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ABSTRACT

Objective Anaemia affects the majority of children in sub-Saharan Africa (SSA). Previous studies of risk factors for anaemia have been limited by sample size, geography and the association of many risk factors with poverty. In order to measure the relative impact of individual, maternal and household risk factors for anaemia in young children, we analysed data from all SSA countries that performed haemoglobin (Hb) testing in the Demographic and Health Surveys.

Design and setting This cross-sectional study pooled household-level data from the most recent Demographic and Health Surveys conducted in 27 SSA between 2008 and 2014.

Participants 96 804 children age 6–59 months.

Results The prevalence of childhood anaemia (defined as Hb <11 g/dL) across the region was 59.9%, ranging from 23.7% in Rwanda to 87.9% in Burkina Faso. In multivariable regression models, older age, female sex, greater wealth, fewer household members, greater height-for-age, older maternal age, higher maternal body mass index, current maternal pregnancy and higher maternal Hb, and absence of recent fever were associated with higher Hb in tested children. Demographic, socioeconomic factors, family structure, water/sanitation, growth, maternal health and recent illnesses were significantly associated with the presence of childhood anaemia. These risk factor groups explain a significant fraction of anaemia (ranging from 1.0% to 16.7%) at the population level.

Conclusions The findings from our analysis of risk factors for anaemia in SSA underscore the importance of family and socioeconomic context in childhood anaemia. These data highlight the need for integrated programmes that address the multifactorial nature of childhood anaemia.

Strengths and limitations of this study

- This analysis of survey data across an entire region provides a unique perspective on the epidemiology of anaemia in a high-risk population.
- The size of this dataset provided sufficient power to estimate the effect size of individual risk factors in a multivariable model, adjusting for many known confounders.
- The data based on self-reporting are limited by recall and misclassification biases, and only children living at the time of the survey were included.
- The cross-sectional nature of these survey data limits our ability to assess temporal or causal relationships.

INTRODUCTION

Anaemia affects 43% of children under age 5 worldwide, with an even higher prevalence in sub-Saharan African (SSA) countries.[1] Despite implementation of control programmes including iron supplementation, deworming and insecticide-treated bednet distribution, anaemia remains a major global concern in child health, especially in SSA.[2] While it may be difficult to separate the effects of anaemia (low haemoglobin (Hb)) from those of its underlying biological mechanisms (eg, nutritional deficiencies, chronic infections, haemoglobinopathies), anaemia has been independently associated with overall increased mortality in young children,[3] with lower cognitive performance,[4 5] and in severe cases, lower aerobic exercise capacity and heart failure.[6 7] The higher oxygen demands of the paediatric brain make it particularly susceptible to the effects of severe anaemia.[8 9]

Several regional or national studies have examined the role of demographic, social, environmental and geographic determinants of anaemia. These studies have identified younger age,[10–14] male sex,[10 11 13] maternal age and education,[10 15] maternal anaemia,[16–18] malnutrition (especially stunting),[10 13 19–21] insufficient meals per day,[22] parasitic infection[21] and recent diarrhoea,[12 23] fever[23] and absence of deworming[14 24] as significant risk factors for childhood anaemia. An analysis of the National Family and Health Survey (the

local implementation of the Demographic and Health Surveys (DHS)) in India found that high-polluting cooking fuel, family structure, building type and toilet facilities were associated with anaemia,[14] but a study in Cape Verde evaluating the impact of 'household conditions' (water/sanitation, cooking facilities, appliances, building materials) did not find a significant association with anaemia, though the power to detect an association may have been limited by the study's sample size.[12] A 2009 country-level analysis of DHS data level found that per capita Gross National Income predicts rates of severe anaemia.[25]

Because of the complex interconnectedness of many of these risk factors, especially in relation to poverty, it is important to evaluate potential risk factors for anaemia in a multivariable model. Each of the aforementioned studies has evaluated a subset of risk factors separately, but to our knowledge, there has been no continent-wide analysis that integrates the wide array of household and individual risk factors for anaemia among children in SSA. Building on these prior studies, we analysed data from all SSA countries that performed Hb testing during the most recent administration of the DHS. The objective of this study is to offer a population-level analysis of anaemia in young children in SSA by measuring the relative impact of individual, maternal and household risk factors for anaemia across the region.

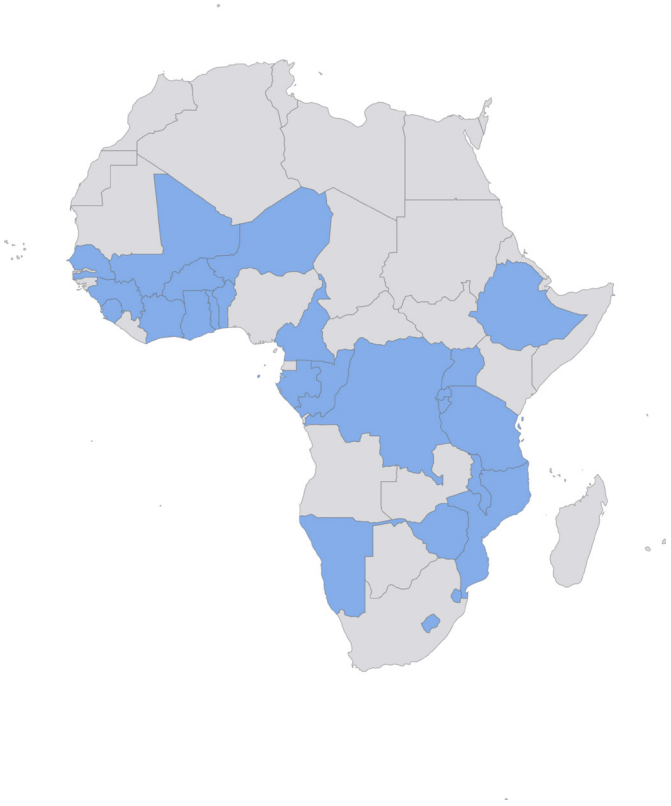

Figure 1 Map of 27 sub-Saharan African countries included in analysis.

SUBJECTS AND METHODS

Population and data source

The DHS provides a unique perspective on child health in low-and-middle-income countries. These are nationally representative, probability-weighted, community-based household surveys, funded by the U.S. Agency for International Development with support from donors and host countries. The DHS programme enables countries to measure a wide variety of demographic and health indicators, including fertility, child mortality, nutrition, growth and access to healthcare. Since 1984, household surveys have been supported by DHS in >90 countries.[26 27] Participating households are selected using a stratified two-stage cluster design. First, enumeration areas are selected using stratified random sampling from national census regions (strata); within these areas, households are randomly selected for survey administration. The household questionnaire is administered to women and men of reproductive age (typically age 15–49 years); the women's questionnaire includes questions about child health.

We included data from children age 6–59 months in the 27 SSA countries participating in the DHS that performed anaemia testing (see figures 1 and 2). We analysed the Children's Recode using data from the most recent surveys available (2008–2014). In most cases, we used data from DHS-VI; for Ghana we used data from DHS-VII; for Sao Tome and Principe and Swaziland we used data from DHS-V. Madagascar was excluded from the analysis because of missing data on children's weight. Responses were recoded to harmonise questionnaires that varied between countries and survey phases.

