Spatio-temporal trends in anaemia among pregnant women, adolescents and preschool children in sub-Saharan Africa

Kelechi Weze[2], Ajibola Ibraheem Abioye[1], Chiagoziem Obiajunwa[3] and Moshood Omotayo[4,5],*

[1]Department of Nutrition, Harvard T.H. Chan School of Public Health, Boston, MA, USA: [2]Department of Environmental Health, Harvard T.H. Chan School of Public Health, Boston, MA, USA: [3]Providence St Peter Family Medicine, Olympia, WA, USA: [4]Division of Pediatric Global Health and Centre for Global Health, Massachusetts General Hospital (MGH), Boston, MA 02114, USA: [5]Department of Pediatrics and Department of Emergency Medicine, Harvard Medical School, Boston, MA, USA

Abstract

Objective: We investigated the spatiotemporal trends in the burden of maternal, adolescent and child anaemia in sub-Saharan Africa (SSA) and evaluated some individual and household predictors of anaemia.
Design: Average Hb concentrations and anaemia prevalence were estimated, plotted over time and mapped by country and sub-region. Multilevel linear regression models were used to evaluate individual and household predictors of Hb concentration.
Participants: Data from Demographic and Health Surveys (DHS) spanning 2000–2018 were merged into data sets for 37 623 pregnant women, 89 815 older adolescent girls and 401 438 preschool children.
Setting: The merged DHS represent nationally representative samples from thirty-three countries.
Results: Prevalence of anaemia remains high in SSA, affecting 60, 36 and 44 % of children, adolescents and pregnant women, respectively. Anaemia prevalence among children did not materially improve from 2000 to 2018. Anaemia prevalence among older adolescent girls and pregnant women did not also improve, but this masks a period of improvement followed by depreciation in population anaemia status. Pregnant adolescents had 12·5 g/l (95 % CI: 11·3, 13·6) lower Hb concentration compared with non-pregnant adolescents and 1·7 g/l (95 % CI: 0·7, 2·6) lower Hb concentration compared with pregnant women > 40 years, respectively. Stunting and wasting were associated with 1·3–3·3 g/l lower Hb concentration among children. Other significant predictors of Hb concentration were educational attainment, wealth quintiles, source of drinking water, number of children < 5 years in the household and possession of bed-nets.
Conclusion: Anaemia in SSA has not improved remarkably since year 2000 and remains excessive among children.

Anaemia is a major contributor to the global burden of disease with a prevalence of 32·9 % as at 2010 and resulting in 68·4 million years lived with disability. Pregnant women and children under the age of 5 years in sub-Saharan Africa (SSA) are most commonly affected[1]. Common causes of anaemia are micronutrient deficiencies, infections such as malaria and HIV and inherited blood diseases[2]. Iron deficiency alone accounts for about half of all cases[1]. Certain social and cultural factors may also predispose to anaemia[3]. Among pregnant women, anaemia leads to reduced physical functioning and substantially increases the risk of maternal and perinatal mortality, preterm births and low birth weight[4]. Among children, anaemia is associated with increased risk of mortality and poor cognitive development[4,5]. Among adolescent girls, anaemia is associated with impaired cognition and obstetric complications if the adolescent becomes pregnant[6].

Corresponding author: Email momotayo@mgh.harvard.edu

Over the last two decades, landmark studies[7–15] have significantly improved our understanding of the determinants and impact of anaemia or led to re-evaluation of the policies and guidelines relating to anaemia. There has also been increased recognition of the role of adolescent nutrition in delaying pregnancy and improving the health of pregnant women and children[16]. Iron supplementation, daily in pregnant women and weekly in adolescent girls, has been the mainstay of public health programming; however, uptake has remained stagnant at <10 % in most parts of Africa[17]. Adherence to supplementation tends to be poor[18]. Increased coverage for malaria control interventions has led to rapid decline in malaria burden[19], potentially influencing the distribution of anaemia across countries over time. Access to antiretroviral therapy has also improved greatly, leading to reduced HIV-related mortality and disease progression[20], an important determinant of anaemia in Africa. These changes have led to considerable changes in the prevalence of anaemia in some countries. For instance, the prevalence of anaemia among pregnant women in Zimbabwe was 43 % in 2005 and 32 % in 2015[21,22]. For optimal targeting of public health interventions and resources, it is important to understand this changing landscape, by characterizing patterns and drivers of spatio-temporal distribution of anaemia among pregnant women, adolescent girls and children, at regional, national and sub-national levels. Specifically, we are unaware of any recent study that examined the changes in the burden of anaemia across sub-Saharan African countries over time, while exploring the possible role of important clinical and socio-economic factors.

To fill this gap, we leveraged data from nationally representative Demographic and Health Surveys (DHS) conducted across SSA between 2000 and 2018 to investigate the spatial and temporal trends in average Hb concentrations in pre-school children, adolescent girls and pregnant women and to assess individual-level and household determinants of anaemia in these important demographic groups.

Methods

This was a multi-level analysis of cross-sectional nationally representative data from the DHS conducted between 2000 and 2018 in 32 countries in SSA. These surveys are conducted every 4–6 years, depending on the socio-political situation of the country. All African countries except the North African countries (Algeria, Egypt, Libya, Morocco, Sudan, Tunisia and Western Sahara) were regarded as being in the SSA region, as defined by the UN[23]. In addition to the DHS, the Malaria Indicator Survey, another set of nationally representative surveys, were included. The Malaria Indicator Survey is based on a similar design as the DHS, but prioritise the collection of additional malaria-related data. These surveys are typically complex in design, with stratified two-stage sampling. Each country is divided into clusters selected in proportion to the population size and location (rural/urban). A complete listing of the households in each cluster serves as the sampling frame for the second stage. A systematic sampling is often done at this stage till a pre-specified number of households are interviewed in each cluster[24].

These surveys collect a wide range of biomarkers and self-reported data in the areas of population, health and nutrition. Briefly, these include information on the household structure, urban/rural living, socio-economic factors such as wealth and education, demographic information and health behaviours. For children living in the household, anthropometry is done, and health outcomes data are collected. Detailed reproductive and fertility data of women of reproductive age are often collected. Biological samples are sometimes collected for biomarker testing. The DHS is designed, using standardised data collection procedures, to allow for comparability across multiple countries, with only limited changes over time. Response rate is usually very high[24].

For this analysis, all DHS surveys conducted in SSA between 2000 and 2018 with Hb testing done was identified[25]. Hb testing was done using the Hemocue blood Hb testing system using blood collected via finger prick for adolescents and women and heel prick for children[26]. Unique survey ID were created to represent each country, survey, cluster, house and the individual. Three separate data sets for children under the age of 5, adolescent girls 15–19-years-old and pregnant women from the different countries and across multiple years were created. Variables were renamed and categorised as appropriate. The nesting structure of the data was considered in the analysis of the data – individuals nested in clusters, clusters nested in countries.

