

BMJ Open Inequities in childhood anaemia at provincial borders in Mozambique: cross-sectional study results from multilevel Bayesian analysis of 2018 National Malaria Indicator Survey

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ABSTRACT

Objectives This study aims to identify the child-level, maternal-level, household-level and community-level determinants of anaemia among children aged 6–59 months, and determine the inequities of anaemia prevalence across communities in Mozambique.

Design Cross-sectional study.

Setting Mozambique.

Participants This study used data of a weighted population of 3946 children, 6–59 months, delivered by women between 15 and 49 years of age, from the 2018 Mozambique Malaria Indicator Survey.

Primary outcome measure Child's anaemic status, measured as altitude-adjusted haemoglobin concentration (in g/L); the severity of anaemia was categorised based on predefined threshold values. Multilevel Bayesian linear regressions identified key determinants of childhood anaemia. Based on data availability and policy implications, spatial analysis was used to determine geographical variation of anaemia at the community level and areas with higher risks.

Results The mean prevalence of childhood anaemia was 77.7% (SD: 5.5%). Provincially, Cabo Delgado province (86.2%) had the highest prevalence, Maputo province (70.2%) the lowest. Children with excess risk were mostly found in communities that had proximity to provincial borders: Niassa-Cabo Delgado-Nampula triprovincial border, Gaza-Inhambane border, Zambezia-Nampula border and provinces of Manica and Inhambane. Children with anaemia tended to be younger, males and at risk of having malaria because they were not sleeping under mosquito nets. In addition, children from poor families relative to children from wealthier households and those living in female-headed households were prone to anaemia.

Conclusion Findings from this study provide evidence that spatial inequities in childhood anaemia exist in Mozambique, mostly concentrated in the communities living close to the provincial borders. Anaemia among children could be effectively reduced through malaria prevention, for example, bed netting. Interventions are needed that generate income for households, increase community support for households headed by women,

Strengths and limitations of this study

- Contextual effects at multiple hierarchical levels, community, household and maternal, used to understand determinants of anaemia among children aged 6–59 months in Mozambique.
- Uncertainty around point estimates is minimised, hence generating more accurate models, using multilevel Bayesian methods.
- Direct measures of relevance, such as inflammatory syndrome, recent malaria illness, food insecurity, HIV and intestinal worm infestation, were not available in the datafile. To overcome this challenge, we used mosquito bed net usage (as a proxy for malaria illness), household sanitation (as a proxy for worm infestation), and household wealth index (as a proxy for food insecurity).
- A limitation is that the national survey is of a cross-sectional design; hence, temporality cannot be established. It is therefore important to interpret our findings as associations rather than causal relationships.

improve malaria control, build capacity of healthcare workers to manage severely anaemic children and health education for mothers.

INTRODUCTION

Anaemia—a condition typically defined as shortage of red blood cells or haemoglobin (Hb) of less than the fifth percentile for the individual's age (ie, <13 g/dl in males and <12g/dl in females) is a common public health problem worldwide.¹ Nearly two billion people are anaemic, affecting mostly poor women and children—corresponding to one-third of the world's population.² Despite the huge physiological and socioeconomic impacts of anaemia in the recent decades, it has attracted less attention by policy-makers.³

Moraleda *et al*⁸ argued that the long neglect of anaemia could be partly due to its comorbidity with other major health conditions, which are frequently more prioritised. Moreover, although the Sustainable Development Goals 2 and 3 were formulated to tackle hunger/food insecurity, and maintain optimal health/well-being for people, respectively,^{4,5} there is currently no clear target for monitoring global progress for anaemia among children.

Recent findings from a systematic analysis of 328 diseases in 195 countries highlighted that iron-deficiency anaemia is among the first five leading causes of years lived with disability (DALY).⁶ The negative societal impacts of anaemia are more pronounced in the low-/middle-income countries, where it causes premature morbidity and mortality of pregnant women and under-five children, resulting in significant human capital and economic losses.⁶ As previously reported in literature, anaemia impairs cognitive functioning during the early childhood developmental stage,⁷ and those children affected often suffer from other complications of iron and vitamin B₁₂ deficiencies.^{8–10} The main long-term consequences are poor psychomotor skills, academic performances and susceptibility to infections.^{8–10} The need to urgently tackle global food insecurity is therefore a top priority as studies have acknowledged that poor nutrition is the most common cause of anaemia worldwide.^{8–10} Other important proximal contributors to childhood anaemia in sub-Saharan Africa are malaria, haemoglobinopathies, HIV, tuberculosis and intestinal worm infestations.^{8 11–13}

The global prevalence of anaemia among children aged 6–59 months remains high at 39.8% since 2019, declining slightly from 41.7% in 2016.¹⁴ According to WHO, Mozambique is one of the sub-Saharan African countries with high prevalence of childhood anaemia—68.9% in 2019, ranking 13th in league tables.¹⁴ The government of Mozambique is currently making efforts to address nutritional anaemia among women and the children through programmes specifically targeted to these populations—such as mass deworming, iron supplementation and malaria chemoprophylaxis at antenatal care (ANC)—as well as by providing emergency food assistance, food vouchers and nutrition counselling to populations in need.¹⁵ However, findings from the 2011 Mozambique Demographic and Health Survey showed that food insecurity persisted, 63% of under-five children showing signs of moderate to severe chronic malnutrition.¹⁶ Malnutrition is also an underlying cause of about 26% of under-five deaths in Mozambique.¹⁷

Some studies in sub-Saharan Africa have recognised the individual-level and community-level factors associated with childhood anaemia;^{18 19} however, the key determinants of childhood anaemia and its variation across the provinces and districts of Mozambique are less understood. Most of the previous studies are hospital based and extensively focused on medical causes of childhood anaemia, with less attention to its social determinants,³ or used data from multiple countries,^{19 20} making evidence

needed for action difficult. In one of the few nationwide studies in Mozambique, Mabunda *et al*²¹ concluded that there was no significant difference in the provincial mean Hb concentration among children under 10 years old. Adeyemi *et al*,²² however, observed a significant spatial pattern of childhood anaemia—worse in central Mozambique in 2011.