Survey procedures and anaemia testing

A questionnaire was administered to an eligible adult respondent, and anthropometry and Hb testing were conducted on children age 6–59 months and their mothers during the study visit. In all countries but Tanzania and Zimbabwe, where universal testing was performed, only a subset of households were selected for anaemia testing. Capillary Hb testing was performed with the HemoCue

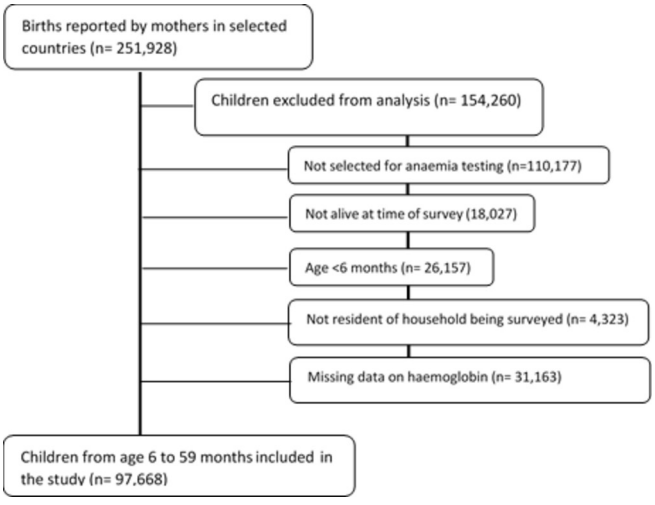

Figure 2 Selection of study population. Note that some children were excluded for multiple reasons.

Photometer, which is commonly used in screening for anaemia in low-resource settings.[28] Children found to have severe anaemia were referred to local health facilities for treatment.[29] Anaemia severity was classified according to the WHO's 'Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity' as mild, moderate or severe based on blood Hb,[30] and the relevant thresholds for anaemia severity were used for children, pregnant and non-pregnant women.

Analytic approach

We performed bivariate analyses and multivariable logistic and linear regression using survey procedures in Stata V.14. The *svy* procedures are a set of commands that account for sampling weights, clustering and stratification in complex survey data. For the purposes of this analysis, the levels of clustering that were considered in the variance estimates include country-based primary sampling unit, the household and the mother. The original individual sample weight from each dataset was used for each respondent. We selected variables from the DHS questionnaire based on potential association with risk of anaemia. We grouped risk factors as follows: *demographic* (child's age, sex), *environmental* (urban vs rural location, altitude, floor type in home, biomass fuel used for cooking), *socioeconomic* (wealth index (a standardised variable constructed by the DHS using permanent income indicators),[31] maternal years of education, maternal literacy), *family structure* (number of household members, number of children, birth order, multiple births), *water/sanitation* (use of shared toilet facilities, unimproved toilets, unimproved water source, water source located off premises, unsafe stool disposal), *nutrition and growth* (height-for-age Z score (HAZ), weight-for-age Z score (WAZ), weight-for-height Z score (WHZ), ever breast fed, meat consumption in the last 24 hours, consumption of high-iron foods in the last 24 hours), *maternal health* (maternal age, height, weight, body mass index (BMI), Hb, current pregnancy, iron supplementation and deworming during pregnancy), *recent illnesses* (diarrhoea or fever in the past two weeks) and *prophylactic measures* (iron supplementation in the last week, deworming in the last six months, bednet usage last night).

Variable definitions

Following WHO guidelines,[32] unimproved toilet facilities were defined as pit latrines without slabs or platforms, open pit, hanging latrines, bucket latrines or open defecation. Improved toilet facilities were defined as a flush toilet, ventilated improved pit latrine, pit latrine with a slab, composting toilet or Ecosan. Unsafe stool disposal was defined as a child's stool put or rinsed into drain or ditch, thrown into garbage, rinsed away or left in the open/not disposed of. Safe stool disposal was defined as a child's use of toilet or latrine, faecal matter put or rinsed into a toilet or latrine, faecal matter buried, use of disposable diapers or use of washable diapers. An improved water source was defined as the main source of drinking water of piped connection to water supply, private and public tap, borehole, protected/dug well, protected spring, rainwater or bottled water. All other sources were considered unimproved. Unimproved floor was defined as natural, earth, sand, dung or rudimentary floor in the home. Cooking fuels were classified as biomass/high-polluting (kerosene, coal, lignite, charcoal, wood, straw, shrub, grass, agricultural crop, animal dung, gasoline or other) or non-biomass/low-polluting (electricity, liquefied petroleum gas, natural gas or biogas). Having a high-iron diet was defined as reporting one or more iron-rich foods in the past 24 hours, which includes infant formula, grains, meat or meat organs, leafy greens or other foods such as beans, peas, lentils and nuts. For maternal iron supplementation and maternal deworming during pregnancy, in children >12 months these variables were coded as 'not applicable'. While the DHS reports altitude-adjusted Hb values in its publicly available data, in order to allow estimation of the effect of altitude on Hb and because altitude was missing for 26.4% of the sample, our analyses used unadjusted Hb rather than altitude-adjusted Hb values.

A pairwise correlation was performed to determine the relationship between highly correlated variables. For this test, anything >0.6 was considered to be highly correlated. When choosing among highly correlated variables (eg, HAZ/WAZ/WHZ, maternal height/weight/BMI, number of household members/number of children, maternal iron supplementation/deworming during pregnancy), we selected the single variable that when added to the multivariable model improved the predictive value of the model most (greatest contribution to overall R^2). For the bivariate analysis, we determined significance using ordered logistic regression to reflect natural ordering in multilevel categorical variables. All multivariable models included country as a fixed effect.

Missing data

Because several predictor variables were missing in a substantial number of respondents (online Supplementary table A1), we constructed three multivariable linear regression models: (1) model 1, which included only variables present in >90% of respondents; (2) model 2, which included variables present in >80% of respondents; and (3) model 3, which included all potentially relevant variables. For the anthropometric variables, which were missing in 4.7% of respondents, we performed a sensitivity analysis in which we assigned extreme values to all missing cases (HAZ =+2 or HAZ = −2).

Population-attributable fraction

With the risk factors used in model 1, we constructed a multivariable logistic regression model to measure the association between the risk factors of interest and anaemia (as a dichotomous variable). To facilitate ease of interpretation, we converted continuous variables to categorical and standardised the reference group to ensure ORs were >1. We used the OR estimates to calculate

population-attributable fraction (PAF), the proportion of anaemia in children age 6–59 months that can be attributed to the risk factor in question. This was calculated using the *punaf* command in Stata,[33] which measures the proportion of respondents who would no longer be anaemic if the risk factor in question were removed (or at its lowest risk category) and all other risk factors held constant. Respondents provided informed consent prior to participation and provided separate consent for blood testing.

RESULTS

Data on a total of 251 928 children across 27 countries were reviewed, of which 97 668 had valid data for analysis (residents of households selected for anaemia testing, alive at the time of the survey and age≥6 months; see figure 2). The mean age of children in the survey was 31.5 months (SD 15.5), with 49.6% of the children female. The mean Hb among tested children was 10.4 g/dL (SD 1.8); 23.6% of children were found to have mild anaemia (Hb 10.0–10.9 g/dL), 34.4% of children had moderate anaemia (Hb 7.0–9.9 g/dL) and 3.39% of children had severe anaemia (Hb <7 g/dL). The prevalence of anaemia (of any severity) ranged from 23.7% in Rwanda to 87.9% in Burkina Faso (see table 1).

