the objective of studying community and household variations. As Kandala et al. (2006) successfully illustrated, use of higher level classifications to explain lower level characteristics may conceal important information on lower levels due to generalisations. This study therefore, contributes to the existing literature by quantifying diarrhoeal prevalence at community and household levels within a district.

Chikwawa, a district in southern Malawi, has a surface area of 4,755 km^2 with an elevation of only 100 m above sea level. Out of a population of approximately 477,524 people, 17% are children under five years of age, 23% are women of child-bearing age, and the expected number of expectant women is 23,876 (NSO 2005). Chikwawa is faced with a number of environmental and socio-economic problems that are responsible for various infectious diseases. Currently diarrhoeal morbidity in the district is estimated at 24.4% (Kandala et al. 2006). This is statistically higher than the national average (World Health Statistics 2006).

While this is the case there is little, if any, empirical evidence on the distribution and cause of diarrhoeal disease within the district. This hampers strategic planning and may cause problems since intervention programmes in the district may rely on health facility information, political dictates, or research results that may not give details of information within the district.

Use of health facility data in rural areas may not be adequate since it relies on information gained from those families that have reasonable access to or can afford to devote the time and effort to attend such facilities (Morse et al. 2007). In contrast, data for those treated at home or elsewhere, or those that do not seek any medical attention is not reported (Mulholland 2005).

This paper seeks to determine the pattern of variation of diarrhoeal prevalence in Chikwawa with associated risk factors. The study is based on reported cross-sectional data and analysis is performed using multilevel modelling technique with Bayesian estimation. Specifically the paper examines: (i) the best fitting binary logistic multi-level model for diarrhoea prevalence in Chikwawa, (ii) factors that influence the occurrence of diarrhoea at individual, household and community levels, and (iii) the nature of household and community as well as coefficient random effects associated with diarrhoeal disease.

Methods

Sample

A survey was conducted in Chikwawa to obtain a representative sample of individuals, households, and villages. To determine the pattern and risk factors of infectious diseases at household and community levels, a two-stage survey methodology was adopted to produce a district representative sample of households. The first stage involved sampling of villages that were strategically selected with a probability proportional to the number of enumeration areas in each traditional authority (Chikwawa has 11 traditional authorities and each traditional authority has several villages under its jurisdiction). The second sampling stage took place on the day of interviews. Households were systematically chosen with equal probability sampling. Only women responsible for households were selected for interview. The study comprised 33 villages, 30 of which had at least 30 households in each. In total 1,380 households were sampled. Information for a total number of 6,789 individuals was obtained. In summary, we obtained information for 6,789 individuals nested within 1380 households nested within 33 villages.

The survey was carried out in the month of September 2007. Information sought included the months of January 2007 through September 2007.

Measures

Each household member's reported diarrhoea prevalence was used as the outcome variable. Respondents were asked if a member of their household had diarrhoea since January of 2007 to the time of the survey (September 2007). The response was dichotomised with 1 representing yes and 0 representing no.

Age, an individual's highest level of school (school in this study refers to highest level of formal education) attended, gender, frequency of malaria-like episodes per individual, and whether a person was pregnant or not, were all included as individual (level one) predictor variables. During the survey mothers were not given a precise definition of what constitutes an episode of childhood malaria. We relied on the mother's perception of malarial illness other than clinical or actual definitions. Mothers were required to explain in detail why they thought an illness constituted malaria other than through fever. This study used the Malawi Ministry of Health guidelines to health workers that fever without another identifiable cause should be treated as malaria if accompanied by one of the following symptoms: headache, chills, shivering, or loss of appetite (Malawi Government Ministry of Health 2002). Thus, any information on additional symptoms of malaria to fever as indicated above or information of a test at a health facility, or if anti-malarial drugs cured an ailment, was desirable to confirm a malaria episode. This study therefore, uses the words 'malaria-like' episodes, illness or symptoms to reflect this picture.

Maternal age, household size, employment status of head of household, drinking water source, sanitation, distance to the nearest river,[1] type of nearest health facility and wealth status were included as household (level two) predictor variables. The community's proximity to the nearest active trading centre was included as a village predictor.

Although drinking water sources, sanitation and distance to the nearest river can be viewed as shared facilities by whole communities, it was observed and typical of most communities that households from the same community had access to different drinking water sources (e.g. boreholes, piped water supply, ponds) or used different types of toilet facilities (e.g. ownership of a pit latrine, access to a neighbours latrine, use of a water closet), or were located by varying distances from the nearest river. It was decided therefore, that these variables be included as household variables and not community variables.

Individual age variable was categorised as: 1: 0–5 years, 2: 6–18 years, 3: 19–40 years, 4: 41–60 years, and 5: above 60 years. The categories were selected based on observed clusters on a scatter plot. Individual highest levels of school were categorised as: 1: no school, 2: primary school education, 3: secondary and tertiary education. Gender was classified as 1: male and 2: female. Existence of an expectant woman was scored 1 otherwise 0. Individual malaria episodes predictor was included as a continuous variable.

Maternal age and household size were also included as continuous variables. A household head was scored 1 if he/she was employed and 0 otherwise.