Hb concentrations adjusted by altitude were employed. Among pregnant women and children, anaemia was defined as Hb below 110 g/l[27,28]. Among older adolescent girls, anaemia was defined as Hb < 120 g/l. In all three population groups, anaemia was regarded as moderate to severe if Hb < 100 g/l[27,28]. Mean (±SD) of Hb concentration and the proportions (with 95 % confidence intervals) of participants with any anaemia and moderate to severe anaemia were estimated, accounting for the survey weights. In all cases where weights are used, the relevant weight specified for that individual in that survey was used – whether the survey was a DHS or Malaria Indicator Survey.

A scatter plot with Loess non-parametric smoothing was used to estimate the mean Hb level in SSA, over time, from 2000 to 2018 among pre-school children, adolescent girls and pregnant women. To provide an understanding of the burden of disease as well as make comparison across countries possible, bar charts were constructed for the average prevalence of anaemia in pre-school children, adolescents and pregnant women across various countries over the period of the study (2000–2018). The average prevalence of anaemia for the 2000–2018 period was also presented in maps to allow for visualisation of the spatial distribution and in smaller time periods: 2000–2005, 2006–2010, 2011–2015 and 2016–2018.

To predict the determinants of Hb concentration among both pre-school children, adolescent girls and pregnant women, we utilised multilevel mixed effects models which account for the clustering of these surveys by country and by year. Random effects were used to model various variables identified from prior studies to be important predictors of anaemia and Hb concentration. DHS survey weights were incorporated in the models to account for the unequal probability of selection into the survey. We specified Rwanda as the reference categories for country fixed effects due to its lowest prevalence of anaemia in the data set.

Model selection was purposeful – as a variation of the approach described by Hosmer and Lemeshow[29]. A list of variables (below) with known or potential relationships with anaemia or Hb concentration were identified for inclusion in regression models based on published literature[30–40]. Of these, variables that were significant at $P < 0.25$ in univariate models for the clinical outcomes were considered for inclusion[29]. Selected variables were included in the multivariate models. Multiple modelling approaches were considered, varying the form of the covariates (continuous or categorical) to include, and whether to allow for random intercepts or random slopes models, or to introduce interaction terms. Model fit was evaluated using the likelihood ratio test and Akaike's Information Criterion, depending on whether the alternative models were nested or not.

Variables considered for inclusion in the regression models for pregnant women, adolescents and children were household wealth index (in quintiles), the number of children in the household below 5 years (0 or 1, 2 or 3, > 3), place of residence (rural, urban), type of toilet or sanitary facilities (flush, pit and other/unsanitary), source of drinking water (piped, borehole, well, surface/rain, water tanker and bottled water), possession of a bed-net (yes, no), bed-net use the previous night (yes, no) and type of fuel used for cooking (electricity or gas, kerosene, coal/charcoal, wood/animal or plant residue and no cooking at home).

Variables considered for inclusion in the regression model for pregnant women only were age in years (15–< 20, 20–< 30, 30–< 40 and 40–49), duration of current pregnancy in months (≤ 3, 4–6 and > 6), iron supplement use (yes, no and not applicable), the number of antenatal visits (none, 1–3, 4–10 and > 10), educational attainment (none, primary, secondary, and higher), parity (0, 1–2, 3–4 and > 4).

Variables considered for inclusion in the regression model for adolescent girls were age in years (15–< 18, 18–20), pregnant (yes, no), educational attainment (none, primary, secondary, and higher), parity (0, 1–2, 3–4, > 4), and BMI z-scores (BMI–underweight, normal or healthy weight, overweight or obese). BMI z-scores were estimated based on the World Health Organization Growth Reference Standards[41]. BMI Z-scores were defined.

Variables considered for inclusion in the regression model for children were age in years (< 1, 1–< 3, > 3), sex (male, female), height-for-age Z-score (stunted i.e. HAZ < −2, not stunted), weight-for-height z-score (no wasting, i.e. WHZ ≥ −2, moderate wasting, i.e. WHZ −2 to < −3 and severe acute malnutrition, i.e. WHZ ≤ −3), maternal education (none, primary, secondary and higher).

The surveys were conducted by ICF Macro, Calverton, MD, USA, in conjunction with national statistical or related agencies. Anonymous deidentified data were obtained from ICF Macro and no further ethical approval was required. The data sets were originally obtained in SAS formats and prepared for analysis using SAS *v*.9·4 (SAS Institute Inc). The analysis was conducted in RStudio 1.0.153 with the lme4 and zscorer package[42,43]. P-values were two-sided, and significance was set at < 0·05. Values presented in the text are means (95 % CI), means (±SE) and percent (95 % CI).

Results

Surveys from 33 countries conducted from 2000 to 2018 with 33 984 pregnant women, 83 122 adolescent girls and 397 577 preschool children were included in the analysis.

The burden of anaemia was substantial across all countries and all survey years. The prevalence of anaemia in 2016–2018 was 65, 21 and 50 % among children, adolescents and pregnant women respectively. Across the population subgroups, the overall mean Hb concentrations and anaemia prevalence were greatest in West Africa, compared to other sub-regions (Table 1).

We estimated and plotted aggregate average Hb concentrations in SSA from 2000 to 2018 (Fig. 1). The smoothed mean Hb concentrations trended slightly upwards among children. Among pregnant women and adolescents, the mean Hb trended upwards to peak in 2008 and then reduced. From 2000 to 2018, the mean Hb increased from 108 g/l to 109 g/l among pregnant women, 121 g/l to 122 g/l among adolescent girls and 100 g/l to 103 g/l among children. The prevalence of anaemia reduced from 52 % to 50 % among pregnant women, from 23 % to 21 % among adolescent girls, and from 69 % to 65 % among children.