Bivariate analyses

Bivariate analyses demonstrated a significant association between many potential predictor variables and level of anaemia (see tables 2 and 3). For tables 2 and 3, linear regression was used to show the association between each predictor on each level of the outcome (no anaemia, mild, moderate, severe anaemia). On average, children with

Table 1 Prevalence of anaemia in children age 6–59 months in countries included in analysis

Country	Survey year	Children (n)*	Proportion of children with anaemia (%)	95% CI
Benin	2011–2012	3249	58.8	(56.9 to 60.7)
Burkina Faso	2010	5998	87.9	(86.9 to 88.8)
Burundi	2010	3164	34.0	(32.1 to 35.9)
Cameroon	2011	4442	59.2	(57.5 to 60.9)
Congo Brazzaville	2011–2012	3215	66.7	(64.3 to 69.1)
Congo Democratic Republic	2013–2014	7085	57.5	(55.8 to 59.2)
Cote d'Ivoire	2011–2012	2665	75.8	(73.6 to 77.8)
Ethiopia	2011	8812	27.7	(26.3 to 29.1)
Gabon	2012	2478	60.9	(58.0 to 63.8)
Gambia	2013	2713	73.5	(71.2 to 75.7)
Ghana	2014	2253	66.8	(64.2 to 69.3)
Guinea	2012	2772	77.3	(75.5 to 79.1)
Lesotho	2009–2010	1242	28.3	((25.5 to 31.2)
Malawi	2010	4173	60.7	(58.8 to 62.7)
Mali	2012–2013	4207	81.9	(80.5 to 83.2)
Mozambique	2011	4596	68.7	(67.0 to 70.4)
Namibia	2013	1382	44.1	(41.2 to 47.0)
Niger	2012	4541	73.7	(72.1 to 75.3)
Rwanda	2010	3745	23.7	(22.3 to 25.2)
Sao Tome and Principe	2008–2009	1405	63.7	(60.6 to 66.6)
Senegal	2010–2011	3101	76.8	(74.9 to 78.7)
Sierra Leone	2013	4161	79.9	(78.4 to 81.4)
Swaziland	2006–2007	1768	40.9	(38.4 to 43.4)
Tanzania	2009–2010	5912	53.6	(52.0 to 55.1)
Togo	2013–2014	2716	70.9	(69.0 to 72.7)
Uganda	2011	1786	43.2	(40.4 to 46.2)
Zimbabwe	2010–2011	3223	52.9	(51.0 to 54.8)
Total		96 804	59.9	(59.5 to 60.3)

*Counts are weighted to reflect multistage survey sampling weights.

Table 2 Bivariate associations between continuous predictors and level of anaemia

	No anaemia (Hb≥11 g/dL)		Mild anaemia (Hb 10.0–10.9 g/dL)		Moderate anaemia (Hb 7.0–9.9)		Severe anaemia (Hb<7.0)		
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	P values
Age (months)	35.27	(35.10 to 35.44)	30.67	(30.43 to 30.91)	27.97	(27.79 to 28.15)	25.74	(25.20 to 26.28)	<0.0001
Altitude (m)	1141	(1131 to 1151)	736	(724 to 748)	597	(586 to 606)	560	(527 to 592)	<0.0001
Maternal education (years)	4.12	(4.06 to 4.17)	3.84	(3.77 to 3.91)	2.96	(2.91 to 3.01)	1.87	(1.74 to 2.01)	<0.0001
Number of household members	6.78	(6.73 to 6.82)	7.28	(7.21 to 7.35)	7.70	(7.63 to 7.76)	7.96	(7.77 to 8.15)	<0.0001
Number of children living in household	2.04	(2.03 to 2.06)	2.21	(2.19 to 2.23)	2.34	(2.32 to 2.36)	2.43	(2.37 to 2.49)	<0.0001
Birth order	1.43	(1.42 to 1.44)	1.37	(1.36 to 1.38)	1.31	(1.31 to 1.32)	1.25	(1.23 to 1.27)	<0.0001
Maternal age (years)	29.87	(29.77 to 29.96)	29.25	(29.14 to 29.36)	28.92	(28.82 to 29.02)	28.57	(28.28 to 28.87)	<0.0001
Mother's weight (kg)	57.22	(57.05 to 57.39)	57.48	(57.27 to 57.69)	56.39	(56.22 to 56.56)	54.38	(53.98 to 54.77)	<0.0001
Mother's height (m)	1.58	(1.580 to 1.582)	1.59	(1.587 to 1.590)	1.59	(1.589 to 1.591)	1.59	(1.587 to 1.592)	<0.0001
Mother's BMI	22.83	(22.77 to 22.89)	22.74	(22.67 to 22.82)	22.27	(22.21 to 22.33)	21.49	(21.35 to 21.63)	<0.0001
Mother's haemoglobin (g/dL)	12.91	(12.88 to 12.93)	12.14	(12.11 to 12.17)	11.79	(11.77 to 11.82)	11.38	(11.30 to 11.46)	<0.0001
Time travelled to get water (min)	29.92	(29.22 to 30.62)	26.25	(25.56 to 26.95)	25.62	(25.00 to 26.24)	26.01	(24.38 to 27.65)	<0.0001
Height-for-age Z score	−1.55	(−1.57 to −1.53)	−1.50	(−1.52 to −1.47)	−1.62	(−1.65 to −1.60)	−2.04	(−2.10 to −1.97)	<0.0001
Weight-for-age Z score	−0.94	(−0.96 to −0.93)	−0.96	(−0.99 to −0.95)	−1.13	(−1.15 to −1.19)	−1.60	(−1.66 to −1.55)	<0.0001
Weight-for-height Z score	−0.09	(−0.11 to −0.07)	−0.17	(−0.20 to −0.15)	−0.32	(−0.33 to −0.30)	−0.66	(−0.72 to −0.60)	<0.0001

P value determined using survey-weighted ordered logistic regression with potential predictor as independent variable and anaemia category as dependent variable. The null hypothesis states that the slope of the relationship between a continuous predictor and the level of anaemia is equal to zero (no significant relationship), and the alternative hypothesis states that the slope is not equal to zero (significant positive or negative relationship).
BMI, body mass index; Hb, haemoglobin.

Table 3 Bivariate associations between categorical predictors and level of anaemia