Water source variables that were considered in this study were: (1) private piped water or private water tanks, (2) public piped water, (3) other safe water sources such as boreholes, protected wells, and springs, and (4) unsafe water sources such as rivers, streams, or ponds. A sanitation variable was measured through categories of: (1) own toilet facility, (2) shared toilet facility, (3) no toilet facility. Health facility variable was considered as: (1) local private clinic, (2) government hospital, (3) health centre, (4) Christian Association of Malawi (CHAM) hospital, and (5) health post or local clinic.

Distance to the river was also categorised as: 1: 0 to <1 km, 2: 1–2 km, 3: more than 2 km. Household wealth index was derived by analysing household possessions, quantity of animals and birds and type and quality of house. The method of 'variations' (Gwatkin et al. 2000) that assigns weights to indicator variables and uses the inverse of the proportion of number of households with an asset or service as the weight for the indicator was used. The principle behind this procedure is that the costlier an item, the wealthier a household needs to be to possess one, giving the highest weights to the least possessed assets. Caution was taken to ensure that problems arising with this weighting scheme in certain assets, such as motorcycles, that are rare, but are not as costly as a car, were either excluded or were included amongst items closer in function and quality. A categorical variable was derived by grouping the wealth index distribution into three distinct segments. These segments are based on observed clusters such that the first segment is from households with indices 0 to less than 0.003; the second segment is from 0.003 to less than 0.01, the third segment is from 0.01 and above.

Analysis and estimation

Binary logistic regression base models (without any predictor variables) were fitted first and were assessed based on their diagnostics and random effects. Since the data were clustered at household and community levels, single-level, two-level and three-level models were tested. These models were extended to incorporate fixed and random covariates. The model with the best fit was used for final analysis on diarrhoea prevalence.

The binary regression model (Rasbash et al. 2004; Souza and Migon 2004) was used to explain the probability of binary diarrhoea prevalence outcomes for individuals. If the i_{th} individual from the j_{th} household from the k_{th} village was reported to have had diarrhoea illness. Then a response would be written

$$y_{ijk} = \begin{cases} 1 & \textit{if } i_{th} \textit{ individual from } j_{th} \textit{ household in } k_{th} \textit{ village was reported ill} \\ 0 & \textit{otherwise} \end{cases}$$

so that $y_{ijk}|\pi_{ijk} = Ber(\pi_{ijk})$, and $\log it(\pi_{ijk}) = x_{ijk}\ \beta + z_{ijk}\ u_{jk} + z_{ijk}\ v_k$ is a general random components model. $i = 1, \ldots, I_j$ individuals; $j = 1, \ldots, J$ households; and $k = 1, \ldots K$ villages, with π_{ijk} as the probability that the i_{th} individual in the j_{th} household belonging to k_{th} community reported sickness. The vector β is a Φ set of fixed regression coefficients corresponding to a set of individual covariates x_{ijk}.

Random effects at the household and community level are respectively modelled through u_{jk} and v_k such that $u_{jk} \sim N(0, \sigma_u^2)$ and $v_k \sim N(0, \sigma_v^2)$. Where household and community level covariates are available, these are captured by z_{ijk}, which may or may not be equal to covariate x_{ijk}. Base models (i.e. models without covariates) are obtained when $x_{ijk} = z_{ijk} = 1$. When $v_k = 0$ we have a two-level model and when $v_k = u_{jk} = 0$ we have a single-level model.

Estimation was performed using Bayesian procedures in MLwiN 2.10 software. Initial estimates to obtain prior samples were derived using second-order penalised quasi-likelihood (PQL) procedures with restricted iterative generalised least-squares (RIGLS) (Goldstein 2003). Stability of all model parameters was monitored by observing the Raftery-Lewis and the Brooks-Draper mean diagnostics (Browne 2003). The maximum number of iterations performed to achieve stability was 60,000.

Model comparison was based on the Deviance Information Criterion (DIC) (Spiegelhalter et al. 1998) such that $DIC = \overline{D} + pD$. The deviance $\overline{D}$ represents goodness-of-fit and is evaluated at the posterior mean of the parameters, while pD is the effective number of parameters and provides a penalty for increasing model complexity. The effective number of parameters is defined as $pD = \overline{D} - D(\overline{\theta})$, where $D(\overline{\theta})$ is the deviance evaluated at the posterior expectations. Small values of DIC are an indication of a good model. Differences of more than 7 in DIC are taken to indicate a statistically significant difference (Spiegelhalter et al. 1998).

Results and discussion

Descriptive statistics

Table 1 shows summary measures for outcome and predictor variables in the models. There were 6,789 individuals nested within 1,380 households, clustered within 33 villages (communities) analysed in this study. Eight in every 10 people ($n = 5{,}431$) had access either to piped water or a borehole and a total of 94% have access to improved water sources.[2] Two-thirds ($n = 4{,}520$) had access to a toilet facility and out of these every two individuals in three ($n = 3{,}028$) used their own household toilet. One in three individuals shared a toilet facility. These figures were in line with the 2015 Millennium Development Goals (MDGs). To meet MDG 7 for water and sanitation this would mean that approximately 89% of the population should have access to improved drinking water sources and 74% access to improved sanitation[3] by 2015 (UNICEF 2006).