In Mozambique, public health planning (ie, policy, strategic development and investment decisions) is centralised at the national level (Ministry of Health).²³ The resources from the centralised system are then deployed to the provincial directorates of Health and further to the district directorates of health.²³ In recent years, the provinces and districts have been reprogramming health services with the aim of ensuring cost-effective services, universal health coverage and reducing health inequities.²³ To ensure more equitable and healthy societies, it is therefore important to look beyond the national and provincial jurisdictions and focus on the districts. Intraprovincial inequities are often overlooked by aggregating health outcomes at both national and provincial levels. The provincial level of aggregation obscures variations in maternal and child health progress which makes identification of hotspots of childhood anaemia in Mozambique more challenging.

Given the scarce evidence needed to improve childhood anaemia in the communities and districts, this study is aimed to broaden the extant knowledge on childhood anaemia in Mozambique by analysing the newly released 2018 Malaria Indicator Survey (MIS). The objectives of this study were to identify the child-level, maternal-level, household-level and community-level determinants of anaemia among children aged 6–59 months, and determine inequities of anaemia prevalence across communities in Mozambique.

METHODS

Study setting

Mozambique is a Southeastern African country that shares boundary with the Indian Ocean to the east, Tanzania to the north, Malawi and Zambia to the northwest, Zimbabwe to the west, and Eswatini and South Africa to the southwest. The country is divided into 10 provinces and a capital city (Maputo), which are further divided into 129 districts. The districts are subdivided into 405 administrative posts and then into local communities—the lowest geographical unit. According to 2017 census, Mozambique's population was estimated at 29 million, with preponderance of young people—nearly half (46.6%) are under age 15 years.²⁴ Almost 6 out of 10 Mozambicans reside in rural areas.²⁵ According to the 2019 United Nations Development Programme Human Development report, Mozambique ranks 181 out of 189 countries in human development league table, and 72.5% of its population lives in poverty.²⁶

Data source

This is a cross-sectional study that used child recode data-file and the global positioning system (GPS) dataset of

the 2018 Mozambique MIS.²⁷ The survey was conducted between March 2018 and June 2018 by the Moçambique Instituto Nacional de Saúde, in collaboration with ICF International Calverton, Maryland, USA, to provide national and subnational estimates of anaemia and malaria indicators for policy and programmatic purposes. The details of the methodology used for the survey has been published elsewhere.²⁸ With a stratified two-stage sampling design, face-to-face standardised questionnaire interviews were conducted among women aged 15–49 years. Using probability proportional to size, the first stage of sampling involved selection of 224 clusters or enumeration areas (otherwise known as the primary sampling units (PSU)) from the 2007 General Population and Housing Census.²⁸ Out of the 224 clusters, 58.9% were in rural areas, while the rest were in urban areas. The second stage involved systematic sampling of 6279 households. Each household was randomly selected from the household listing, with an average of 28 households per cluster. For this study, the clusters are referred to as the ‘communities’ because they are believed to comprise homogenous or kinship populations. Of the 6279 households, the response rate was 99%, while out of the 6290 eligible women identified, 6184 could be interviewed (response rate of 98.3%). With the consent of the parents/caregivers, blood samples were collected in a microcuvette from the heel (of children aged 6–11 months) or fingers (of the children aged 12–59 months) for Hb concentration estimation. After discarding the first drop of blood to avoid possible contamination, Hb concentration was estimated with the second drop, using an automatic haematology analyser (HemoCue 201+). For this study, a subpopulation of 3652 (weighted: 3946) singletons aged 6–59 months who were alive at the commencement of the survey and had Hb concentration results reported were analysed.

Ethical considerations

This is a secondary analysis of data available online²⁷ where the datasets are deidentified of the respondents’ personal information; hence, no ethical approval was required for this specific study. However, prior to the commencement of the primary survey, ethical clearances were obtained by the Demographic and Health Survey (DHS) team from National Committee for Bioethics in Health of Mozambique (Comité Nacional de Bioética para Saúde). Also, written informed consent was obtained from all mothers during the field work. Following registration and submission of research protocol, administrative access to the dataset was granted by the DHS team, USA. The survey data files were provided at no cost for academic research.²⁸

Patient and public involvement

Patient and public involvement was not possible in this study given it was based on an analysis of secondary data.

VARIABLES

Outcome variable

The outcome variable was child’s anaemic status, measured as altitude-adjusted Hb concentration (in

g/L), and the severity of anaemia was categorised based on predefined threshold values: normal (≥ 110 g/L), mild (100–109 g/L), moderate (70–99 g/L) and severe (< 70 g/L).²⁹

Exposure variables

The selection of exposure variables was guided by the socioecological model,³⁰ and on the evidence that the proposed variables are important covariables to be included in relation to the outcome.

The socioecological model proposes that health outcomes are influenced by factors that operate at different levels that is, microlevel (individual), mesolevel (household) and macrolevel (community/district/province). The independent variables comprise of factors that affect the outcome at different levels, for example, child-level factors—age (in months), sex (male and female), birth order (surviving eldest child and non-first-born children), mosquito net usage—as a proxy for risk of malaria illness—(no net, only untreated nets and only treated nets), preceding birth interval (< 24 months and ≥ 24 months) and succeeding birth interval (< 24 months and ≥ 24 months); maternal-level factors—age in years (≤ 19 , 20–34 and ≥ 35), highest maternal educational attainment (no education, primary, secondary and post secondary), parity (≤ 2 , 3–5 and > 5) and adequacy of ANC visits based on WHO guidelines³¹—none, inadequate (1–7 visits) and adequate (≥ 8 visits); household-level variables—sex of household head (male and female), wealth index—proxy for food (in)security. The wealth index is a composite measure of household’s assets and amenities (eg, ownership of television, bicycle, car, livestock, etc), which was calculated using principal components analysis. The standardised scores were divided into quintiles. We recoded MIS wealth index into low (ie, poor and poorest), middle and high (ie, rich and richest) socioeconomic status. Based on the WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) classification,³² household sanitation, source of drinking water and source of cooking fuel (proxy for indoor pollution) were recoded as improved and unimproved. The community-level variables included were social infrastructural development (measured by proportion of households with electricity in the community), place of residence (urban and rural) and province.

STATISTICAL ANALYSIS

The unit of statistical analysis was the individual children (ie, lowest level) who were nested within aggregated units (maternal, household and community levels). Following the preliminary data quality checks, there was no multicollinearity among the independent variables (mean variance inflation factor=1.3, range: 1.0 to 1.6). For the descriptive analyses, we used the complex survey analysis commands in Stata software V.16.1³³ to account for the cluster sampling design and applied the sampling weights provided in the datafile.