	No anaemia (Hb≥11 g/dL)		Mild anaemia (Hb 10.0–10.9 g/dL)		Moderate anaemia (Hb 7.0–9.9)		Severe anaemia (Hb<7.0)		
	Proportion	95% CI	Proportion	95% CI	Proportion	95% CI	Proportion	95% CI	P values
Male sex	0.491	(0.484 to 0.497)	0.502	(0.494 to 0.510)	0.518	(0.512 to 0.525)	0.537	(0.517 to 0.557)	<0.00011
Urban	0.273	(0.268 to 0.279)	0.309	(0.301 to 0.317)	0.251	(0.244 to 0.257)	0.155	(0.140 to 0.171)	<0.0001
Wealth index									<0.0001
Poorest	0.198	(0.193 to 0.203)	0.217	(0.210 to 0.223)	0.251	(0.245 to 0.257)	0.303	(0.285 to 0.322)	
Poorer	0.210	(0.204 to 0.216)	0.220	(0.213 to 0.227)	0.232	(0.226 to 0.238)	0.259	(0.241 to 0.277)	
Middle	0.202	(0.196 to 0.207)	0.204	(0.197 to 0.211)	0.211	(0.205 to 0.217)	0.218	(0.201 to 0.235)	
Richer	0.204	(0.198 to 0.210)	0.199	(0.192 to 0.206)	0.182	(0.177 to 0.188)	0.154	(0.140 to 0.169)	
Richest	0.186	(0.181 to 0.192)	0.160	(0.154 to 0.167)	0.123	(0.119 to 0.128)	0.065	(0.055 to 0.075)	
Maternal literacy (illiterate)	0.483	(0.476 to 0.490)	0.545	(0.537 to 0.553)	0.658	(0.651 to 0.665)	0.793	(0.776 to 0.811)	<0.0001
Product of multiple birth	0.0275	(0.0249 to 0.0300)	0.0292	(0.0259 to 0.0324)	0.0345	(0.0317 to 0.0374)	0.0407	(0.0323 to 0.0491)	<0.0001
Mother pregnant	0.122	(0.117 to 0.126)	0.114	(0.108 to 0.119)	0.113	(0.108 to 0.117)	0.121	(0.107 to 0.135)	0.01
Unimproved water source	0.351	(0.344 to 0.357)	0.351	(0.343 to 0.359)	0.358	(0.352 to 0.365)	0.413	(0.393 to 0.433)	0.001
Water off premises	0.819	(0.813 to 0.824)	0.804	(0.797 to 0.811)	0.821	(0.815 to 0.827)	0.861	(0.847 to 0.875)	0.046
Shared toilet	0.362	(0.355 to 0.370)	0.432	(0.422 to 0.442)	0.453	(0.444 to 0.462)	0.435	(0.408 to 0.462)	<0.0001
Unimproved toilet	0.615	(0.609 to 0.622)	0.627	(0.619 to 0.635)	0.670	(0.663 to 0.676)	0.761	(0.743 to 0.778)	<0.0001
Unsafe stool disposal	0.358	(0.351 to 0.364)	0.400	(0.391 to 0.408)	0.464	(0.456 to 0.471)	0.553	(0.532 to 0.573)	<0.0001
Unimproved floor	0.614	(0.608 to 0.621)	0.552	(0.544 to 0.561)	0.584	(0.577 to 0.591)	0.681	(0.662 to 0.700)	0.0001
High-polluting cooking fuel	0.920 0	(0.917 to 0.924)	0.917	(0.912 to 0.922)	0.942	(0.938 to 0.946)	0.974	(0.967 to 0.982)	<0.0001
Diarrhoea in the last two weeks									<0.0001
No diarrhoea	0.864	(0.860 to 0.868)	0.839	(0.833 to 0.845)	0.810	(0.805 to 0.815)	0.787	(0.770 to 0.803)	
Non-bloody diarrhoea	0.112	(0.108 to 0.116)	0.134	(0.128 to 0.140)	0.157	(0.152 to 0.162)	0.176	(0.161 to 0.192)	
Bloody diarrhoea	0.024	(0.022 to 0.025)	0.027	(0.025 to 0.030)	0.033	(0.030 to 0.035)	0.037	(0.030 to 0.045)	
Fever	0.191	(0.186 to 0.196)	0.227	(0.220 to 0.234)	0.268	(0.262 to 0.274)	0.373	(0.353 to 0.392)	<0.0001
Used mosquito net	0.542	(0.535 to 0.549)	0.536	(0.527 to 0.544)	0.542	(0.535 to 0.550)	0.559	(0.538 to 0.579)	0.56
Ate meat in the last 24 hours	0.129	(0.123 to 0.136)	0.134	(0.127 to 0.141)	0.128	(0.122 to 0.134)	0.099	(0.085 to 0.114)	0.16
High-iron diet	0.720 0	(0.712 to 0.729)	0.732	(0.722 to 0.741)	0.715	(0.707 to 0.723) 0.682	0.682	(0.659 to 0.705)	0.07
Ever breast fed									0.11
Never breast fed	0.026	(0.024 to 0.028)	0.024	(0.022 to 0.027)	0.024	(0.022 to 0.027)	0.018	(0.013 to 0.023)	

Continued

Table 3 Continued

	No anaemia (Hb≥11 g/dL)		Mild anaemia (Hb 10.0–10.9 g/dL)		Moderate anaemia (Hb 7.0–9.9)		Severe anaemia (Hb<7.0)		
	Proportion	95% CI	Proportion	95% CI	Proportion	95% CI	Proportion	95% CI	P values
Currently or ever breast fed	0.974	(0.972 to 0.976)	0.976	(0.973 to 0.978)	0.976	(0.973 to 0.978)	0.982	(0.977 to 0.987)	
Iron supplementation	0.137	(0.132 to 0.142)	0.153	(0.146 to 0.160)	0.151	(0.146 to 0.156)	0.157	(0.141 to 0.172)	0.0001
Maternal iron supplementation during pregnancy									<0.0001
No, don't know or NA (age>12 months)	0.940	(0.937 to 0.942)	0.881	(0.876 to 0.886)	0.854	(0.849 to 0.859)	0.860	(0.846 to 0.874)	
Yes	0.061	(0.058 to 0.063)	0.119	(0.114 to 0.124)	0.146	(0.141 to 0.151)	0.1400	(0.126 to 0.154)	
Maternal deworming treatment during pregnancy									<0.0001
No, don't know, or NA (age>12 months)	0.970	(0.968 to 0.972)	0.941	(0.937 to 0.945)	0.931	(0.927 to 0.934)	0.945	(0.936 to 0.955)	
Yes	0.030	(0.028 to 0.032)	0.059	(0.055 to 0.063)	0.069	(0.066 to 0.073)	0.055	(0.045 to 0.064)	
Deworming treatment	0.489	(0.482 to 0.496)	0.453	(0.444 to 0.461)	0.399	(0.392 to 0.405)	0.343	(0.323 to 0.362)	<0.0001

P value determined using survey-weighted ordered logistic regression with potential predictor as independent variable and anaemia category as dependent variable. The null hypothesis states that the slope of the relationship between a continuous predictor and the level of anaemia is equal to zero (no significant relationship), and the alternative hypothesis states that the slope is not equal to zero (significant positive or negative relationship).
Hb, haemoglobin; Na, not available.

anaemia were younger, more likely to be male, living at lower altitude, using high-polluting cooking fuel, living in a low-income household, be living in a larger household, be the product of a multiple birth, have unimproved toilet facilities and have lower anthropometric indices (HAZ/WAZ/WHZ). Children with anaemia were more likely to have a mother with the following characteristics: younger in age, less educated, lower BMI and lower Hb, taking iron supplementation and having undergone deworming during pregnancy. Children with anaemia were more likely to have recent diarrhoea or fever, be taking iron supplementation and not have undergone deworming treatment. There was no significant association between bednet usage, eating meat in the past 24 hours, having a high-iron diet and anaemia.

Multivariable analyses and PAF

Across all three multivariable linear regression models, eight variables were significantly positively associated with child Hb levels, including age of child (months), sex (female children on average had higher levels of Hb), wealth, HAZ, mother's age, mother's BMI, current maternal pregnancy and mother's Hb. Additionally, two variables negatively predicted Hb levels, namely number of household members (more members in the household was associated with decreased Hb) and presence of fever in the past two weeks. These results are shown in table 4. Several variables (maternal literacy, birth order, unimproved toilet, water source located off premises, maternal deworming treatment, non-bloody and bloody diarrhoea in the past two weeks) were only significant in the models with a larger sample size (model 1 or 2). Of the variables that were only present in a subset of the countries (model 2 or 3), altitude (positively associated with Hb) and unsafe stool disposal (negatively associated with Hb) were significant. Sensitivity analysis assigning either high or low values to HAZ did not result in a significant difference in the parameter estimates of the predictor variables (see online supplementary table A2.