A quarter of individuals ($n = 1{,}734$) reported to have experienced an episode of diarrhoea between January and September 2007. Approximately one in three children under five years of age were reported to have suffered from diarrhoea during this period and a slightly higher percentage (38%) of those without access to safe water sources reported that they had suffered from a diarrhoeal episode during this period. These findings are similar to other studies that also observed more episodes of diarrhoea among children less than five years of age without access to improved water sources and sanitation (Kosek et al. 2003; Bryce et al. 2005).

Fitting binary logistic multilevel model

Table 2 shows base models (with no predictors) that are used to determine estimates for comparison with subsequent models. Model 1 is without random effects, model 2 includes household random effects only, and model 3 includes both household and

Table 1. Summary measures for variables in the diarrhoea prevalence model.

Risk factor	Number at risk	% at risk	% infected
Categorical variables			
Individual age			
Age 0–5 (ref)	1459	21.5	35.57
Age 6–18	1728	25.5	17.77
Age 19–40	1427	21.0	22.21
Age 41–60	1298	19.1	26.96
Age >60	877	12.9	27.48
Individual school			
None (ref)	2578	38.0	31.23
Primary	3612	53.2	22.76
Secondary	599	8.8	17.86
Individual sex			
Male (ref)	3351	49.4	24.32
Female	3438	50.6	26.73
Employment of head of household			
Not employed (ref)	438	6.5	34.70
Employed	6351	93.5	24.91
Health facility by household			
Private clinic (ref)	1966	29.0	32.24
Government hospital	3336	49.1	22.43
Health centre	924	13.6	27.07
CHAM hospital	104	1.5	24.57
Local clinic	459	6.8	14.42
Distance to nearest river			
<1 km (ref)	2499	36.8	22.57
1–2 km	2887	42.5	25.84
>2 km	1403	20.7	30.22
Water source by household			
PPWOPWT (ref)	420	6.2	20.95
Public piped water	1043	15.4	28.19
Other safe water sources	4933	72.7	24.37
Unsafe water sources	393	5.8	38.17
Sanitation			
Own toilet	3028	44.6	24.4
Shared toilet	1492	22.0	24.5
No toilet	2269	33.4	27.8
Wealth index by household			
Lower category (ref)	4400	64.8	27.20
Middle category	1385	20.4	23.90
Higher category	1004	14.8	20.52
Villages near active trading centres			
>2 km	4421	1044	23.61
≤ 2 km	2368	690	29.14
Continuous variables			
Household maternal age (in years)	Mean = 35.06 SD = 13.51	Median = 31.0 IQR = 17.0	Minimum = 15 Maximum = 89
Household density (per household)	Mean = 5.59 SD = 2.05	Median = 5.00 IQR = 3.00	Minimum = 1 Maximum = 13
Malaria episodes (per person in 8 months)	Mean = 1.07 SD = 1.30	Median = 1.00 IQR = 2.00	Minimum = 0 Maximum = 5

CHAM, Christian Association of Malawi. PPWOPWT, private piped water or private water tanks.

Table 2. Diagnostics and random effects at household and community level for the null models.

	Model 1		Model 2		Model 3	
	β	SE	β	SE	β	SE
Constant	−1.070	0.028****	−1.488	0.076****	−1.477	0.103****
Community and household effects:						
σ_u^2(household)	–	–	2.786	0.403****	2.703	0.243****
σ_v^2(community)	–	–	–	–	0.204	0.094**
Model diagnostics:						
$\overline{D}$	7716.08		5639.88		5608.01	
$D(\overline{\theta})$	7715.08		4814.02		4797.55	
pD	1.00		825.86		810.46	
DIC	7717.08		6465.74		6418.46	

*$p \leq 0.10$; **$p \leq 0.05$; ***$p \leq 0.01$; ****$p \leq 0.001$.

community random effects. Model 1 is the least complex but fits poorly. Model 2 is more complex but with improved fit that lowers the DIC substantially by over a 1,000 units. Model 3 is also more complex and improved the DIC from model 2 with over 47 units suggesting this is the best model of the three. Thus, the inclusion of household and community random effects leads to significantly improved models although their model complexity has increased.

Household random effects for base models 2 and 3 were highly significant ($p < 0.001$) indicating significant variation in diarrhoea prevalence at household level. Model 3 added community effects which were also significant ($p < 0.05$) and they explained about 5% of the variation. This again suggested significant variation in diarrhoea prevalence at community level.

Models with predictor variables at individual, household, and community levels are given in Table 3. Models 4 and 5 are less complex than models 2 and 3 in spite of increased parameters. Their (models 4 and 5) DIC are lower by over 220 units each when compared to models 2 and 3 indicating they are better models.

The difference in DIC between models 4 and 5 was over 26 signifying model 5 was a better model. Household random effects for models 4 and 5 were highly significant indicating more unobserved activity at household level in spite of added household predictors to the models.

Fitting a random coefficient model

Model 6 has included random coefficient effects and is simply an extension of model 5. Its covariance structure both at household and community levels is shown in Table 4. Model 5 underestimates most of the error terms when compared to model 6. The DIC for the random coefficient model was much lower by at least 330 units. This was the best model so far and it has been adopted for final interpretation of diarrhoea morbidity in Chikwawa.