Considering the nested nature of the data, we used multi-level Bayesian linear regression with four-level models. Practically, modelling Hb concentration as a continuous outcome variable prevented non-convergence, misclassification and allowed for retention of maximum information in the linear regression, which could have been lost with categorisation.³⁴ In order to maximise simulation efficiency and reduce the long computational time often required to achieve convergence for multilevel Bayesian models, the outcome variable (Hb concentration) was log transformed.³³ Also, two Monte Carlo Markov Chains (MCMC) were simulated with a hybrid algorithm of random-walk Metropolis–Hastings and Gibbs sampling to improve the precision of parameter estimates.³³ The prior specifications for the regression parameters were set to follow a non-informative normal distribution—zero mean and a variance of 10 000, because there was no prior knowledge of the directions and effect sizes of the independent variables. We fitted 25 000 iterations per chain (including a burn-in period of 5000 iterations per chain), hence generating a MCMC sample size of 40 000 iterations with an acceptable Monte Carlo errors (<5% of the posterior SD). Using the MCMC sampling, the Bayesian approach is more robust against missing data compared with the frequentist approach.³⁵ During the simulation process, the MCMC sampling automatically imputes missing values and make predictions based on posterior distribution.^{35 36}

Convergence of MCMC samples is crucial in making reliable inferences from Bayesian analysis; hence, monitoring was done with a strict convergence rule of Gelman-Rubin statistic $R_c < 1.1$.³³ The model chains for all the parameters had adequate acceptance rates (range: 69.29%–69.99%), and the average simulation efficiency rates were within the acceptable limit of >10% for Gaussian random-walk Metropolis-Hastings sampling (see online supplemental figures S1–S5 for the details). In addition, the Markov chains were checked by visually inspecting the histograms, trace, autocorrelation and kernel density plots (online supplemental figures S1–S5).

MODEL BUILDING

We fitted five models. Model 0 was an empty/null model which did not include any covariate, but specified three-random intercepts attributable to mothers, households and communities. Model 1 added child-level variables to model 0. Using parsimonious approach, model 2 retained variables from model 1 and added maternal-level variables. Model 3 comprised variables retained from model 2 and added household-level factors. Model 4 (full model) retained variables in model 3 and added community-level variables.

We fitted parsimonious models using forward block-wise selection method of variables and selected models with the smallest average Bayesian Deviance Information Criterion (DIC). All Bayesian models were fitted in the Stata V.16.1 software.³³

Measures of associations (fixed effects)

The measures of association were presented as posterior exponential β coefficients and 95% Bayesian Credible Intervals (95% CIs) because the outcome variable (Hb concentration) was log transformed. The exponentiated coefficient represents the ratio of two geometric means: that of the category considered, compared with that of the reference category. The level of statistical significance was determined by the non-inclusion of one (ie, $\exp(0)$) in the 95% CIs.

Measures of variations (random effects)

To evaluate the extent of variation of childhood anaemia among the women, households and communities, intra-class correlation coefficient (ICC) (eq i–iii), and proportional change in variance (PCV) were calculated

$$ICC_{maternal} = \frac{V_c + V_h + V_m}{V_c + V_h + V_m + \left(\frac{\pi^2}{3}\right)} \quad (i)$$

$$ICC_{household} = \frac{V_c + V_h}{V_c + V_h + V_m + \left(\frac{\pi^2}{3}\right)} \quad (ii)$$

$$ICC_{community} = \frac{V_c}{V_c + V_h + V_m + \left(\frac{\pi^2}{3}\right)} \quad (iii)$$

where V_m , V_h and V_c are the variances of childhood anaemia at the maternal, household and community levels, respectively.

The PCV estimated the total variance attributable to the independent variables for each level of the multilevel model (eq. iv)

$$PCV = \frac{V_e - V_i}{V_e} \times 100 \quad (iv)$$

where V_e and V_i are variances of empty model and model with independent variables, respectively

Spatial analyses

Rates-calculated maps

Initially, we generated unadjusted provincial prevalence maps (excess risk and spatial empirical Bayesian smoothed maps) in GeoDa V.1.14.³⁷ The smoothed provincial map was based on geometric centroids and spatial (arc) distance of 396.2 km in a geographical coordinate map (WGS84: EPGS4326). The empirical Bayesian smoothed prevalence map accounted for the intrinsic variance instability of small area disease risks associated with complex survey data, by minimising the standard errors.³⁸ The smoothing is important to avoid spurious representation of the spatial patterns of the risk of childhood anaemia for Mozambique. The following equations were used to account for spatial heterogeneity and spatial dependence between provinces³⁸

$$\pi_i^{EB} = w_i r_i + (1 - w_i) \theta, \quad (v)$$

where π_i^{EB} is the empirical Bayesian estimate for the risk in province i , θ is the prior estimate, r is the weighted average of crude rate.

$$w_i = \frac{\sigma^2}{\sigma^2 + \frac{\mu}{P_i}} \quad (vi)$$

where P_i is the population at risk in province i , and μ and σ^2 are the mean and variance of the prior distributions.

Identification of hot spots

We linked the weighted cases of anaemia and weighted population-at-risk to each community (vector points) in the 2018 Mozambique MIS geographical shapefile and determined the presence of geographical clustering (positive spatial autocorrelation) with global Moran's I index and local indicator spatial autocorrelation maps at a Monte Carlo Randomization of 999 permutations and p value < 0.05.

For comparison purpose, the crude and adjusted posterior means of the community-level random effects from the multilevel Bayesian linear regression were mapped. The actual values of the posterior means were mapped instead of the exponential of the regression coefficients to easily show the directions of effects of geographical area on Hb concentration. The negative sign (as depicted by red colour) shows the areas associated with lower Hb concentration, and positive sign (as depicted by green colour) connotes areas associated with higher haemoglobin concentration. The geographical coordinate shapefile used for mapping the posterior means was collected by the DHS team using GPS receiver at the level of PSUs (ie, communities). In order to predict the mean Hb concentration for other communities that were not captured in the 2018 MIS, we used spatial interpolation with inverse weighing distancing in QGIS V.2.8.9 software.³⁹ With isopleth maps, it is easier to identify the districts and provinces with different posterior means of Hb concentration.