The prevalence of anaemia among children exceeded 30 % in all countries and all survey years (see online supplementary material, Supplemental Table 1, Figs 2 and 3). The aggregate prevalence of anaemia across all years was highest in Mali (> 80 %) and lowest in Eswatini and Rwanda (see online supplementary material, Supplemental Figure 1). In the most recent survey year for each country, the prevalence was highest (80 %) in Mali (2018), Liberia (2018) and Sierra Leone (2013). Notably, the burden of anaemia worsened substantially among children in Angola, Liberia and Mozambique during the survey years while the burden improved among children in Burkina Faso and Zimbabwe (see online supplementary material, Supplementary Table 1). The prevalence of anaemia worsened from 54 % in 2011 to 65 % in 2015 among children in Angola, from 65 % in 2009 to 80 % in 2018 among children in Liberia, and from 66 % in 2011 to 78 % in 2018 among children in Mozambique. The prevalence of anaemia

Table 1 Temporal and spatial change in Hb concentration and anaemia prevalence

| Variable	Population	Years	Overall		Central Africa		East Africa		Southern Africa		West Africa	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Hb, g/l	Pregnant women	2000–2005	108	24	109	17	111	19	113	44	103	18
		2006–2010	111	19	107	17	114	19	116	16	105	18
		2011–2016	110	17	109	16	114	18	111	17	106	17
		2016–2018	109	17	NA		116	19	113	16	106	17
	Adolescents	2000–2005	121	25	120	17	125	19	125	39	115	22
		2006–2010	122	18	118	17	127	18	126	17	116	18
		2011–2015	122	18	119	20	128	18	122	18	117	17
		2016–2018	122	17			127	17	125	17	118	16
	Children	2000–2005	100	19	102	18	102	19	106	15	95	19
		2006–2010	102	17	102	16	106	16	108	14	96	17
		2011–2015	103	17	104	15	107	16	106	15	98	17
		2016–2018	103	16	NA		105	16	105	16	101	15
Anaemia, %	Pregnant women	2000–2005	52	0·3	50	0·7	44	0·3	41	1·4	67	0·4
		2006–2010	46	0·2	53	0·6	36	0·3	35	0·4	60	0·3
		2011–2015	50	0·1	52	0·3	40	0·3	43	0·3	60	0·2
		2016–2018	50	0·2	NA		38	0·4	38	0·4	58	0·2
	Adolescents	2000–2005	23	0·3	24	0·7	19	0·3	16	1·4	33	0·4
		2006–2010	21	0·2	26	0·6	14	0·3	15	0·4	32	0·3
		2011–2015	22	0·1	26	0·3	15	0·3	21	0·3	28	0·2
		2016–2018	21	0·2			13	0·4	16	0·4	27	0·2
	Children	2000–2005	69	0·3	67	1·2	64	0·4	58	0·7	80	0·2
		2006–2010	65	0·2	67	1·0	55	0·3	53	0·5	80	0·5
		2011–2015	64	0·2	654	0·5	55	0·3	55	0·3	74	0·3
		2016–2018	65	0·2	NA		57	0·4	58	0·4	70	0·3
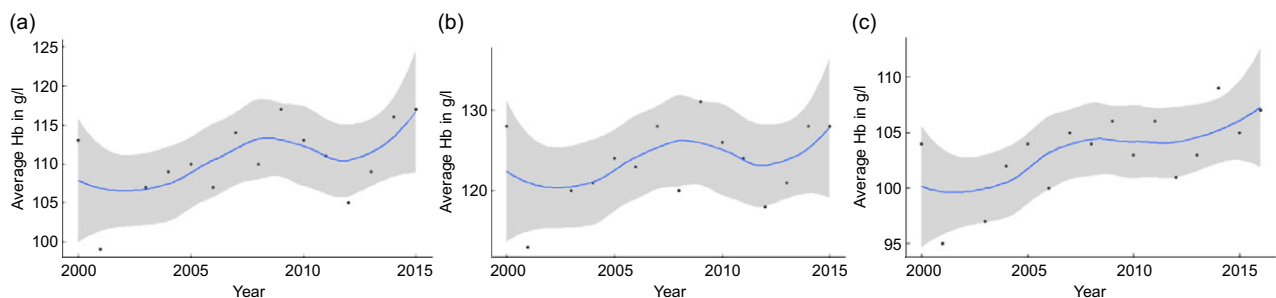
Fig. 1 (colour online) Aggregated Average Hb concentration among A) pregnant women, B) adolescent girls, and C) children in sub-Saharan Africa from 2000 to 2018

improved from 91 % in 2003 to 58 % in 2018 among children in Burkina Faso, and from 58 % in 2005 to 38 % in 2015 among children in Zimbabwe.

The prevalence of anaemia among pregnant women exceeded 20 % in all countries across all survey years, except in Rwanda (see online supplementary material, Supplemental Table 2, Figs 4 and 5). The aggregate prevalence of anaemia was highest in The Gambia (> 70 %) and lowest in Rwanda (20 %, see online supplementary material, Supplemental Figure 2). The prevalence of anaemia in the most recent survey for each country was also highest in The Gambia (71 %, in 2013) and lowest (22 %) in Rwanda. The prevalence of anaemia among pregnant women in Burkina Faso and Guinea reduced considerably–from 64 % in 2003 to 40 % in 2018 in Burkina Faso and from 66 % in 2003 to 48 % in 2018 in Guinea.

The prevalence of anaemia among older adolescent girls was ≥ 5 % in all countries and across all years (see online supplementary material, Supplemental Table 3, Figs 6 and 7). The aggregate prevalence of anaemia across all years was highest in Mali and lowest in Rwanda (see online supplementary material, Supplementary Figure 3). The prevalence of anaemia in the most recent survey for each country was highest (> 35 %) in Mali (2018) and Gabon (2012), and lowest (< 10 %) in Rwanda (2014) and Namibia (2013). The prevalence of anaemia reduced considerably from 44 % in 2001 to 33 % in 2017 among adolescents in Benin and from 29 % in 2003 to 18 % in 2018.

Age (in years) and gestational age were the most important factors associated with Hb concentration among pregnant women (Table 2). Compared to pregnant adolescents aged 15–19 years, the Hb concentration among women aged
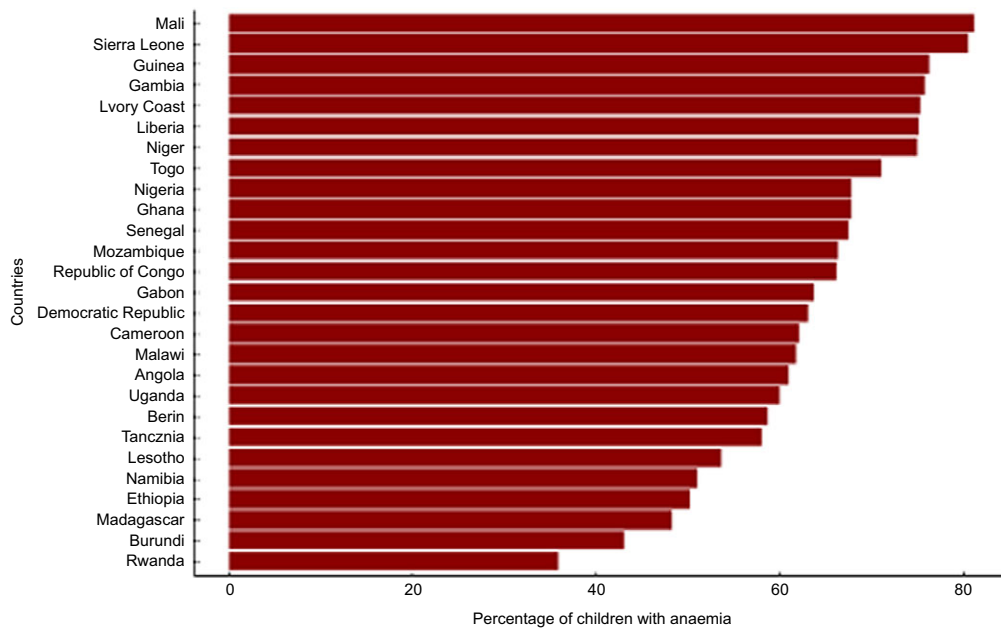
Fig. 2 (colour online) Percentage of children who are anaemic by country in sub-Saharan Africa in the most recent survey for each country