In linear multivariable models 1 and 2, we found a significant association between maternal deworming during pregnancy and higher child Hb. Otherwise, findings from the logistic regression model were similar to the linear regression models, demonstrating significant associations between several risk factor groups and anaemia (see table 5). Maternal factors were associated with the greatest PAF (16.8% (95% CI 11.9% to 21.3%)), followed by socioeconomic factors (PAF 13.0% (95% CI 10.9% to 15.6%)).

DISCUSSION

In a large survey of 96 804 children age 6–59 months across 27 SSA countries, we found a 59.9% prevalence of anaemia. Further, we found that many individual and household factors were associated with a child's risk for anaemia, especially maternal and socioeconomic factors. At a population level, these groups of variables are responsible for 67.8% of the burden of childhood anaemia.

When treating an individual child with anaemia, a paediatrician works to identify treatable causes, including micronutrient deficiencies and treatable infections (eg, malaria, intestinal parasites). Similarly, at a population level, reducing the prevalence of anaemia requires identifying and targeting the underlying upstream risk factors.[34] In our analysis of DHS data, we found that demographic factors, environmental factors, socioeconomic factors, family structure, water/sanitation, nutrition and growth, maternal factors, recent illnesses and prophylactic measures all contributed to anaemia among young children in SSA. Notably, the individual effect size of several common public health interventions in our survey—bednet usage, iron supplementation and deworming—is substantially smaller than the effect size associated with maternal and socioeconomic factors.

Our data indicate that child-level interventions may have some benefit in reducing the risk of anaemia, but not as much as measures focused on improving the health of the mother and the community. For example, we noted that across all models maternal pregnancy was associated with higher Hb levels in the child; this may reflect greater exposure to healthcare for the mother and indirectly better healthcare for the child or the effect of unmeasured confounding variables. In the linear multivariable models, we found that maternal BMI, maternal deworming and higher maternal Hb were associated with a higher child Hb. Similarly, reducing household crowding and improving sanitation (even more than clean water) were associated with higher child Hb levels.

Our findings are consistent with an analysis of 31 815 mother–child pairs in the 25 SSA countries in the DHS by Wilunda *et al*, which found that children age 6–23 months whose mothers who took iron for at least 6 months prenatally or those who took both iron and deworming drugs prenatally had a lower risk of moderate/severe anaemia compared with those whose mothers did not take iron and deworming drugs.[35] A 2015 systematic review for the US Preventive Services Task Force of iron supplementation in developed countries did not find any benefit to prenatal iron supplementation in infant haematological indices at 6 months,[36] though it is unclear how these findings apply to a low-income, middle-income country setting with high baseline prevalence of anaemia.

Translating the findings of this analysis into practice is feasible. Programmes targeting individual risk factors have been demonstrated to be successful, including iron supplementation,[37–39] deworming[40] and malaria control (including insecticide-treated bednets, antimalarial chemoprophylaxis and insecticide residual spraying).[41] Implementation of an integrated programme that combines these individual interventions, however, has even greater potential. Siekmans *et al* reported on the effects of an integrated approach to reducing child vulnerability to anaemia in Ghana, Malawi and Tanzania.[20] They found that a multifaceted intervention including

Table 4 Multivariable linear regression models of predictors of haemoglobin

	Model 1 n=87 272			Model 2 n=60 416			Model 3 n=20 234		
	β	95% CI	P values	β	95% CI	P values	β	95% CI	P values
Intercept (β_0)	8.14***	(7.9 to 8.44)	<0.001	8.33***	(8.02 to 8.52)	<0.001	7.6***	(7.21 to 8.08)	<0.001
Age (months)	0.027***	(0.026 to 0.028)	<0.001	0.025***	(0.023 to 0.026)	<0.001	0.021***	(0.018 to 0.025)	<0.001
Male versus female sex	−0.077***	(−0.102 to −0.053)	<0.001	−0.092***	(−0.121 to −0.064)	<0.001	−0.109***	(−0.158 to −0.088)	<0.001
Rural versus urban location	−0.001	(−0.040 to 0.039)	0.966	−0.003	(−0.048 to 0.042)	0.90	0.013	(−0.063 to 0.088)	0.741
Altitude (m)							0.001***	(0.001 to 0.001)	<0.001
Unimproved floor	0.032	(−0.005 to 0.070)	0.088	0.017	(−0.027 to 0.060)	0.45	−0.022	(−0.103 to 0.058)	0.582
High-polluting cooking fuel	0.016	(−0.046 to 0.079)	0.606	−0.052	(−0.137 to 0.034)	0.236	−0.071	(−0.191 to 0.050)	0.250
Wealth index									
Poorest	Ref			Ref			Ref		
Poorer	0.057**	(0.018 to 0.097)	0.004	0.062**	(0.015 to 0.108)	0.010	0.005	(−0.089 to 0.100)	0.914
Middle	0.120***	(0.078 to 0.162)	<0.001	0.119***	(0.070 to 0.168)	<0.001	0.035	(−0.059 to 0.129)	0.467
Richer	0.216***	(0.167 to 0.265)	<0.001	0.236***	(0.178 to 0.294)	<0.001	0.205***	(0.101 to 0.309)	<0.001
Richest	0.358***	(0.293 to 0.423)	<0.001	0.372***	(0.294 to 0.450)	<0.001	0.417***	(0.287 to 0.547)	<0.001
Maternal literacy	0.144***	(0.111 to 0.177)	<0.001	0.128***	(0.090 to 0.167)	<0.001	0.060	(−0.002 to 0.123)	0.056
Number of household members	−0.011***	(−0.014, to −0.007)	<0.001	−0.011***	(−0.015 to −0.008)	<0.001	−0.018***	(−0.026 to −0.010)	<0.001
Product of multiple birth	−0.072	(−0.158 to 0.015)	0.105	−0.094	(−0.190 to 0.003)	0.058	−0.030	(−0.214 to 0.154)	0.778
Birth order	−0.035*	(−0.063 to −0.007)	0.014	0.004	(−0.029 to 0.037)	0.81	0.038	(−0.043 to 0.119)	0.362
Use of shared toilet facilities	–			–			−0.017	(−0.076 to 0.042)	0.579
Unimproved toilet	−0.048**	(−0.081 to −0.014)	0.005	−0.047*	(−0.086 to −0.007)	0.021	−0.042	(−0.104 to 0.020)	0.180
Lack of clean drinking water	−0.014	(−0.044 to 0.015)	0.347	−0.032	(−0.066 to 0.003)	0.074	−0.047	(−0.109 to 0.015)	0.135
Water source located off premises	−0.045*	(−0.084 to −0.006)	0.024	−0.053*	(−0.098 to −0.007)	0.024	−0.058	(−0.130 to 0.014)	0.116
Unsafe stool disposal				−0.082***	(−0.120 to −0.044)	<0.001	−0.095**	(−0.160 to −0.030)	0.004
Height-for-age Z-score	0.103***	(0.095 to 0.112)	<0.001	0.107***	(0.097 to 0.117)	<0.001	0.090***	(0.073 to 0.107)	<0.001
Currently or ever vs never breast fed	−0.074	(−0.159 to 0.010)	0.088	−0.011	(−0.117 to 0.096)	0.85	−0.070	(−0.227 to 0.086)	0.379
High-iron diet	–			–			−0.031	(−0.095 to 0.033)	0.348
Mother's age (years)	0.006***	(0.004 to 0.008)	<0.001	0.006***	(0.004 to 0.008)	<0.001	0.007**	(0.002 to 0.011)	0.003
Mother's BMI	0.010***	(0.004 to 0.008)	<0.001	0.012***	(0.008 to 0.016)	<0.001	0.009*	(0.002 to 0.016)	0.012
Mother currently pregnant	0.199***	(0.156 to 0.241)	<0.001	0.197***	(0.149 to 0.246)	<0.001	0.223***	(0.119 to 0.328)	<0.001