RESULTS

Sample characteristics

Table 1 summarises the sample characteristics. The mean age (SD) of the children in the study was 31.2 (± 15.5) months, with a male to female ratio of 1.1:1. Sixty-seven per cent of mothers of children in the study were between 20 and 34 years of age. On average, mothers had four children. Almost half (49%) of the children lived in poor households. Most children's mothers had not finished or had only primary school education (79.5%); 97% households used polluting fuels for cooking, 73% resided in rural communities, and 72% lived in households that were headed by men.

Prevalence of anaemia

Overall, four out of five children had anaemia, translating to a national prevalence of 80.3% (95% CI 78.1% to 82.4%). The mean (\pm SD) Hb concentration was 95.4 (± 16.3) g/L. Twenty-four per cent of children had anaemia classified as mild, 50% moderate and 7% severe (table 1). The prevalence of anaemia was clearly higher in males (81.5%), those born late in the birth order (87.4%), born to mothers who delivered a succeeding child close together (less than 2 year gap)—77.8%, delivered after

2 years of a preceding birth (89%), delivered by teenage mothers (86.7%), living in houses with unimproved sources of drinking water (83.9%), and residing in rural communities (81.6%). The prevalence of anaemia was higher in children with mothers without formal education (83.2%), delivered by women who had more than five births (81.8%), and those from poor households (84.6%). Across the provinces, Cabo Delgado had the highest prevalence of childhood anaemia (86.2%) and lowest in Maputo province (70.2%).

Factors influencing childhood Hb concentration values

Figure 1 present the results of the fixed-effect estimates from the multilevel Bayesian linear regression for child-level factors (model 1–A), child and maternal-level factors (model 2–B), child, maternal and household-level factors (model 3–C) and child, maternal, household and community-level factors (model 4–D). From the final multivariate model, the mean Hb concentration value was 2.2% higher for female children than for male children (posterior exp(β): 1.02, 95% CI 1.01 to 1.03) (figure 1D). For each 10-month increase in child's age, there was a 3% increase in mean Hb concentration value. For children sleeping under untreated mosquito net, there was a 2.8% increase in the mean Hb concentration value, compared to those not sleeping under mosquito net (posterior exp(β): 1.03, 95% CI 1.00 to 1.06). However, there was no difference between the mean Hb concentration value among children who slept under treated net and those without net. A dose–response relationship was observed for household wealth and the mean Hb concentration value. The increment in mean Hb concentration value was 2.8% in children of households with middle-wealth index (posterior exp(β): 1.03, 95% CI 1.01 to 1.03), 5.4% in children of households with rich-wealth index (posterior exp(β): 1.05, 95% CI 1.03 to 1.08), compared to those from poor households. Children living in households headed by women, compared to those living in households with male-heads, had their mean Hb concentration value decreased by 1.3% (posterior exp(β): 0.99, 95% CI: 0.97 to 1.00). Compared to children living in Maputo province, those from Cabo Delgado province had the largest reduction (8.2%) in mean Hb concentration value (posterior exp(β): 0.92, 95% CI: 0.88 to 0.96), followed by 8.1% drop in Sofala province, posterior exp(β): 0.92, 95% CI: 0.88 to 0.96. There was 6.8% decrease in mean Hb concentration value for Nampula province, posterior exp(β): 0.93, 95% CI: 0.89 to 0.98; 6.7% reduction in Niassa, posterior exp(β): 0.93, 95% CI: 0.89 to 0.98, and 6.5% decrease in Zambezia province, posterior exp(β): 0.94, 95% CI: 0.89 to 0.98).

With an average DIC of –2490 for model 3 and model 4, adding household and community-level factors improved the models (table 2). Although, both models had similar average DIC value, model four was selected because of the further reduction in variance across the communities, with the addition of community-level factors.

Table 1 Sample characteristics of children aged 6–59 months, Mozambique Malaria Indicator Survey 2018

Variables	N (%) (weighted)	Prevalence of anaemia % (95% CI) (weighted)
Haemoglobin concentration (g/L)		
Mean (SD)	95.4 (16.3)	
Anaemic status		
No anaemia	776 (19.7)	
Mild anaemia	937 (23.7)	
Moderate anaemia	1977 (50.1)	
Severe anaemia	257 (6.5)	
Child-level factors		
Child's age (in months)		
Mean (SD)	31.2 (15.5)	
Child's sex		
Male	2024 (51.3)	81.5 (79 to 83.9)
Female	1922 (48.7)	79.1 (75 to 81.8)
Birth order		
Surviving eldest child	2719 (68.9)	77.2 (74.6 to 79.6)
Non-first-born children	1227 (31.1)	87.4 (84.6 to 89.7)
Slept under mosquito net last night		
No net	705 (17.9)	79.1 (74.9 to 82.8)
Treated net	2939 (74.5)	81.2 (78.7 to 83.5)
Untreated net	301 (7.6)	74.9 (67.9 to 80.8)
Preceding birth interval		
≤24 months	372 (30.3)	83.5 (77.2 to 88.4)
>24 months	855 (69.7)	89.0 (86.1 to 91.4)
Succeeding birth interval		
≤24 months	315 (26.8)	77.8 (71.9 to 82.7)
>24 months	870 (73.2)	72.5 (67.4 to 77)
Maternal-level factors		
Maternal age (in years)		
≤19	430 (10.9)	86.7 (81.7 to 90.5)
20–34	2640 (66.9)	79.6 (76.8 to 82.1)
≥35	876 (22.2)	79.5 (75.5 to 83)
Educational attainment		
None	1028 (26.1)	83.2 (79.9 to 86)
Primary	2150 (54.5)	80.8 (78.1 to 83.3)
Secondary	741 (18.8)	75.4 (72.2 to 78.3)
Post secondary	27 (0.7)	70.1 (49.8 to 84.7)
Parity		
≤2	1350 (34.2)	79 (75.6 to 82)
3–5	1696 (43)	80.6 (77.7 to 83.3)
>5	901 (22.8)	81.8 (77.4 to 85.5)
Frequency of ANC visit		
None	140 (5.3)	79.6 (68.4 to 87.5)
1–7	2459 (93)	83.7 (81.7 to 85.5)
≥8	42 (1.6)	75.8 (63.5 to 84.9)
Household-level factors		
Wealth index		
Poor	1918 (49)	84.6 (81.8 to 86.9)