Based on model 6, infants and children of five or less years were more likely to be suffering from diarrhoea than children of 6–18 years of age [$\beta = 1.048$; 95% CI: 0.680, 1.416]. Similarly, those in the 19–40 and 41–60 age categories were more likely to have diarrhoea than those aged 6–18 years [$\beta = 0.51$; 95% CI: 0.175, 0.845] and [$\beta = 0.748$; 95% CI: 0.252, 1.244], respectively. However, the likelihood of diarrhoea

Table 3. Diagnostics, random effects and estimated coefficient summaries fitted to data on diarrhoea prevalence.

Risk factors	Model 4 β	Model 4 SE	Model 5 β	Model 5 SE	Model 6 β	Model 6 SE
Constant	−0.237	0.502	−0.809	0.529	−0.432	0.649
Individual level:						
Categorical variables						
Individual age						
Age 6–18 (ref)	0.000		0.000		0.000	
Age 0–5	0.861	0.137****	0.856	0.134****	1.048	0.188****
Age 19–40	0.448	0.102****	0.449	0.100****	0.510	0.171***
Age 41–60	0.755	0.158****	0.764	0.167****	0.748	0.253***
Age $>$ 60	0.467	0.238**	0.484	0.243**	0.387	0.337
Individual school						
None (ref)	0.000		0.000		0.000	
Primary	−0.162	0.103	−0.161	0.102	−0.279	0.142**
secondary	−0.769	0.182****	−0.766	0.175****	−1.039	0.267****
Continuous variables						
Frequency of malaria episodes	0.484	0.030****	0.488	0.031****	0.606	0.049****
Household level:						
Categorical variables						
Employment – head household						
Not employed (ref)	0.000		0.000		0.000	
Employed	−0.526	0.216**	−0.490	0.183***	−0.619	0.266**
Health facility						
Private clinic (ref)	0.000		0.000		0.000	
Government hospital	−0.539	0.235**	−0.252	0.256	0.008	0.334
Health centre	−0.278	0.236	−0.084	0.235	0.227	0.303
CHAM hospital	−0.463	0.240*	−0.405	0.275	−0.537	0.329
Local clinic	−1.246	0.435***	−1.036	0.476**	−1.120	0.675*
Distance to nearest river						
<1 km (ref)	0.000		0.000		0.000	
1–2 km	0.215	0.130*	0.209	0.139	0.188	0.187
>2 km	0.436	0.162***	0.388	0.157**	0.507	0.216**
Household water source						
Other safe water sources[5](ref)	0.000		0.000		0.000	
PPWOPWT[4]	−0.598	0.268**	−0.491	0.274*	−0.494	0.385
Public piped water	−0.223	0.194	−0.164	0.203	−0.132	0.323
Unsafe water sources[5]	0.819	0.248****	0.719	0.275***	0.681	0.366*
Household wealth index						
Lower category (ref)	0.000		0.000		0.000	
Middle category	−0.085	0.125	−0.115	0.135	−0.255	0.180
Higher category	−0.349	0.175**	−0.326	0.164**	−0.316	0.226
Continuous variables						
Maternal age: x	−0.011	0.005**	−0.010	0.005**	−0.013	0.006**
Household density: x	−0.450	0.118****	−0.329	0.129**	−0.669	0.167****
x^2	0.034	0.010****	0.024	0.011**	0.044	0.035
Village level:						
Categorical variable						
Proximity to trading centre						
>2 km radius (ref)	0.000		0.000		0.000	
≤ 2 km radius	0.531	0.160****	0.540	0.190***	0.760	0.398*

(*Continued*)

Table 3. (*Continued*).

Risk factors	Model 4 β	Model 4 SE	Model 5 β	Model 5 SE	Model 6 β	Model 6 SE
Community and household effects:						
σ_u^2 (household)	1.873	0.634***	1.959	0.643***	4.476	1.222****
σ_v^2 (community)	–	–	0.069	0.057	0.240	0.228
Model diagnostics:						
$\overline{D}$	5475.44		5432.66		4616.86	
$D(\overline{\theta})$	4753.52		4694.49		3394.45	
pD	721.92		738.17		1222.40	
DIC	6197.35		6170.84		5839.26	

*$p \leq 0.10$; **$p \leq 0.05$; ***$p \leq 0.01$; ****$p \leq 0.001$. PPWOPWT, private piped water or private water tanks.

Table 4. Covariance structures at household and community levels.[§]

Household covariance matrix

	u_{0jk}	u_{1jk}	u_{3jk}	u_{4jk}	u_{5jk}	u_{6jk}	u_{7jk}	u_{8jk}
u_{0jk}	σ_u^2 4.476 (1.222)***							
u_{1jk}		$\sigma_u^{2(1)}$ 0.972 (0.494)**						
u_{3jk}	$\sigma_u^{(0,3)}$ −1.264 (0.703)*		$\sigma_u^{2(3)}$ 1.682 (0.584)***					
u_{4jk}				$\sigma_u^{2(4)}$ 2.469 (0.915)***				
u_{5jk}					$\sigma_u^{2(5)}$ 1.027 (0.847)			
u_{6jk}						$\sigma_u^{2(6)}$ 0.780 (0.390)**		
u_{7jk}							$\sigma_u^{2(7)}$ 0.963 (0.613)	
u_{8jk}	$\sigma_u^{(0,8)}$ −0.592 (0.235)**							$\sigma_u^{2(8)}$ 0.341 (0.081)***