Continued

Table 4 Continued

	Model 1 n=87 272			Model 2 n=60 416			Model 3 n=20 234		
	β	95% CI	P values	β	95% CI	P values	β	95% CI	P values
Mother's haemoglobin (g/dL)	0.175***	(0.167 to 0.184)	<0.001	0.171***	(0.161 to 0.181)	<0.001	0.166***	(0.148 to 0.183)	<0.001
Maternal deworming treatment during pregnancy (vs no/unsure/ age>12 months)	0.111***	(0.051 to 0.171)	<0.001	0.114***	(0.046 to 0.183)	0.001	0.036	(−0.068 to 0.139)	0.497
Diarrhoea in the past two weeks									
No	Ref			Ref			Ref		
Non-bloody diarrhoea	−0.063**	(−0.101 to −0.025)	0.001	−0.072**	(−0.118 to −0.027)	0.002	0.028	(−0.045 to 0.101)	0.457
Bloody diarrhoea	−0.100*	(−0.178 to −0.023)	0.011	−0.119*	(−0.209 to −0.029)	0.010	−0.089	(−0.237 to 0.060)	0.241
Fever in the past two weeks	−0.325***	(−0.357 to −0.293)	<0.001	−0.363***	(−0.401 to −0.325)	<0.001	−0.410***	(−0.472 to −0.347)	<0.001
Iron supplementation	–			0.017	(−0.027 to 0.061)	0.451	−0.020	(−0.098 to 0.060)	0.624
Deworming treatment	0.026	(−0.003 to 0.055)	0.075	0.011	(−0.022 to 0.043)	0.53	0.008	(−0.044 to 0.066)	0.690
Used mosquito net	–			−0.025	(−0.057 to 0.007)	0.130	0.002	(−0.053 to 0.061)	0.886
Model R^2	0.307			0.254			0.247		

Model 1 includes only variables present in >90% of respondents; model 2 includes variables present in >80% of respondents; model 3 includes all potentially relevant variables. All models were adjusted for country as a fixed effect.
*p <0.05, **p <0.01, ***p <0. 001.
Ref, reference group for multilevel variable.

Table 5 Logistic regression model: risk factors for childhood anaemia (defined as haemoglobin (Hb) <11 g/dL) and population-attributable fraction (PAF)

Risk factor	OR	95% CI	PAF (%)	95% CI
Demographic			11.3	(10.5 to 12.2)
Age (months)				
6–11	2.90***	(2.66 to 3.16)		
12–23	2.12***	(2.00 to 2.23)		
23–59	–			
Male sex	1.12***	(1.08 to 1.17)		
Environmental			1.3	(0.3 to 2.3)
Urban location	1.06*	(1.00 to 1.13)		
Improved floor	1.06*	(1.00 to 1.13)		
Clean cooking fuel	0.99	(0.90 to 1.10)		
Socioeconomic			13.0	(10.7 to 15.3)
Wealth index				
Poorest	1.61***	(1.46 to 1.79)		
Poorer	1.48***	(1.35 to 1.63)		
Middle	1.40***	(1.28 to 1.52)		
Richer	1.25***	(1.16 to 1.35)		
Richest	–			
Maternal illiteracy	1.19***	(1.13 to 1.25)		
Family structure			10.7	(6.6 to 14.6)
Number of household members				
0–3	–			
4–6	1.06	(0.98 to 1.13)		
7–9	1.16***	(1.07 to 1.25)		
10–12	1.20***	(1.10 to 1.32)		
12+	1.28***	(1.16 to 1.42)		
Product of multiple birth	1.08	(0.95 to 1.24)		
Birth order				
1	1.29***	(1.16 to 1.43)		
2	1.20***	(1.08 to 1.33)		
3+	–			
Water/sanitation			4.0	(2.1 to 5.9)
Unimproved toilet	1.04	(0.98 to 1.09)		
Lack of clean drinking water	1.04	(0.99 to 1.09)		
Water source located off premises	1.12***	(1.05 to 1.19)		
Nutrition and growth			6.8	(2.6 to 10.8)
Stunted	1.32***	(1.27 to 1.38)		
Currently or ever breast fed	1.11	(0.98 to 1.26)		
Maternal factors			16.8	(11.9 to 21.4)
Mother's age (years)				
≤18	1.30***	(1.13 to 1.48)		
19–24	1.23***	(1.16 to 1.31)		
25–28	1.13***	(1.07 to 1.20)		
29–34	1.06	(1.00 to 1.12)		
35+	–			

Continued

Table 5 Continued

Risk factor	OR	95% CI	PAF (%)	95% CI
Mother's BMI				
<18.5	1.20***	(1.10 to 1.30)		
18.5–24.9	1.13***	(1.07 to 1.19)		
>24.9	–			
Mother not currently pregnant or unsure	1.04	(1.00 to 1.107)		
Maternal anaemia	1.85***	(1.76 to 1.95)		
No anaemia	–			
Mild anaemia (Hb<11 g/dL)	1.64***	(1.55 to 1.73)		
Moderate anaemia (Hb<10 g/dL)	2.10***	(1.98 to 2.22)		
Severe anaemia (Hb<7 g/dL)	2.35***	(1.95 to 2.83)		
Maternal deworming during pregnancy				
Yes	–			
No, don't know or NA (age>12 months)	1.05	(0.93 to 1.18)		
Age>12 months (NA)	–			
Recent illnesses			3.2	(2.8 to 3.6)
Diarrhoea in the past two weeks				
No	–			
Non-bloody diarrhoea	1.11**	(1.04 to 1.18)		
Bloody diarrhoea	1.21**	(1.07 to 1.36)		
Fever in the past two weeks	1.42***	(1.35 to 1.49)		
Prophylactic measures			1.0	(0.3 to 1.8)
No deworming treatment	1.06**	(1.02 to 1.11)		
Overall model PAF			67.8	(61.3 to 73.2)

Model adjusted for country as fixed effect. No OR (–) listed for reference groups included in table.
*p <0.05, **p <0.01, ***p <0.001.
BMI, body mass index; NA, not available.

nutrition education, breastfeeding promotion, dietary diversification, micronutrient supplementation, malaria and other parasitic disease control, water and sanitation promotion, and community and health facility level training and advocacy significantly reduced the effect of malaria on children's Hb. Similarly, a cluster randomised controlled trial in Burkina Faso demonstrated that an integrated agriculture, nutrition and behaviour change programme targeting mothers improved Hb among young infants.[42]

According to the most recent estimates from the United Nations Population Division, the under 5 population in SSA is 157.4 million,[43] of which approximately 141.1 million are age 6–59 months (based on the age distribution in the DHS sample). Applying the observed anaemia prevalence of 59.9%, about 85 million children age 6–59 months in SSA would be anaemic. Addressing maternal factors would have the potential to reduce anaemia in 16.8–30.2 million children; similarly, improving socioeconomic factors might prevent anaemia in 15.1–21.6 million children. Although these numbers are an estimate, anaemia itself has a substantial social and economic cost,[44] and reducing the prevalence of anaemia can help break the cycle of poverty in low-income countries.