Continued

Table 1 Continued

Variables	N (%) (weighted)	Prevalence of anaemia % (95% CI) (weighted)
Middle	804 (20)	79.8 (75.2 to 83.6)
Rich	1225 (32)	74.1 (70.7 to 77.2)
Source of drinking water		
Unimproved	1564 (40)	83.9 (80.8 to 86.6)
Improved	2350 (60)	78 (75.4 to 80.4)
Sanitation		
Unimproved	2823 (35.5)	80 (76.4 to 83.3)
Improved	2524 (64.5)	80.6 (77.9 to 83)
Type of cooking fuel		
Polluting	3823 (97.7)	80.5 (78.3 to 82.6)
Clean	91 (2.3)	73.9 (65.7 to 80.7)
Sex of household head		
Male	2860 (72.5)	80.13 (77.6 to 82.5)
Female	1086 (27.5)	80.86 (77.7 to 83.7)
Community-level factors		
Place of residence		
Urban	1034 (26.2)	76.7 (73 to 80.1)
Rural	2912 (73.8)	81.6 (78.9 to 84.1)
Infrastructural development score		
Mean (SD)	1.2 (0.3)	
Province		
Niassa	249 (6.3)	79.7 (70.9 to 86.3)
Cabo Delgado	302 (7.7)	86.2 (81.8 to 89.7)
Nampula	906 (23)	84.1 (78.07 to 88.7)
Zambezia	798 (20.2)	84 (77.8 to 88.7)
Tete	378 (9.6)	75.7 (70.9 to 79.9)
Manica	296 (7.5)	72.5 (63.3 to 80)
Sofala	373 (9.5)	82.0 (75 to 87.4)
Inhambane	192 (4.9)	75.8 (68.3 to 82)
Gaza	178 (4.5)	74 (66.8 to 80.2)
Maputo province	169 (4.3)	70.2 (59.6 to 79)
Maputo city	106 (2.7)	72.9 (62.6 to 81.3)

ANC, antenatal care; n, weighted sample size.

Measures of variance and clustering in multilevel Bayesian regression

For the intercept-only model (model 0), [table 2](#) shows low ICCs, implying an existence of weak correlation of childhood anaemia within the clusters of women (0.3%), households (0.2%) and communities (0.1%). In the final model, inclusion of child, maternal, household and community-level factors marginally reduced the variability within the clusters. In the final model, close to half of the variance across the communities were explained by the child-, maternal-level, household-level and community-level factors (PCV=41.9%). Importantly, as determined by PCV, 37.2% of the community-level variance of childhood anaemia were accounted for by factors outside the children—joint effects of maternal-level, household-level and

community-level factors (ie, difference between PCV of child-level variables (model 1) and PCV of child, maternal, household and community-level variables (model 4)).

Spatial variation of childhood anaemia

After accounting for uncertainty and variance instability with spatial empirical Bayesian smoothing map, the smoothed prevalence of childhood anaemia by province ranged from 0.7 (Maputo city) to 0.8 (Cabo Delgado, Zambezia, Niassa and Nampula), with a national smoothed mean (SD) of 0.8 (± 0.1) ([figure 2](#)). Children living in four provinces (Cabo Delgado, Nampula, Zambezia and Sofala) had excess risk of anaemia relative to the national average ([figure 2](#)).

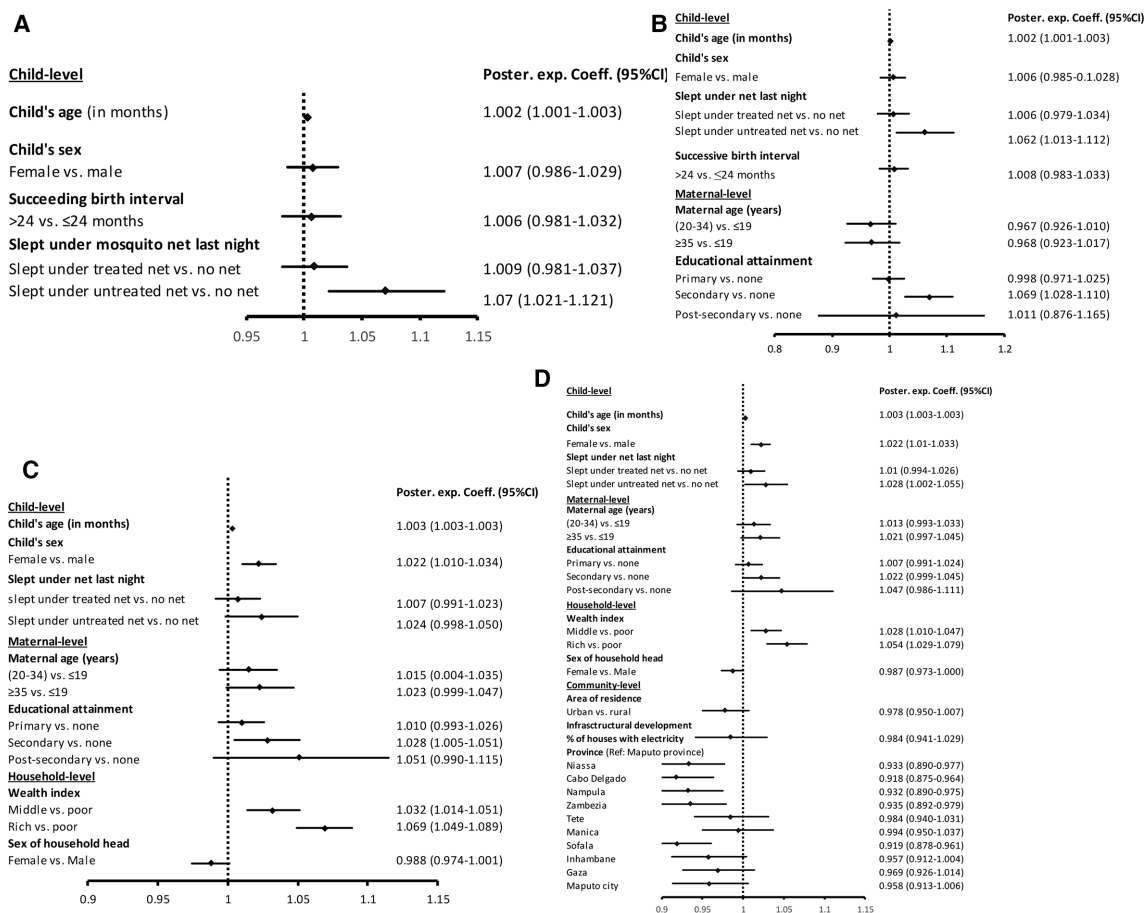


Figure 1 Parameter estimates (fixed-effects) of the association between childhood haemoglobin concentration and child, maternal, household, and community-level factors. (A) Model 1 (child-level factors). (B) Model 2 (child and maternal level factors). (C) Model 3 (child, maternal and household level factors). (D) Model 4 (child-level, maternal-level, household-level and community-level factors), Mozambique Malaria Indicator Survey, 2018.