Community covariance matrix

	v_{0k}	v_{10k}	v_{11k}
v_{0k}	$\sigma_v^2 = 0.240$ (0.228)		
v_{10k}		$\sigma_v^{2(10)} = 0.086$ (0.040)**	
v_{11k}			$\sigma_v^{2(11)} = 0.030$ (0.008)***

*$p \leq 0.10$; **$p \leq 0.05$; ***$p \leq 0.01$; ****$p \leq 0.01$. [§]Only variances (diagonal) and significant covariance terms (off-diagonal) have been included in the covariance matrices. Numbers in brackets are standard errors.

prevalence for these groups was still lower than that of children of five years or lower. There was no statistical difference between 6- to 18-year-olds and those above the age of 61 years.

The higher likelihood of diarrhoea prevalence amongst children below the age of five is in accordance with a number of studies, including those undertaken in Malawi (Morse 2006; Kazembe et al. 2007; Reither et al. 2007). Studies have attributed this occurrence to underdeveloped immune systems in infants, poor breastfeeding practices, malnutrition and lack of child health knowledge (Morse 2006; International Monetary Fund [IMF] 2007). In this study it was observed that young children seldom wore shoes whilst playing in and around households and whilst seated on the ground often played with soil. Domesticated animals (chickens, goats, pigs, etc.) were observed to roam freely and evidence was clearly visible of indiscriminate animal defecation. Children because of their *pica* and the potential for faecal-oral transmission of pathogens as a result of such practices in the absence of good hygiene are more susceptible to contracting diarrhoeal disease (Grimason et al. 2000; Burt et al. 2003; Taulo et al. 2009). Proposed solutions include encouraging maternal breastfeeding (sometimes discouraged in young mothers), personal and household hygiene and village health committees to implement the World Health Organization healthy village concept (Howard et al. 2002).

The significant gradual increase in diarrhoea prevalence likelihood from the ages of 19–60 years may be explained by the fact that most of those in this group were among the 14% in the age group 15–49 years that are infected with HIV/AIDS in Malawi (IMF 2007). These individuals may have had weakened immunities that rendered them vulnerable to infection. Waning of immunity in the elderly may have also been a factor (Agtini et al. 2005). Low diarrhoea prevalence amongst those that were young (6- to 18-year-olds) may explain the fact that this age group was outside the HIV/AIDS vulnerable grouping. This may be explained by their exposure to health education within the school curriculum. Erratic results for those above 60 years may be a reason for lack of evidence of any difference with those in the 6–18 year category.

Individuals who had attended primary or secondary school were less likely to suffer from diarrhoea than those who had no formal schooling [$\beta = -0.279$; 95% CI: -0.557, -0.001] and [$\beta = -1.039$; 95% CI: -1.562, -0.516, respectively]. Those who attended school may have benefited from that part of the school curriculum which addressed the cause and prevention of disease. These findings are similar to those observed in other studies on the prevalence of diarrhoea (Kandala et al. 2006; Morse 2006; Masangwi et al. 2008).

The higher the number of malaria-like episodes an individual had, the more likely they were to suffer from diarrhoeal illness during the same period [$\beta = 0.606$; 95% CI: 0.510, 0.702]. This supports a study on the effect of malaria endemicity in childhood fever, diarrhoea and pneumonia in Malawi that observed marginal positive association between diarrhoea prevalence and high malaria endemicity levels relative to low malaria endemicity (Kazembe et al. 2007). Other studies have explained the high risks associated with co-morbidity of malaria and diarrhoea likely to aggravate illness leading to death (Fenn et al. 2005).

While the categories for household possessions were not significantly different from each other in diarrhoeal prevalence, families whose head of household was employed were less likely to suffer with diarrhoea than those whose head of household was not employed [$\beta = -0.619$; 95% CI: -1.140, -0.098]. Those that were employed were more likely to have a greater disposable income than the unemployed. They were also more likely to be in a position to afford the costs associated with accessing health facilities, the purchase of medicines, to obtain drinking water from safe water sources, to have access to improved sanitary facilities, better nutrition, etc. This in turn would have reduced exposure of these individuals to many of the factors associated with the onset and transmission of diarrhoeal disease. Indeed, a study by Veenstra (2000) showed that households with greater disposable income positively related to better health.

Type of health facility had no noticeable association with diarrhoea prevalence except with local clinics or health posts that were marginally associated with less likelihood of diarrhoeal prevalence when compared with local private clinics [$\beta = -1.120$; 90% CI: -2.234, -0.006]. Malawi's health service delivery system consists of community, primary, secondary and tertiary care levels (Zere et al. 2007). Health posts are normally administered at community level where service is provided through health surveillance assistants (HSAs). The focus is on preventive interventions. Intervention programmes by non-governmental organisations (NGOs) and other non-profit organisations involved in healthcare delivery issues use these health posts to reach the local communities. The communities in turn benefit from frequent health initiatives including the provision of water disinfectants, safe water provision, and health education. Such organisations rarely use district hospitals, health centres or local private clinics. The reduced risk of diarrhoeal prevalence at local health posts may be a reflection of this scenario.