20–30 years, 30–40 years and 40–49 years were higher by 1·7 g/l (95 % CI: 0·7, 2·6), 1·8 g/l (95 % CI: 0·6, 2·9) and 2·5 g/l (0·9–4·0), respectively. Hb concentration was substantially lower with advancing gestation. The mean difference of the second and third trimesters compared to the first were −6·5 g/l (95 % CI: −7·0, −5·9) and −7·2 g/l (−7·8, −6·6), respectively.

Being the head of the household, level of education completed and antenatal clinic attendance were also significantly related to Hb concentration among pregnant women (Table 2). Pregnant women who were heads of their household had a lower Hb concentration compared with those who were not (Mean difference: −1·0 g/l (95 % CI: −1·8, 0·2). Compared to women who completed no formal education, women who completed primary education had a 1·0 g/l (95 % CI: 0·4, 1·6) higher Hb concentration and women who completed higher education had a 5·8 g/l (95 % CI: 3·7, 7·9) higher Hb concentration. Pregnant women who had attended no antenatal clinic visits in the current pregnancy had a lower Hb concentration compared to those who had attended 4–10 visits (Mean difference: 0·6 g/l (95 % CI: 0·1, 1·1). Iron supplement use was not significantly associated with the Hb concentration (mean difference: 0·2 g/l; 95 % CI: −0·5, 0·8) and there was no data on how regular iron supplement use was.

Among adolescents, being pregnant was the most important factor related to Hb concentration (Table 2). Pregnant adolescents had 12·5 g/l (95 % CI: 11·3, 13·6) lower Hb concentration compared to non-pregnant adolescents. In addition, educational attainment, number of children < 5 years in the household, socio-economic and nutritional status were also significant factors. The Hb concentration of adolescents in the

highest wealth quintile was higher than those in the lowest quintile by 2·9 g/l (95 % CI: 1·2, 4·5). Adolescents who were overweight had −2·4 g/l lower Hb concentration than those who were of normal BMI (95 % CI: −0·5, −4·4). Adolescents with at least primary education had higher Hb concentration than those with no educational level completed. Adolescents who live in homes with 2 or more children < 5 years old had 1·0 g/l lower Hb concentration and the Hb concentration was slightly worse when there were > 3 children.

The direction of some other factors identified among adolescents to be significantly related to Hb concentration were contrary to expectation (Table 2). For instance, adolescents from homes that cooked with electricity and gas had 9·1 g/l (95 % CI: 4·7, 13·5) lower Hb concentration than those who cooked with kerosene, or other cooking fuels. Also, adolescents who had bed-nets had 1·2 g/l lower Hb than those who did not (95 % CI: 0·4, 2·1).

Age, malaria prevention, water and sanitation indicators were some important factors related to Hb concentration among children (Table 2) Hb concentration was lowest in infants and children aged 3–5 years had 7·7 g/l (95 % CI: 7·5, 7·9) greater Hb concentration. Children who had bed-nets had 0·2 g/l (95 % CI: 0·1, 0·4) higher Hb concentration compared to those who did not. Children who lived in homes without toilets or sanitary facilities had 0·8 g/l (95 % CI: 0·4, 1·2) lower Hb concentration than those who had flush toilets in their homes. Compared to homes with pipe borne water, children from households with drinking water from boreholes and wells, and water tankers had lower Hb concentration, while children from households that drink bottled water had a higher Hb concentration. Socioeconomic status, birth-spacing and nutritional status were also related to Hb
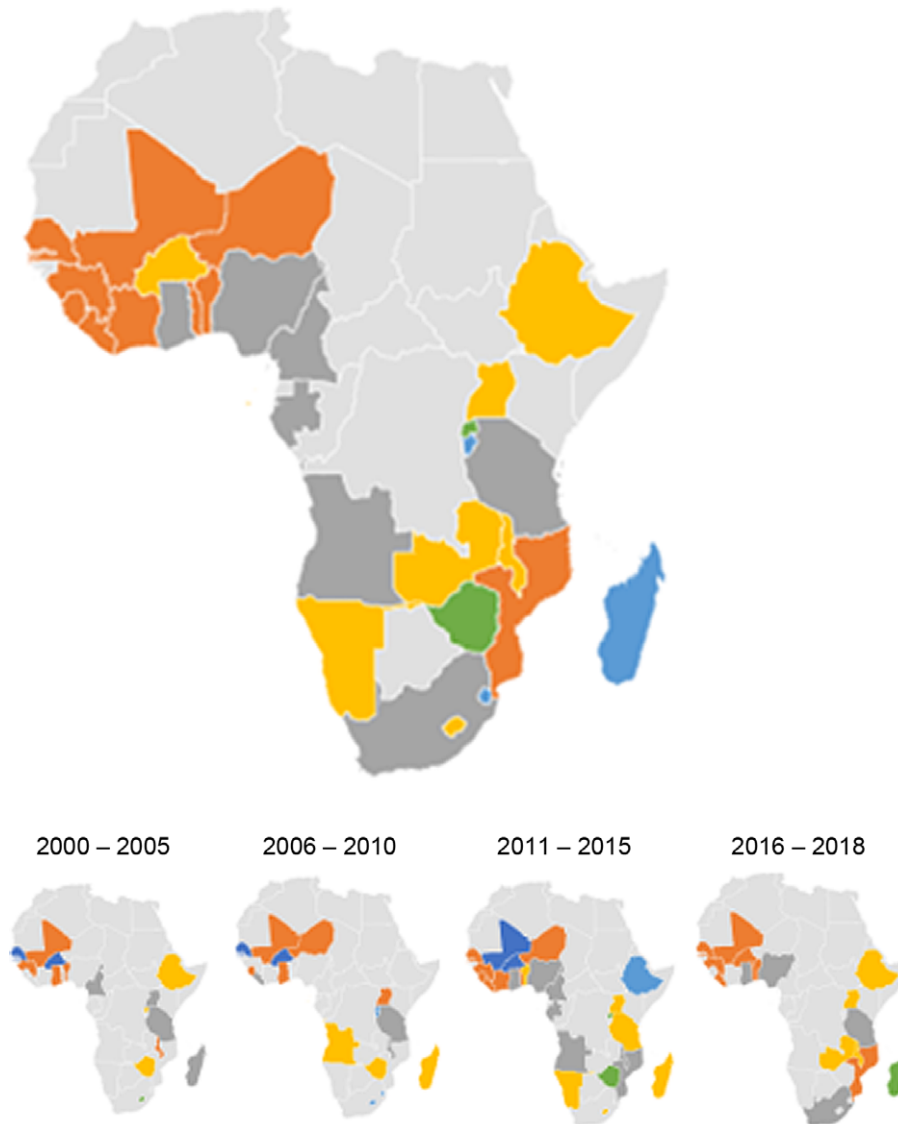
Fig. 3 (colour online) Map of Africa showing average Hb among children in sub-Saharan African countries, overall and across 5-year intervals. ■, 31–40; ■, 41–50; ■, 51–60; ■, 61–70; ■, 71–80; ■, 81 and above