Poster. exp. Coeff. = Posterior Exponentiated Coefficient.

There was significant clustering of prevalence of childhood anaemia across the communities. Strong spatial clustering of prevalence of childhood anaemia was observed at the provincial level (Moran's $I=0.6$, p value=0.01), while clustering was weaker at the community-level ($I=0.1$, p value=0.001) (online supplemental figure S6). Forty-four communities (20%) clustered to form cold spots of childhood anaemia that is, clustering of communities with relatively lower prevalence of childhood anaemia compared with average of spatial units. All the cold spots were in the southern part of the country—13 communities in Maputo province, 12 in Gaza, 11 in Maputo city, and 8 in Inhambane. Conversely, all the 47 (21.4%) communities that formed the hot spots with relatively higher prevalence of childhood anaemia (compared with the community average) were found in northern Mozambique—16 communities in Cabo Delgado, 15 in Nampula, 10 in Zambezia and 6 in Niassa. Also, there were 18 communities (8.2%) in the low-high clusters (communities with low prevalence of childhood anaemia adjacent to hot spots)—located in Nampula and Zambezia. Twenty-seven communities (12.3%) recorded higher prevalence

and were adjacent to communities with low prevalence (high-low clusters).

Figure 3 shows the crude and adjusted predictive maps of community-level random effects of posterior mean Hb concentration from the multilevel Bayesian regression. Compared to the crude predictive map (model 0), the adjusted map (model 4) shows markedly reductions in areas with low Hb concentration and some residual spatial variation across the communities after controlling for child-level, maternal-level, household-level and community-level factors, but disparities persist along the administrative boundaries. Children from the communities around Gaza-Inhambane boundary, Niassa-Cabo Delgado-Nampula tripoint and Zambezia-Nampula boundary, and in Manica and Inhambane provinces have negative posterior means, indicating that these communities were significantly associated with low Hb concentration. Table 3 shows the specific districts with significant clustering of children with low Hb concentration after adjusting for the independent variables.

Table 2 Random-effect, efficiency and Gelman-Rubin convergence diagnostic summaries

Variables	Model 0 (empty)	Model 1 (child)	Model 2 (child and maternal)	Model 3 (child, maternal and household)	Model 4 (child, maternal, household and community)
Variance (log)					
Community	0.0043	0.0041	0.0036	0.003	0.0025
Household	0.003	0.0059	0.0056	0.0033	0.003
Maternal	0.0026	0.004	0.0042	0.003	0.0034
ICC					
Community (%)	0.13	1.2	0.11	0.09	0.08
Household (%)	0.22	0.3	0.28	0.19	0.17
Maternal (%)	0.3	0.42	0.41	0.28	0.27
PCV					
Community (%)	Ref.	4.65	16.28	30.23	41.86
Household (%)	Ref.	-96.6	-86.6	-10	0
Maternal (%)	Ref.	-53.85	-61.54	-15.39	-30.77
Average efficiency (%)	22.84	10.66	13.03	16.47	13.55
Average acceptance rate (%)	69.76	69.52	69.99	69.29	69.67
Maximum Gelman-Rubin Rc	1.10	1.08	1.02	1.02	1.09
Average DIC	-2100	-782.24	-784.98	-2490	-2490

DIC, Deviance Information Criteria; ICC, intraclass correlation; PCV, proportional change in variance.

DISCUSSION

This study examined the influence of individual-level (child and maternal), household-level and community-level factors on the geographical distribution of anaemia among children aged 6–59 months in Mozambique using the 2018 MIS. A key finding is that childhood anaemia is highly prevalent although showed spatial variation

across the communities and provinces in Mozambique and were related to socioeconomic factors. Within the study population, children with anaemia tended to be younger, males and at risk of having malaria because they were not sleeping under mosquito nets. Furthermore, there is evidence that children from poor families, those living in female-headed households were at greater risk