Households utilising unsafe water sources (i.e. rivers, streams, ponds, and other stagnant water bodies) were marginally more likely to have suffered from diarrhoea than those using safe water sources such as boreholes, protected wells or springs [$\beta = 0.681$; 90% CI: 0.077, 1.285]. There was no evidence of difference in diarrhoeal prevalence between those using boreholes, protected wells, or springs and those drinking from piped water supplies. Unsafe water sources are usually only used by villagers for bathing and laundry purposes but occasionally people collected river water for drinking water purposes, e.g. as a result of overcrowding around safe water sources or by personal preference. Unsafe water sources were subject to contamination from both point sources (e.g. indiscriminate faecal littering of the environment by humans who either did not have access to a latrine or preferred not to use a latrine and domestic animals which roamed freely) and diffuse pollution (e.g. surface run-off from land into rivers, streams, etc.) during the rainy season and flooding events (Muirhead et al. 2004; Sirajul Islam et al. 2006). Animals were often observed drinking and cooling themselves in ponds of stagnated water, e.g. caused by inadequate drainage at the end of poorly constructed borehole soak-aways. It was also noted that farmers brought their cattle to river sources for drinking both upstream and downstream of the location used by women and children for bathing and laundry purposes. Faecal contamination of such water resources exposes human beings to zoo-anthropoonotic sources of diarrhoeal disease. The use of river water for drinking purposes and other domestic chores was found to be a significant risk factor associated with the incidence of cryptosporidiosis in paediatric children in Chikwawa (Morse 2006).

Diarrhoea risks were also associated with regards to the proximity of households to a river or stream after controlling for rivers and streams as drinking water sources. Families in households that were more than 2 km from a river were significantly at a higher risk of suffering from an episode of diarrhoea than those that were within 1 km of the nearest river [$\beta = 0.507$; 95% CI: 0.084, 0.930]. The distance to a safe water source, the quantities that can be collected and time and effort required for collection and transportation are important factors in water use and management within households. Some women preferred to recycle water that had previously been collected from a safe water source for cleaning kitchen utensils, rather than walk over a kilometre to obtain fresh water from a safe water source such as a borehole for the same task. Hands, food, floors, cooking surfaces, kitchen utensils, and children were less likely to be kept clean and hygienic when water from safe water sources had to be carried from distance, was in short supply, and required valuable time, energy resources and effort to be devoted (Bartlett 2003). Studies in Papua New Guinea and Burkina Faso (Bukenya and Nwokolo 1991; Curtis et al. 1997) reported a significant reduction in diarrhoeal disease in communities who had access to safe water sources within their compounds compared with those that had to fetch safe water from outside their compounds. Communities who had access to abundant safe water sources within their compounds were more likely to adopt good hygiene practices such as hand-washing after using a latrine.

A negative relationship was found between maternal age and reported diarrhoeal episodes. The older the responsible matriarchal figure in a household, the less likely it was reported that its members suffered from diarrhoea within the time period [$\beta = -0.013$; 95% CI: -0.025, -0.001]. This may be due to the experience and knowledge gained over many years of family caring and dealing with diarrhoeal disease. Another factor may be that many of the inhabitants in such households were older and thus less likely to have suffered from diarrhoeal disease compared with households with younger mothers and children.

Household size has a quadratic relationship with diarrhoea prevalence. Increasing sizes in households from one to six members had a negative relationship with diarrhoea prevalence [$\beta = -0.669$; 95% CI: -0.996, -0.342] while increasing household size from seven and above had a non-significant positive relationship with diarrhoea prevalence [$\beta = 0.044$; 95% CI: -0.025, 0.113]. Small households comprising of two or three people are mostly associated with young single mothers or newlywed couples who may be less experienced and not as prepared to deal with the challenges associated with child caring (Hobcraft 1993; Pongou et al. 2006; Osumanu 2007). The decreasing prevalence in diarrhoea may reflect increasing experience with years as the family expands until this reaches a threshold of about a six-member family when the impact of overcrowding outweighs any gains from experience.

At community level, villages living within 2 km of an active[4] trading centre were marginally more likely to experience diarrhoea than those living more than 2 km from an active trading centre [$\beta = 0.760$; 90% CI: 0.103, 1.417]. Factors that may have influenced this include the observed unhygienic practices associated with the preparation and presentation of foodstuffs for sale to the public in an unsanitary environment and unhygienic stalls. Vendors trade in the sale of live and dead animals in an open, dusty and overcrowded environment. Further work is required to improve the food hygiene practices operated by vendors and proprietors of trading centres through the implementation of a proper licensing and inspection system which incorporates the provision for basic food hygiene training for those involved in the production and sale of foodstuffs.