While WHO recommends daily iron supplementation for all children 6 months and older living in areas where anaemia is highly prevalent,[45] identification of risk factors might also direct more aggressive promotion of anaemia testing and prevention programmes to high-risk groups. For example, we found that children who are young, stunted and in the lowest socioeconomic group, and those with mothers who are illiterate, young, anaemic and underweight are at highest risk of anaemia. These children might benefit most from programmes focused on testing, deworming, iron supplementation and bednet promotion. Since the placenta is a rich source of blood and iron for the newborn at the time of delivery, it is important to emphasise the current WHO recommendations on delayed cord clamping of all deliveries.[46–48] Interestingly, we also found that male children are at slightly higher risk of anaemia, perhaps related to X-linked diseases such as glucose-6 phosphate dehydrogenase (not tested in this study).

Our findings must be interpreted in the context of the study's limitations. As a household survey, responses are

subject to recall and misclassification bias. These data only capture events within the time window ascertained by the survey questions; for example, a history of iron supplementation (rather than recent supplementation in the past seven days) would not be captured in these data, a possible explanation for the apparent lack of association between iron supplementation and higher Hb. Anaemia testing was limited to Hb; no further information on types of anaemia is available in these data. In addition, only a sample of living children were eligible to have their Hb measured, and children who died were sicker and more susceptible to both the risk factors for anaemia and its deleterious effects. Furthermore, DHS data on risk factors are limited to household and individual-level questions; the survey fails to capture school or community-level risk factors. To permit estimation of the effect of altitude on Hb, our analyses used measured Hb values unadjusted for altitude. We would anticipate that use of altitude-adjusted Hb values as a threshold for defining anaemia would increase the estimated prevalence of anaemia. Finally, because DHS anaemia data are only available for 27 of the 48 SSA countries, this also limits the generalisability of the findings.[49]

A further limitation relates to the challenges in translating cross-sectional associations into conclusions on causation. Cross-sectional data make distinguishing cause from effect difficult; for example, anaemia may be both a cause and effect of stunting. As such, PAFs must be interpreted with caution. For some preventive measures (eg, bednet usage, iron supplementation), there may be confounding by indication. For example, families living in areas with high malaria rates may be more likely to use bednets, and this would to some extent mitigate the observed benefit of bednets. Similarly, there may be confounding by indication (eg, iron supplementation would be more common among children with anaemia). Many of the characteristics of poverty, including household crowding, poor water/sanitation, poor nutrition and access to medical care (including iron treatment), have complex interrelationships,[49] and unpacking the causal relationships among these factors in causing or preventing anaemia requires further studies.

CONCLUSION

In summary, the findings from our analysis underscore the importance of family and socioeconomic context in childhood anaemia. Identifying risk factors for anaemia highlights potential targets for interventions, and these findings can guide policymakers wishing to reduce the prevalence of anaemia. In light of the multidimensional causes of anaemia, an integrated approach is needed to address childhood anaemia and its deleterious effects on neurocognitive development, response to infections and children's growth and well-being.

Contributors PPM conceptualised and designed the study, carried out the initial analyses, drafted the initial manuscript and approved the final manuscript as submitted. LA, OA and DH contributed to analysis of the data, revised the initial manuscript and approved the final manuscript as submitted. MOW, WD, JPK, DCC and PLH contributed to the study design and interpretation, critically reviewed and revised the initial manuscript, and approved the final manuscript as submitted.

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Competing interests None declared.

Patient consent Not required.

Ethics approval General procedures and questionnaires for the DHS programme were reviewed and approved by the Informed Consent Form (ICF) International Institutional Review Board (IRB). Country-specific DHS protocols were additionally reviewed by the ICF IRB and by the IRB in each country. This analysis was reviewed and deemed exempt by the Partners Human Research Committee.

Provenance and peer review Not commissioned; externally peer reviewed.

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REFERENCES

1. Stevens GA, Finucane MM, De-Regil LM, *et al*. Global, regional, and national trends in haemoglobin concentration and prevalence of total and severe anaemia in children and pregnant and non-pregnant women for 1995-2011: a systematic analysis of population-representative data. *Lancet Glob Health* 2013;1:e16–e25.
2. Kassebaum NJ, Jasrasaria R, Naghavi M, *et al*. A systematic analysis of global anemia burden from 1990 to 2010. *Blood* 2014;123:615–24.
3. Scott SP, Chen-Edinboro LP, Caulfield LE, *et al*. The impact of anemia on child mortality: an updated review. *Nutrients* 2014;6:5915–32.
4. Hurtado EK, Claussen AH, Scott KG. Early childhood anemia and mild or moderate mental retardation. *Am J Clin Nutr* 1999;69:115–9.
5. Ai Y, Zhao SR, Zhou G, *et al*. Hemoglobin status associated with performance IQ but not verbal IQ in Chinese preschool children. *Pediatr Int* 2012;54:669–75.
6. Greisen G. Mild anaemia in African school children: effect on running performance and an intervention trial. *Acta Paediatr Scand* 1986;75:662–7.
7. Adekanmbi AF, Ogunlesi TA, Olowu AO, *et al*. Current trends in the prevalence and aetiology of childhood congestive cardiac failure in Sagamu. *J Trop Pediatr* 2007;53:103–6.
8. Dhabangi A, Ainomugisha B, Cserti-Gazdewich C, *et al*. Cerebral Oximetry in Ugandan Children With Severe Anemia: Clinical Categories and Response to Transfusion. *JAMA Pediatr* 2016;170:995–1002.
9. MacCormick IJ, Beare NA, Taylor TE, *et al*. Cerebral malaria in children: using the retina to study the brain. *Brain* 2014;137(Pt 8):2119–42.
10. Ngesa O, Mwambi H. Prevalence and risk factors of anaemia among children aged between 6 months and 14 years in Kenya. *PLoS One* 2014;9:e113756.