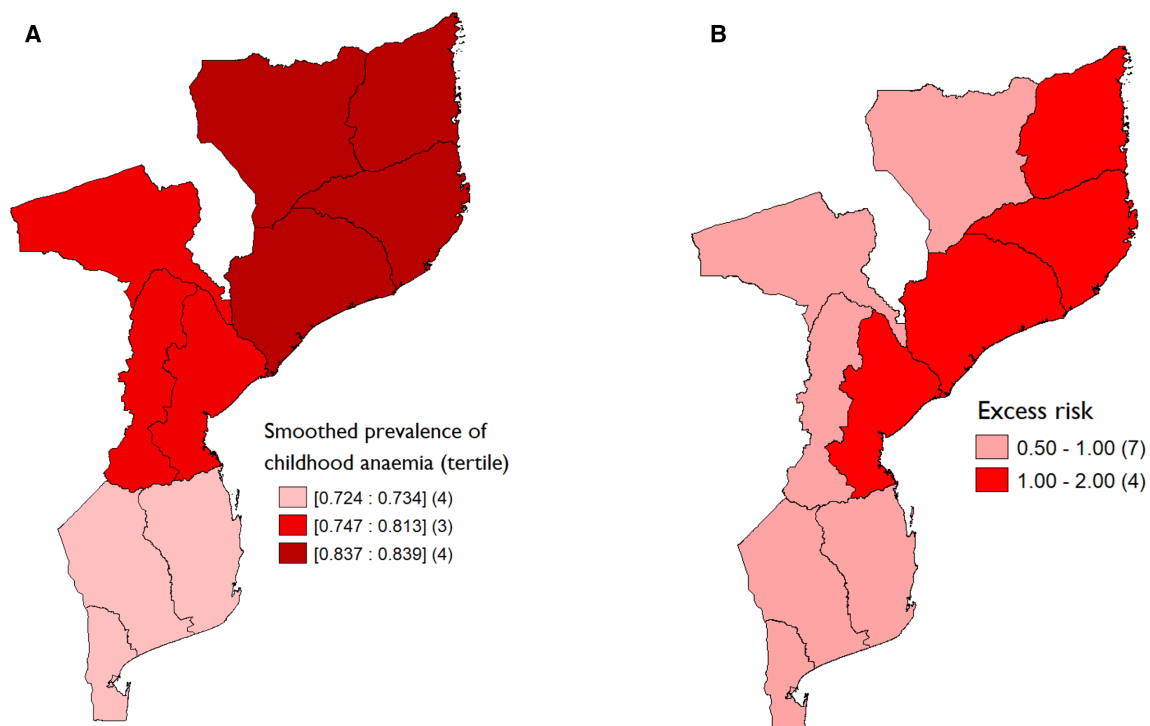


Figure 2 Spatial distribution of childhood anaemia by province in Mozambique. (A) Spatial empirical Bayesian smoothed prevalence. (B) Excess risk, Mozambique Malaria Indicator Survey, 2018.

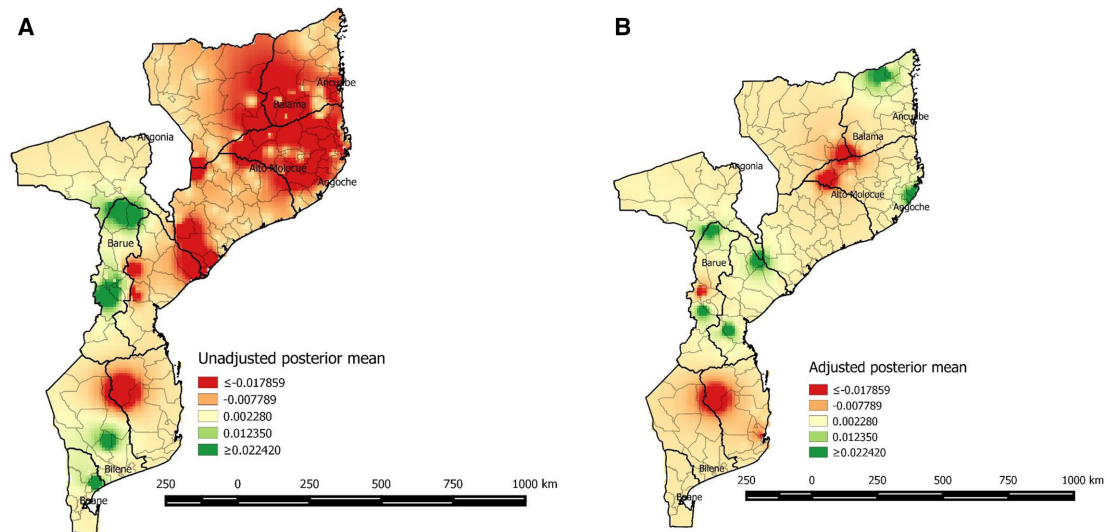


Figure 3 Spatial distribution of posterior means of haemoglobin concentration across communities in Mozambique. (A) Crude map. (B) Adjusted map, Mozambique Malaria Indicator Survey, 2018. Color code: Red denotes high risk, green denotes lower risk.

of developing anaemia, and several provinces (located majorly in northern Mozambique)—Cabo Delgado, Nampula, Niassa, Sofala and Zambezia were prone to anaemia.

Our analysis showed a mean national childhood anaemia prevalence of 77.7% (SD: 5.5%), mostly moderate anaemia at the time of survey (2018). With such a high prevalence of anaemia in children—exceeding 40% across the provinces—childhood anaemia remains a severe public health threat in Mozambique, as indicated by the population benchmark by WHO for classifying prevalence of anaemia as a problem of public health significance.²⁹ Although estimated national prevalence in this report is higher than the 69% previously reported,¹⁶ the observed pattern of variation is consistent with the 2011 Mozambique DHS report—Maputo province with the lowest prevalence and districts within Cabo Delgado, Zambezia and Nampula the highest.¹⁶ It is also important to note that, with the exception of Maputo province, which had prevalence of severe anaemia of 0.3%, other provinces had exceeded the recommended 2% (ranged

from 2.9% in Maputo city to 12.2% in Cabo Delgado). As recommended by the International Nutritional Anaemia Consultative Group,⁴⁰ the policy implication of this finding is that training and supervision of healthcare workers in the primary care centres on early detection and treatment/referral of children with severe anaemia should be intensified.

The seasonality of transmission of malaria parasites has been widely discussed in literature, peaking during the rainy seasons (ie, November–March).^{41–42} Considering that Mozambique has a tropical climate that sustains continuous transmission of malaria parasites throughout the year, the period of sampling (ie, March–June 2018) could not have significantly affected the prevalence of malaria. The seasonality of malaria might not have influenced the high prevalence of anaemia observed. Despite the varying data collection periods for the previous surveys, the prevalence of malaria in Mozambique has also stabilised in the recent years, 38% (May–November 2011), 40% (June–September 2015) and 39% (March–June 2018).²³

After addressing potential confounders, we observed higher risk of childhood anaemia in communities located near administrative borders. Most of the communities were found around the triprovincial border of Niassa-Cabo Delgado-Nampula (ie, Nipepe, Lalaua, Balama, Namuno); district boundaries of Mabote-Funhalouro-Chigubo in Gaza and Inhumbane provinces; Malema, Ribaue, Alto Molocue, Gurue in Zambezia and Nampula provinces; Malema, Ribaue, Alto Molocue, Gurue in Manica province and Morrumbene, Maxixe in Inhumbane province. This variation was mainly due to maternal-level factors (maternal age and educational attainment), household-level factors (sex of household head and household wealth) and community-level factors (place of residence and infrastructural development).