concentration among children. The Hb concentration of children in the highest wealth quintile was higher than those in the lowest quintile by 3·8 g/l (95 % CI: 3·5, 4·1). Also, the greater the number of children < 5 years in a household, the lower the Hb concentration of children and adolescents in that household. Children who were stunted (HAZ –2), moderately wasted (WHZ –2 to –3) or who had severe acute malnutrition (WHZ ≤ –3) had 3·3 g/l (3·2–3·4), 1·3 g/l (1·1–1·6), and 2·1 g/l (1·8–2·5) lower Hb concentration, respectively, compared to their counterparts.

Discussion

Using multilevel modelling, we estimated the mean Hb concentration across 33 countries in SSA and examined

spatial and temporal trends in Hb concentration and anaemia prevalence. Our analysis demonstrates the Hb concentration and anaemia risk did not considerably improve over the two decades across much of Africa, and the burden of anaemia among children remains exceedingly high. We also examined individual and household level predictors of Hb concentration and found that socioeconomic status, nutritional status, adolescent pregnancy, antenatal care, access to water resources, sanitation, and hygiene (WASH) explained the spatial and temporal variation in Hb concentration across SSA.

Optimal targeting of policy and programmatic interventions requires timely evaluation of regional, national and sub-national spatio-temporal trends in the burden of diseases, and an updated understanding of the role of public health determinants and interventions in shaping these
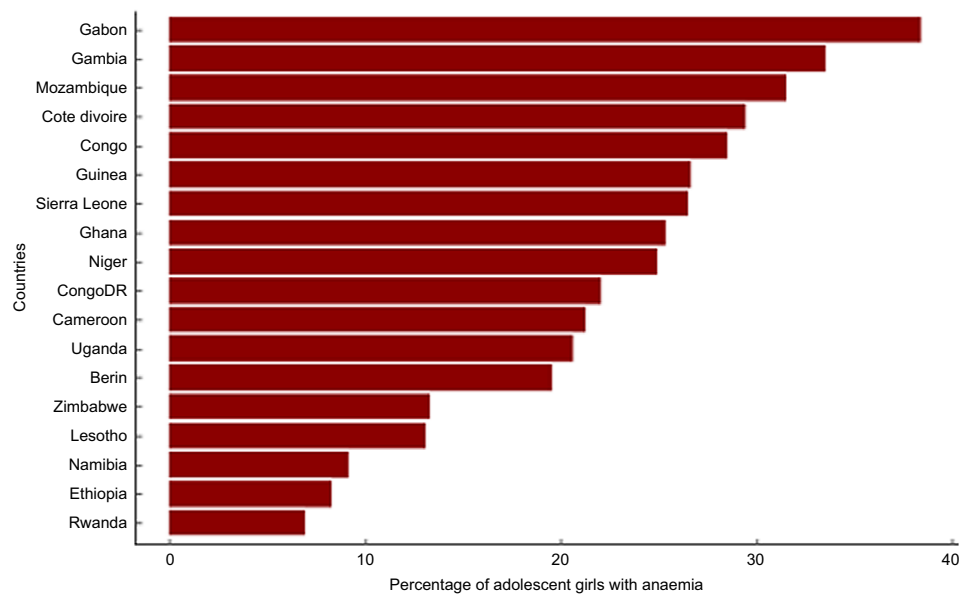
Fig. 4 (colour online) Percentage of pregnant women who are anaemic by country in sub-Saharan Africa in the most recent survey for each country

trends. In this analysis of nationally representative data sets, we found that while the burden of anaemia among pregnant women and adolescent girls improved and then worsened slightly, anaemia in children remains very high – 60 % prevalence in 2016 to 2018. The most common cause of anaemia globally is iron deficiency, and it often results from inadequate intake of iron-rich foods in a setting of increased demands for growth and metabolism. During pregnancy, a widespread cause of iron deficiency anaemia is the lack of iron supplementation or of adherence to it. Addressing the burden of iron deficiency would require simple but effective public health programs at scale. Iron supplementation is effective to prevent and treat iron deficiency anaemia, but its coverage is dismal[17]. Only 12 % of children in our analysis were taking iron tablets, sprinkles, or syrups, despite policy consensus that it is safe and beneficial in the context of good malaria prevention[44]. Iron deficiency anaemia among children is associated with poor cognitive and psychomotor development among children, with substantial impact over the course of the child's life[5].

Addressing anaemia among women of reproductive age – including older adolescents – may prevent a considerable proportion of childhood anaemia. Infants are born with iron stores that typically last them 4–6 months, particularly if their mothers are not severely iron deficient[4]. Infants of iron-deficient mothers experience faster depletion of their iron stores, if the diets they are weaned on do not provide sufficient amounts of dietary iron[4]. Our analysis confirms the value of antenatal clinic visits as great opportunities to deliver a package of interventions to prevent and treat maternal anaemia. Surprisingly, iron supplementation was not significantly associated with Hb concentration among pregnant

women. Iron supplementation improves Hb concentration considerably if duration of use exceeds 90 d during pregnancy[45]. Unfortunately, adherence to iron supplementation tends to be poor. Ensuring that pregnant women commence antenatal care early in the first trimester, receive or buy iron supplements regularly, and use them for > 90 d may be helpful for maximum impact[17,45]. Patient education may be associated with successful adoption of better complementary feeding practices[46].

The impact of infections on the occurrence of anaemia in developing country settings is well-documented[4]. Among children, besides clinical diarrhoea, gut inflammation from parasitic infestations such as hookworm and schistosomiasis, as well as subclinical microbial infections, are important in this regard. We observed that certain sources of drinking water and the use of unsanitary toilet facilities were associated with lower Hb concentration among children in these surveys. From our analysis, a male infant who drinks water from a well and uses unsanitary toilet facilities may have a 3 g/l lower Hb concentration on average compared to his counterparts from the same country. Severe malaria infection in children also frequently leads to severe anaemia, with a high risk of mortality if not properly treated. Owning a bed-net was associated with a higher Hb concentration among children in these surveys. Efforts to eradicate malaria, and to improve access to safe drinking water and sanitary facilities will likely have tremendous impact on anaemia risk among children in Africa.