Figure 1 shows a caterpillar plot of household residuals (i.e. household random effects). A number of households had their residuals significantly higher than a zero indicating significant differences between households and extreme vulnerability in such households. This is supported by the covariance structure in Table 4 that shows significant variation in diarrhoea prevalence at household level [$\sigma_u^2 = 4.476$; 95% CI: 2.081, 6.871]. Prevalence of diarrhoea also varied across households amongst the age groups 0–5 years [$\sigma_u^{2(1)} = 0.972$; 95% CI: 0.004, 1.940]; 19–40 years [$\sigma_u^{2(3)} = 1.682$; 95% CI: 0.537, 2.827]; and 41–60 years [$\sigma_u^{2(4)} = 2.469$; 95% CI: 0.676, 4.262]. Household variation was also observed amongst those that had primary education [$\sigma_u^{2(6)} = 0.780$; 95% CI: 0.016, 1.544] and those that had varying degrees of malaria-like episodes [$\sigma_u^{2(8)} = 0.341$; 95% CI: 0.182, 0.500]. Although the age group 19–40 years showed a high probability of diarrhoea prevalence than the age group 6–18 years, they showed less variability in their pattern of diarrhoea prevalence [$\sigma_u^{(0,3)} = -1.264$; 90% CI: -2.424, -0.104]. Similarly, those with varying degrees of malaria-like episodes showed less variability in their pattern of diarrhoea prevalence [$\sigma_u^{(0,8)} = -0.592$; 95% CI: -1.053, -0.131].

Figure 2 shows a caterpillar plot of community residuals. No single community residual was significantly above zero indicating no difference in diarrhoea prevalence between communities and this is supported by Table 4. However, there was variation in diarrhoea prevalence based on household sizes of 1–6 members [$\sigma_u^{2(10)} = 0.086$; 95% CI: 0.008, 0.164] and those with seven or more members [$\sigma_u^{2(11)} = 0.030$; 95% CI: 0.014, 0.046] indicating significant differences in diarrhoea prevalence based on household sizes at community level.

Recommendations and concluding remarks

The contributions of this paper are two-fold. First, it contributes to research on the variation of diarrhoeal prevalence at household and community levels in southern

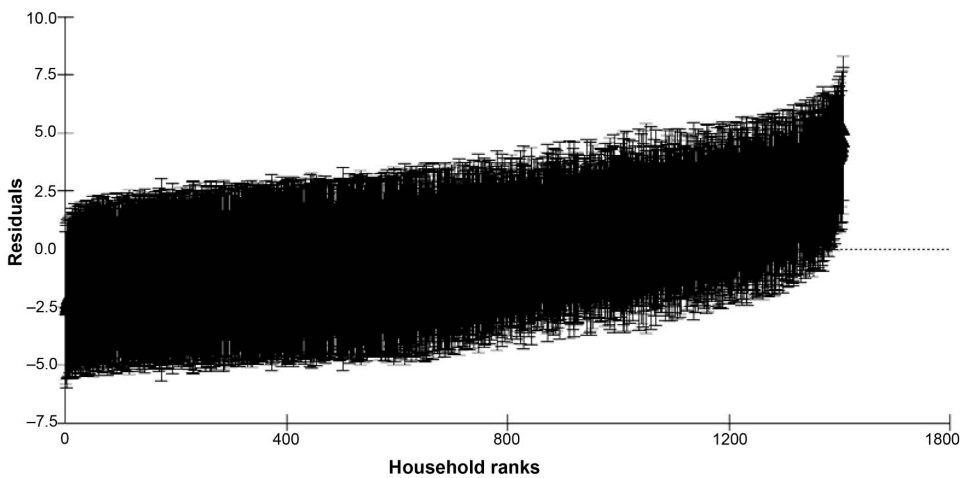

Figure 1. Caterpillar plot of ranked household residuals. The dotted line is the mean of the estimated (shrunken) residuals* which is equal to zero. The brushes represent 95% CI to the estimated residuals. *Estimated or shrunken residual for group j is the residual obtained by multiplying the mean of the residuals of subjects in group j by a shrinkage factor. Shrinkage factor shrinks an observed group mean towards the centre of the population mean.

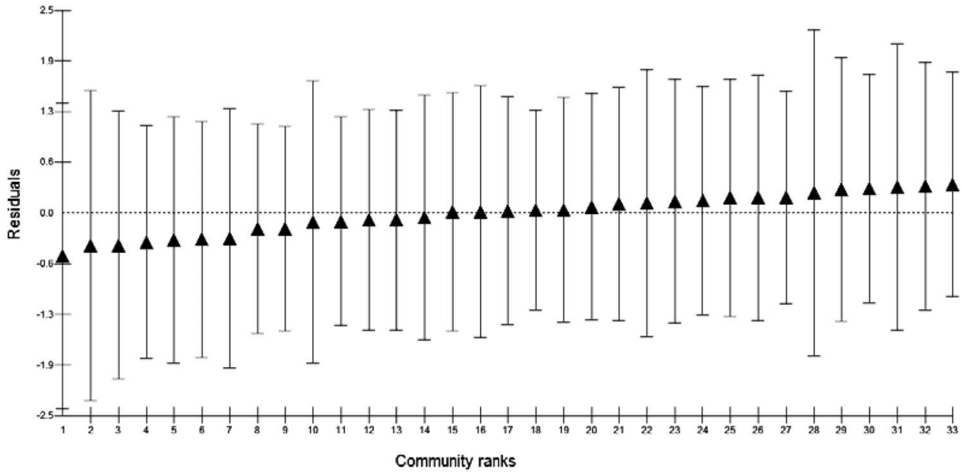

Figure 2. A 95% confidence interval caterpillar plot of ranked village residuals. The triangles indicate estimated (shrunken) community residuals.