Table 3 Areas with significant clustering of children with low Hb concentration after adjusting for child-level, maternal-level, household-level and community-level factors, Mozambique Malaria Indicator Survey, 2018

Province/administrative boundaries	District
Niassa-Cabo Delgado-Nampula	Nipepe, Lalaua, Balama, Namuno
Gaza-Inhambane	Mabote, Funhalouro, Chigubo
Zambezia-Nampula	Malema, Ribaue, Alto Molocue, Gurue
Manica	Vanduzi
Inhambane	Morrumbene, Maxixe

Child-related factors were observed to have lesser effect on the geographical distribution of childhood anaemia in Mozambique. This study reaffirms the need to prioritise community health, especially maternal and child health, around district, provincial and international boundaries. The strong link between international and provincial borders, and health outcomes have been documented in previous studies for maternal malnutrition,⁴³ onchocerciasis⁴⁴ and cholera outbreak.⁴⁵

Several studies have linked childhood anaemia with limited household resources because household wealth is a major determinant of food (in)security and health-care utilisation.^{46–48} Similar to the 2011 UNICEF report on child poverty and disparities in Mozambique,⁴⁹ we observed that nearly half of the children were living in poor households. Our results suggest that childhood anaemia decreases with increasing household wealth. As expected, childhood anaemia was observed to be higher in provinces with higher percentage of households living in poverty. Furthermore, our analysis found that anaemia risk reduces as child grows older. This finding is comparable to similar studies elsewhere.^{46 47 50} Tsai *et al*⁵¹ and Paoletti *et al*⁵² raised concerns about low iron concentration in human breast milk and in most traditional diets, which might be insufficient to meet the daily micronutrient requirements for rapid growth during the period of weaning (after 6 months). This is partly indicative of the inability of households to introduce iron-rich complementary foods after 6 months, arising from their low socioeconomic status. Other dietary factors such as prolonged breast feeding⁵³ and consumption of non-food items such as earth and ice⁵⁴ have also been linked to iron-deficiency anaemia among infants in sub-Saharan Africa.

Experiences in Ghana have indicated that anaemia accounted for more than half of malaria-related deaths.⁵⁵ A potential intervention to reduce the prevalence of anaemia among children is effective malaria prevention. As a key malaria intervention, we found evidence that untreated mosquito bed net use lowers the risk of anaemia. Unexpectedly, the likelihood of childhood anaemia was similar among the children who slept under treated nets and those who did not. Previous research has shown the misuse of long-lasting insecticidal nets in poor coastal communities of Mozambique.⁵⁶ In these fishing communities, the treated nets are often used for socioeconomic activities, exposing the aquatic lives and humans to the toxic effects of pyrethroid insecticides.⁵⁶ Due to the ecological degradation and health concerns caused by these illegal fishing activities, laws have been imposed by governments to stop the use of treated mosquito nets, however, these laws have not been effective in many communities.⁵⁶ Although the practice of using insecticide-treated mosquito nets for fishing has been widely reported in resource-limited countries, the degree of usage of untreated nets for fishing is poorly documented.⁵⁷

One of the strengths of our study is the investigation of determinants conceptualised and applied at four

levels: community, household, maternal and child. To the best of our knowledge, no published literature has taken into consideration the contextual effects at the community, household and maternal levels. Also, we used Bayesian methods to simulate the subnationally representative dataset from the latest MIS for Mozambique. With Bayesian methods, uncertainty around point estimates are minimised, hence generating more accurate models. Using multilevel regression and spatial analysis, our study provides new findings about the geographical distribution (ie, vulnerable groups at the borders) and social determinants of anaemia among children aged 6–59 months in Mozambique. As this study provides analysis in a more granular level (community and district), it provides baseline analysis that can guide general and targeted implementation of the 2025 Mozambique National Development Plan for optimal use of resources. Also, the findings from this study could guide the Maternal, Newborn and Child Health Initiatives and improve the health of the most vulnerable populations within the provinces. A limitation of this study is that the cross-sectional nature limits causal inferences. Also, we could not directly estimate the effects of inflammatory syndrome, recent malaria illness, food insecurity, HIV and intestinal worm infestation because they were not available in the dataset. To overcome the challenge of missing variables, we used mosquito bed net usage (as a proxy for malaria illness), household sanitation (as a proxy for worm infestation) and household wealth index (as a proxy for food insecurity).

The unadjusted prevalence of anaemia is higher when the preceding birth interval exceeds 24 months, but lower when the succeeding birth interval is less than 24 months (89% vs 83.5%). This is counter-intuitive even in an unadjusted finding; therefore, cautious interpretation is required because of possible confounding effects of other variables such as duration of breast feeding and birth weight. Unfortunately, there is no information on the two variables in the datafile. For this unadjusted association observed, we reckon that the higher prevalence of anaemia in younger children delivered after 24 months of delivery of older siblings could be due to 'sibling effects'—inability of the younger siblings to compete with older children in terms of the limited household resources.⁵⁸

It should be noted that preceding birth intervals could not be added to the child-level model because of convergence issues. In addition, there was no significant association in the multivariate (child and maternal levels) models that included succeeding birth interval.

This study provides evidence that anaemia among children aged 6–59 months is a severe public health threat across the provinces in Mozambique. It also identifies inequity in childhood anaemia—worse among communities living close to the provincial borders. We recommend interventions that would generate income for households, increase community support for households headed by women, improve malaria control, build capacity of health-care workers to manage severely anaemic children and health education for mothers. More importantly, there

is need to foster collaborations between communities, districts and provinces to strengthen maternal and child health programmes for the severely affected areas.

POSTSCRIPT

Given this paper is authored by four health professionals representing two continents, three countries and a wide range of experiences, we wish to declare the standpoint from which we write ('pose') and the audience that we intend to reach ('gaze'). The standpoint taken is primarily African, Asian, and trained in African, European, and North American education and clinical training systems. We bring both a local (Mozambican, African) and foreign perspective. The foreign perspective (NM) however is tempered by many years of working with local colleagues. Our gaze is 'local' in that we are writing for the audience of policy-makers, healthcare professionals, government leaders in Mozambique. For a fuller explanation of 'pose' and 'gaze' intersected by local and foreign actors producing research reports such as the present, see: Abimbola S. The foreign gaze: authorship in academic global health. *BMJ Global Health* 2019;4:e002068. doi:10.1136/bmjgh-2019-002068.

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Patient consent for publication Not applicable.

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Provenance and peer review Not commissioned; externally peer reviewed.

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