Nutritional status significantly predicted Hb concentration among pregnant women, adolescents, and children. Stunting and wasting frequently co-occur with anaemia in the context of poor socioeconomic condition and endemic infections[4]. In fact, the relationship of
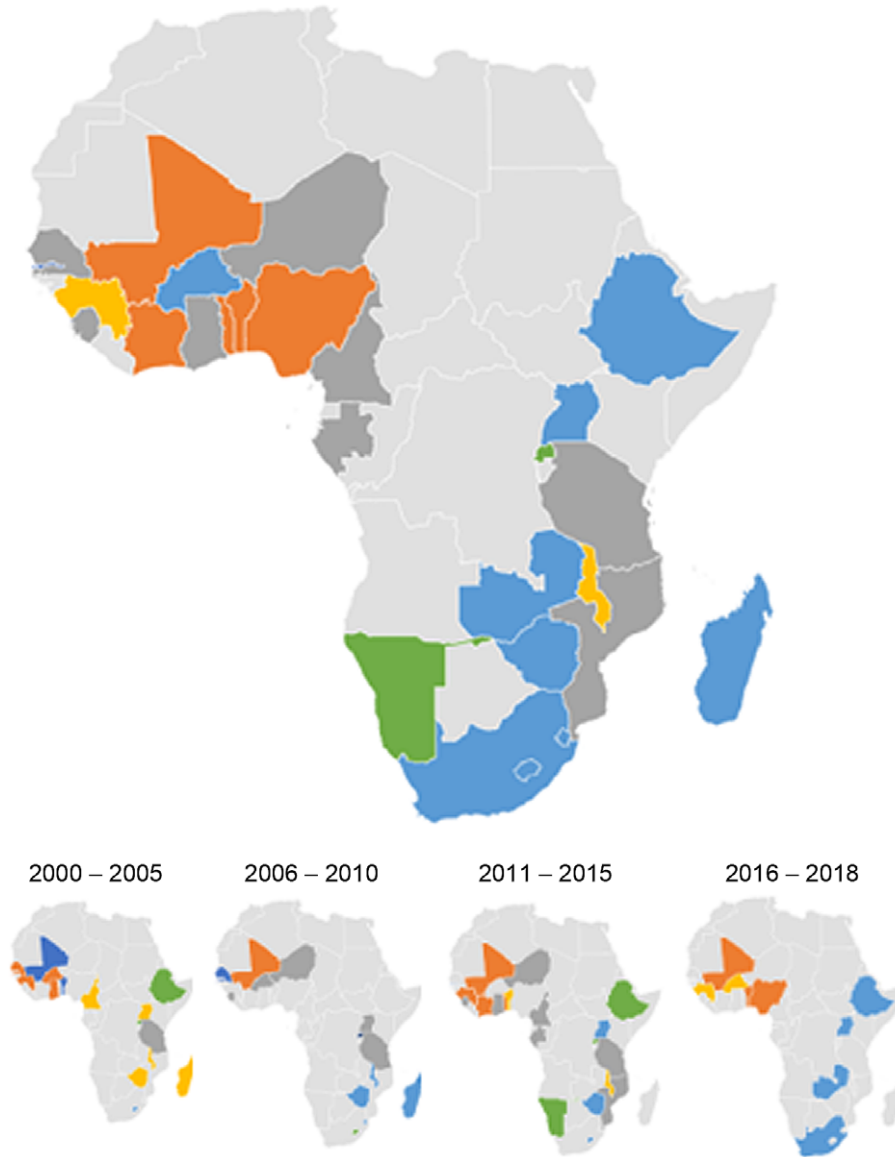
Fig. 5 (colour online) Map of Africa showing average Hb among pregnant women in sub-Saharan African countries, overall and across 5-year intervals. ■, 21–30; ■, 31–40; ■, 41–50; ■, 51–60; ■, 61–70; ■, 71 and above

undernutrition and anaemia is likely causal. Like anaemia, stunting is also known to be related to poor cognitive development[47]. Stunting and wasting remain very common among children in SSA, and account for 15 and 13 % of total deaths of children < 5 years globally[48]. Overweight was associated with increased occurrence of anaemia, potentially signalling the impact of poor quality energy-dense diets on anaemia risk in the context of global nutrition transition. Well-designed nutritional approaches leading to intake of high quality diverse diets would likely prevent all these conditions simultaneously and effectively. For instance, a combined homestead food production and behaviour change communication program in Burkina Faso led to marginally significant reduction in Hb

concentration and wasting[49]. Notably, we found that Hb concentration was lower among adolescents and children in households with 2 or more children < 5 years, potentially due to competition for limited food resources[50,51]. Food insecurity is common in these settings due to rationing, making food-based interventions critical to consider.

We found that approximately 21 % of older adolescent girls in sub-Saharan African countries were anaemic in the period from 2016–2018. This has substantial implications for the cognitive function of the girls. Studies conducted among adolescent girls in Jamaica have shown that performance in school may be impaired by iron deficiency and anaemia[52,53]. Also, pregnancy was common among adolescents (7 %), and 16 % of all pregnant women were
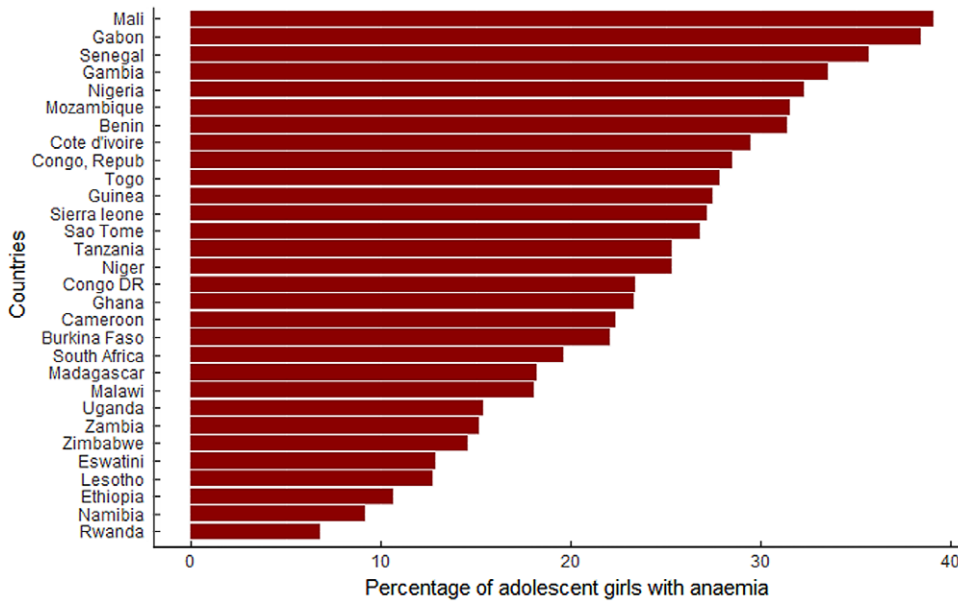
Fig. 6 (colour online) Percentage of adolescent girls (15–19 years) who are anaemic by country in sub-Saharan Africa in the most recent survey for each country