Malawi by adopting a Bayesian multi-level modelling approach. Second, it contributes to the understanding of risk factors within a district based on household and community characteristics.

In contrast with many previous studies in Malawi, this study used data specifically designed for multi-level analysis of communities and households within a district rather than use of national data which has limitations of drawing inferences based on aggregate statistics at regional, district or sub-district level. This study also included specific information that may not have been included by national surveys but may be important in influencing disease in the communities and may be of vital importance in primary healthcare. The models are able to highlight areas that are more vulnerable hence requiring urgent attention. The study, for example, shows that households that use unsafe water sources and are located a long distance from safe water sources are more vulnerable to diarrhoeal infection. This underscores the need, not just for safe water, but safe and abundant water sources.

The main finding of this study is that there is more variation in diarrhoea prevalence between households than between communities. Lack of significant variation at community level has partly been accounted for by the community level predictor that measures proximity to nearest active trading centre. Excess household variability may be due to spatial variability at household level which has not been accounted for in this model. While multi-level models avoid important biases in estimates and standard errors for the risk factors by relying on space fragmented areas such as villages and households, spatial techniques use place indicators that continuously consider the space around the individual's place of residence thereby overcoming the fragmentation of the space into areas when formulating the correlation structure (Chaix et al. 2005). However, in the absence of continuous space information, multi-level techniques are the alternative. Lack of variation at community level may also be due to some unobservable factors that have not been captured by this study. Reported household hygiene practices and water management, for example, may not be the actual daily practices. They may only reflect what respondents perceive to be expected practices. Reported cases may not reflect instances that may have been a source of diarrhoea rather they may only reflect average social, cultural, and other environmental activities in the household. Direct longitudinal household studies may be more appropriate to capture practices such as household behaviour with regard to the quality and quantity of water used for domestic purposes that may be missed by cross-sectional studies.

The pattern of diarrhoeal prevalence in respect to individual age gives an interesting observation and confirms the findings of an earlier study (Masangwi et al. 2008, 2009). Children under five years of age require special attention. Reinforcement of public health education in child care and efforts in encouraging mothers to breastfeed may be appropriate. Reduced risk of diarrhoeal disease reported from those who benefited from having attended primary school emphasises the importance of educating all children on the cause and prevention of waterborne and food-borne disease. At the present time, the burden of responsibility in respect to household chores such as the collection and transportation of water, preparation of food and field-related chores, etc., falls unequally upon mothers and their daughters. As education appears, in part, to positively address this issue, then financial resources from Government should be directed to ensure that both boys and girls are afforded an opportunity to free, secondary education in Malawi.

Finally this study has its limitations. Data was based on retrospective reporting by women in each household. This may create biases due to incomplete responses, and unrepresentative individual data. Furthermore, only information from surviving women was recorded implying that no data was available for households without a matriarchal figure which may create bias. During the survey, mothers were not given a precise definition of what constitutes an episode of childhood diarrhoea. Therefore, questions relied on the mother's perception of the disease other than clinical or actual definitions. This may create variations among different households and villages because perception of an illness episode is not the same across different groups of people. To reduce the effect of these methodological limitations, questionnaires from each enumerator were carefully audited after each day's survey and the data was screened to ensure consistency of approach to questioning and responses and to determine if the data conformed to expected patterns.

The survey required mothers to recall information of up to eight months from January to September 2007 with the aim of capturing data that included the peak of the rain season when diarrhoea morbidity was at its highest. There was a risk that some diarrhoea episodes would not be reported due to the length of the recall period, particularly when the illness was not extreme. However, since the aim of the survey was mostly to understand factors that influence diarrhoea morbidity in individuals, families and communities of Chikwawa, this risk was overlooked on the basis that the information obtained would outweigh the discrepancies in forgotten diarrhoea episodes. Moreover, other studies have concluded that more easily observed symptoms are less likely to suffer from selective reporting (Kazembe et al. 2009). Recall bias is reported to be related to level of mother's education, with more educated mothers most likely to remember and distinguish symptoms for most illnesses, therefore controlling for mother's education in the analysis may capture a large part of the self-selective nature of reporting (Filmer 2005; Kazembe et al. 2009).

Further research needs to address family and community practices with regard to hygiene, sanitation, water storage and safety in order to understand how these may influence diarrhoea patterns in the households and communities. The significant positive relationship between diarrhoea and malaria-like episodes highlights common risk factors and hence the need for common approaches to combating these diseases.

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Notes

1. Notice that distance to the nearest river and nearest health facility were included as household variables because households from the same community could have different proximities to the same nearest river or would have different nearest rivers and they could report to different health facilities based on distances and socioeconomic preferences.
2. WHO definition of improved water source: there must be at least household piped water connections, public standpipes, boreholes, protected dug wells, protected springs or rainwater collection available to the household.
3. WHO definition of improved sanitation: there must be at least a connection to a public sewer, a connection to a septic tank, a pour-flush latrine, a simple pit latrine or a ventilated improved pit latrine available to the household.
4. Active trading centres are those that are busy and have large volumes of people on a daily basis.

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