11. Reithinger R, Ngondi JM, Graves PM, *et al*. Risk factors for anemia in children under 6 years of age in Ethiopia: analysis of the data from the cross-sectional Malaria IndicatorSurvey, 2007. *Trans R Soc Trop Med Hyg* 2013;107:769–76.
12. Semedo RM, Santos MM, Baião MR, *et al*. Prevalence of anaemia and associated factors among children below five years of age in Cape Verde, West Africa. *J Health Popul Nutr* 2014;32:646–57.
13. VanBuskirk KM, Ofosu A, Kennedy A, *et al*. Pediatric anemia in rural Ghana: a cross-sectional study of prevalence and risk factors. *J Trop Pediatr* 2014;60:308–17.
14. Baranwal A, Baranwal A, Roy N. Association of household environment and prevalence of anemia among children under-5 in India. *Front Public Health* 2014;2:196.
15. Mamabolo RL, Alberts M. Prevalence of anaemia and its associated factors in African children at one and three years residing in the Capricorn District of Limpopo Province, South Africa. *Curationis* 2014;37:1–9.
16. Habte D, Asrat K, Magafu MG, *et al*. Maternal risk factors for childhood anaemia in Ethiopia. *Afr J Reprod Health* 2013;17:110–8.
17. Ayoya MA, Ngnie-Teta I, Séraphin MN, *et al*. Prevalence and Risk Factors of Anemia among Children 6-59 Months Old in Haiti. *Anemia* 2013;2013:502968–.
18. Khan JR, Awan N, Misu F. Determinants of anemia among 6-59 months aged children in Bangladesh: evidence from nationally representative data. *BMC Pediatr* 2016;16:3.
19. Magalhães RJ, Clements AC. Mapping the risk of anaemia in preschool-age children: the contribution of malnutrition, malaria, and helminth infections in West Africa. *PLoS Med* 2011;8:e1000438.
20. Siekmans K, Receveur O, Haddad S. Can an integrated approach reduce child vulnerability to anaemia? Evidence from three African countries. *PLoS One* 2014;9:e90108.
21. Soares Magalhães RJ, Langa A, Pedro JM, *et al*. Role of malnutrition and parasite infections in the spatial variation in children's anaemia risk in northern Angola. *Geospat Health* 2013;7:341–54.
22. Turyashemererwa FM, Kikafunda J, Annan R, *et al*. Dietary patterns, anthropometric status, prevalence and risk factors for anaemia among school children aged 5-11 years in Central Uganda. *J Hum Nutr Diet* 2013;26(Suppl 1):73–81.
23. Desai MR, Terlouw DJ, Kwena AM, *et al*. Factors associated with hemoglobin concentrations in pre-school children in Western Kenya: cross-sectional studies. *Am J Trop Med Hyg* 2005;72:47–59.
24. Nkulikiyinka R, Binagwaho A, Palmer K. The changing importance of key factors associated with anaemia in 6- to 59-month-old children in a sub-Saharan African setting where malaria is on the decline: analysis of the Rwanda Demographic and Health Survey 2010. *Trop Med Int Health* 2015;20:1722–32.
25. Alderman H, Linnemayr S. Anemia in low-income countries is unlikely to be addressed by economic development without additional programs. *Food Nutr Bull* 2009;30:265–9.
26. Corsi DJ, Neuman M, Finlay JE, *et al*. Demographic and health surveys: a profile. *Int J Epidemiol* 2012;41:1602–13.
27. Short Fabic M, Choi Y, Bird S. A systematic review of Demographic and Health Surveys: data availability and utilization for research. *Bull World Health Organ* 2012;90:604–12.
28. Nkrumah B, Nguah SB, Sarpong N, *et al*. Hemoglobin estimation by the HemoCue® portable hemoglobin photometer in a resource poor setting. *BMC Clin Pathol* 2011;11:5.
29. International I. *MEASURE DHS biomarker field manual*. Calverton, Maryland, U.S.A: ICF International, 2012. https://dhsprogram.com/pubs/pdf/DHSM7/DHS6_Biomarker_Manual_9Jan2012.pdf
30. World Health Organization. *Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity*. Geneva: World Health Organization, 2011.
31. Rutstein SO, Johnson K. *The DHS wealth index*. Calverton, Maryland, USA: ORC Macro, 2004.
32. WHO/UNICEF Joint Water Supply and Sanitation Monitoring Programme WHO, UNICEF. *Progress on drinking water and sanitation 2012*. New York, N.Y., Geneva: UNICEF, World Health Organization, 2012.
33. Newson RB. Attributable and unattributable risks and fractions and other scenario comparisons. *Stata J* 2013;13:672–98.
34. Pasricha SR, Drakesmith H, Black J, *et al*. Control of iron deficiency anemia in low- and middle-income countries. *Blood* 2013;121:2607–17.
35. Wilunda C, Tanaka S, Esamai F, *et al*. Prenatal anemia control and anemia in children aged 6-23 months in sub-Saharan Africa. *Matern Child Nutr* 2017;13:e12375.
36. Cantor AG, Bougatsos C, Dana T, *et al*. Routine iron supplementation and screening for iron deficiency anemia in pregnancy: a systematic review for the U.S. Preventive Services Task Force. *Ann Intern Med* 2015;162:566–76.
37. Gera T, Sachdev HP, Nestel P, *et al*. Effect of iron supplementation on haemoglobin response in children: systematic review of randomised controlled trials. *J Pediatr Gastroenterol Nutr* 2007;44:468–86.
38. Low M, Farrell A, Biggs BA, *et al*. Effects of daily iron supplementation in primary-school-aged children: systematic review and meta-analysis of randomized controlled trials. *CMAJ* 2013;185:E791–E802.
39. Pasricha SR, Hayes E, Kalumba K, *et al*. Effect of daily iron supplementation on health in children aged 4-23 months: a systematic review and meta-analysis of randomised controlled trials. *Lancet Glob Health* 2013;1:e77–e86.
40. Gulani A, Nagpal J, Osmond C, *et al*. Effect of administration of intestinal anthelmintic drugs on haemoglobin: systematic review of randomised controlled trials. *BMJ* 2007;334:1095.
41. Korenromp EL, Armstrong-Schellenberg JR, Williams BG, *et al*. Impact of malaria control on childhood anaemia in Africa -- a quantitative review. *Trop Med Int Health* 2004;9:1050–65.
42. Olney DK, Pedehombga A, Ruel MT, *et al*. A 2-year integrated agriculture and nutrition and health behavior change communication program targeted to women in Burkina Faso reduces anemia, wasting, and diarrhea in children 3-12.9 months of age at baseline: a cluster-randomized controlled trial. *J Nutr* 2015;145:1317–24.
43. UNDoEaSAP D. World Population Prospects: The 2015 Revision, DVD Edition. *New York* 2015.
44. Plessow R, Arora NK, Brunner B, *et al*. Social Costs of Iron Deficiency Anemia in 6-59-Month-Old Children in India. *PLoS One* 2015;10:e0136581.
45. World Health Organization. *Nutrition for Health and Development, World Health Organization. Guideline. Daily iron supplementation in infants and children*. Geneva: World Health Organization, 2016. http://apps.who.int/iris/bitstream/10665/204712/1/9789241549523_eng.pdf?ua=1&ua=1
46. Gupta R, Ramji S. Effect of delayed cord clamping on iron stores in infants born to anemic mothers: a randomized controlled trial. *Indian Pediatr* 2002;39:130–5.
47. Hutton EK, Hassan ES. Late vs early clamping of the umbilical cord in full-term neonates: systematic review and meta-analysis of controlled trials. *JAMA* 2007;297:1241–52.
48. World Health Organization. *Nutrition for Health and Development, World Health Organization. Guideline. Delayed umbilical cord clamping for improved maternal and infant health and nutrition outcomes*. Geneva, Switzerland: World Health Organization, 2014. http://apps.who.int/iris/bitstream/10665/148793/1/9789241508209_eng.pdf
49. Schickedanz A, Dreyer BP, Halfon N. Childhood Poverty: Understanding and Preventing the Adverse Impacts of a Most-Prevalent Risk to Pediatric Health and Well-Being. *Pediatr Clin North Am* 2015;62:1111–35.