adolescents. Pregnant adolescents had a 14 g/l lower Hb concentration compared to non-pregnant ones in our analysis. Pregnancy may increase micronutrient demands due to fetal growth while also worsening irregular eating[6]. Pregnancy among adolescents may be associated with an increased risk of preterm births, low birth weight and obstetric complications[6]. In addition, women who become pregnant during adolescence are more likely to have large families, and their offspring are more likely to be stunted, perform poorly in school and have behavioural problems[54]. Programs that promote dietary diversity along with the delay of sexual debut and the uptake of contraception are therefore essential features of adolescent nutrition programs. Our analysis also makes a strong case that micronutrient supplementation programs aimed at ensuring adequate preconception nutrition should begin in late adolescence.

Our finding of relatively low anaemia prevalence in Rwanda is remarkable. This finding is likely to be a result of a combination of all the approaches discussed above – improving diet quality, control of malaria and helminth infections, and coverage for micronutrient supplementation. Use of insecticide treated nets and exclusive breast-feeding during the first six months are high in Rwanda. In addition, approximately 87 % of Rwandans have access to health insurance – typically through community based schemes[55]. Robust health financing and universal health coverage improves access to primary healthcare for the most vulnerable in the population considerably, and primary healthcare is an excellent vehicle for the sustainable delivery of nutritional and infection control interventions[56].

West Africa had the greatest prevalence of anaemia across all population groups – but the greatest disparity was among children. First, feeding practices are likely the key factors driving this regional disparity. Exclusive breast-feeding rates are extremely low in West Africa. Less than 20 % of infants < 6 months in most West African communities were exclusively breastfed between 2000 and 2017, compared with > 50 % in East Africa[57,58]. Data on intake of iron-rich foods among children were not available for most of the surveys. Second, the incidence of malaria was higher in certain West African countries such as Burkina Faso and Cote d'ivoire than in most of East Africa during the period between 2000 and 2017, though the overall burden is trending lower. Coverage for bed-net use and antimalaria treatment tends to be lower in West Africa[59].

Our study was limited by the irregularity in the conduct of the DHS surveys and Hb testing. The generalisability of the findings of this study may be limited to African countries south of the Sahara. We were also limited by the type of variables available from the DHS surveys and were unable to examine some of the very important causes of anaemia. For instance, in most surveys, malaria testing was restricted to individuals for whom a febrile illness was suspected. HIV testing was also done in a subset of participants. We also did not examine population-level factors that may be related to the prevalence of anaemia such as coverage for antiretroviral therapy.

There are noteworthy strengths of this analysis. First, by using individual-level data, this analysis avoids the limits of population-level interpretation that bedevil
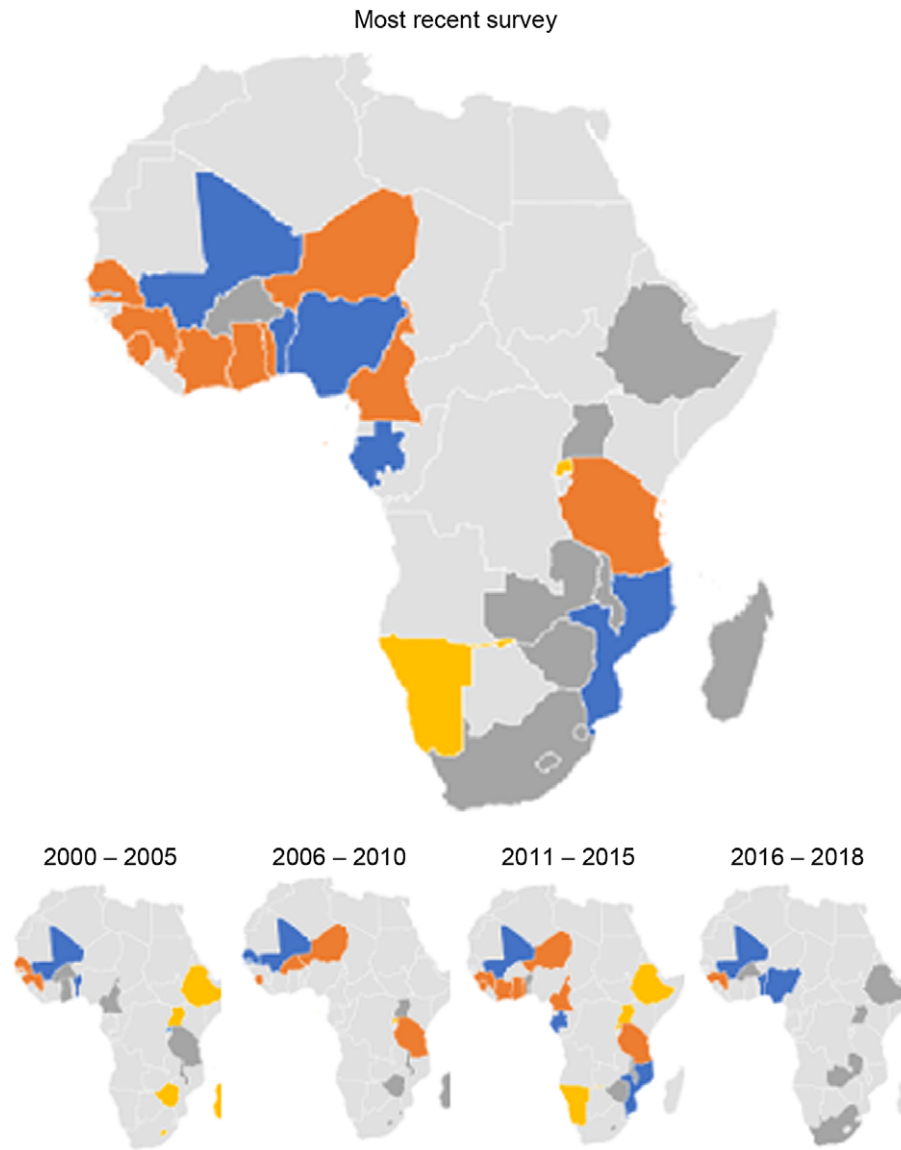
Fig. 7 (colour online) Map of Africa showing average Hb among older adolescent girls in sub-Saharan African countries, overall and across 5-year intervals. ■, 5–10; ■, 11–20; ■, 21–30; ■, 31–40

ecological studies. Second, Hb testing was based on the same well-standardised method, limiting any potential bias due to outcome ascertainment across countries or regions, or over time.

Our manuscript has important policy implications. First, anaemia continues to be an important public health problem in all countries of SSA, among population groups considered – with the highest burden in West Africa. Concerted action to address this challenge is particularly important. Second, the burden of anaemia in children, especially among infants and toddlers, is particularly high, suggesting a need to deploy interventions targeted at this age group. Third, stunting and wasting can be important indices for selecting children for targeted interventions. Fourth, providing access to pipe-borne water and safe toilet facilities has the potential to reduce anaemia prevalence in many communities considerably. Fifth, adolescent anaemia may be considerably addressed by preventing adolescent pregnancy through abstinence and contraception programme and delaying marriage beyond the teenage years. Finally, strategies for integrating micronutrient supplementation into primary healthcare and improving adherence need to implemented more effectively[60–62].

Conclusion

The burden of anaemia in SSA has not improved materially over the past two decades, although there is substantial variability in the prevalence and trajectory among the different countries. Access to improved water, sanitation and hygiene

Table 2 Regression models to predict Hb concentration*

	Pregnant women (n 33 984)			Adolescent girls (n 83 122)			Children (n 397 577)		
	n %	Diff	SE	n %	Diff	SE	n %	Diff	SE
Age, years									
< 1							14	Ref	
1–< 3							45	1·22	0·09§
3–< 5							41	7·70	0·09§
15–< 18				61	−0·60	0·40			
18–< 20				39	Ref				
15–< 20	16	Ref							
20–< 30	51	1·66	0·50§						
30–< 40	29	1·76	0·58‡						
40–< 49	5	2·46	0·78‡						
Sex									
Male							50	−1·01	0·06§
Gestational age, months									
< 4	26	Ref							
4–< 7	40	−6·46	0·29§						
≥ 7	34	−7·19	0·30§						
Household head									
Yes	9	−1·03	0·40†						
Wealth index									
Lowest	23	Ref		18	Ref		26	Ref	
Low	22	0·02	0·34	18	−0·15	0·53	22	0·68	0·10§
Mid	20	0·60	0·37	19	−0·07	0·57	20	1·32	0·11§
High	19	0·99	0·40†	20	0·91	0·63	18	2·08	0·12§
Highest	16	1·25	0·51†	26	2·86	0·83§	15	3·79	0·16§
Educational attainment									
None	40	Ref		18	Ref				
Primary	37	1·30	0·31§	40	1·14	0·51†			
Secondary	21	0·58	0·42	41	0·72	0·61			
Higher	2	5·78	1·06§	1	15·2	9·06			
Number of children < 5 years in household									
0 or 1				70	Ref		29	Ref	
2 or 3				18	−0·98	0·44†	40	−0·36	0·08§
> 3				12	−1·11	0·49†	31	−0·89	0·09§
Parity									
1–2		Ref							
3–4		0·11	0·30						
> 4		−0·35	0·40						
Pregnant									
Yes				7	−12·46	0·59§			
Place of residence									
Rural							74	−0·89	0·13
Toilet or sanitary facilities									
Flush	8	Ref					9	Ref	
Pit	60	0·05	0·58				54	−0·16	0·13
Other/unsanitary	32	−1·21	0·64				37	−1·13	0·15§
Source of drinking water									
Piped							25	Ref	
Borehole							20	−0·50	0·13§
Well							26	−0·42	0·12§
Surface/rain							25	−0·11	0·13
Water tanker							1	−0·49	0·35
Bottled water							3	1·26	0·29§
BMI z-score									
Underweight, < −2				13	0·31	0·53			
Normal weight, −2 to < 1				78	Ref				
Overweight, > 1 to ≤ 2				8	−2·43	0·99			
Obese, > 2				1	0·44	4·80			
Stunting									
HAZ < −2, stunted							37	−3·33	0·07
Wasting									
WHZ ≥ −2, no wasting							92	Ref	
WHZ −2 to < −3, moderate wasting							5	−1·33	0·14§
WHZ ≤ −3, severe acute malnutrition							3	−2·13	0·18§
Malaria control									
Has bednet	64	−0·40	0·28	62	−1·24	0·43‡	72	0·24	0·08§

Table 2 Continued

	Pregnant women (n 33 984)			Adolescent girls (n 83 122)			Children (n 397 577)		
	n %	Diff	SE	n %	Diff	SE	n %	Diff	SE
Cooking fuel									
Electricity and gas				9	Ref		6	Ref	
Kerosene				1	9·09§	2·23	1	−0·50	0·13
Coal and charcoal				32	0·90	1·18	27	−0·17	0·16
Wood, animal or plant residue				58	2·04	1·17	66	−0·09	0·18
No food cooked in home				0·1	2·88	6·27	0·01	−0·50	1·54
Antenatal visits									
None	15	−0·43	0·47						
1–3	39	Ref							
4–10	44	0·58	0·27†						
> 10	2	−0·53	0·89						
Iron									
Yes	67	0·17	0·32	71	−0·13	0·44			

*Linear mixed effects regression models were estimated to predict Hb concentration, in g/l. P-values were denoted with asterisks as follows
†< 0.05.
‡< 0.01.
§< 0.001.

services, ante-natal care attendance and socio-economic status are key determinants of spatiotemporal variation of anaemia in SSA, important to different extents in the key population groups. These factors should be the focus of evidence-based interventions.

Acknowledgements

Supplementary material

For supplementary material accompanying this paper visit https://doi.org/10.1017/S1368980020004620

References

1. Kassebaum NJ, Jasrasaria R, Naghavi M et al. (2014) A systematic analysis of global anemia burden from 1990 to 2010. *Blood* **123**, 615–624.
2. Balarajan Y, Ramakrishnan U, Özaltin E et al. (2011) Anaemia in low-income and middle-income countries. *Lancet* **378**, 2123–2135.
3. Semedo RML, Santos MMAS, Baião MR et al. (2014) Prevalence of anaemia and associated factors among children below five years of age in Cape Verde, West Africa. *J Health Popul Nutr* **32**, 646–657.
4. Lynch S, Pfeiffer CM, Georgieff MK et al. (2018) Biomarkers of nutrition for development (BOND)-Iron review. *J Nutr* **148**, 1001s–1067s.
5. Georgieff MK (2011) Long-term brain and behavioral consequences of early iron deficiency. *Nutr Rev* **69**, S43–S48.
6. Delisle H, Chandra-Mouli V & de Benoist B (2001) Should adolescents be specifically targeted for nutrition in developing countries? To address which problems, and how. *Bull World Health Organ* 1–26. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.600.999&rep=rep1&type=pdf (accessed December 2020).
7. Sazawal S, Black RE, Ramsan M et al. (2006) Effects of routine prophylactic supplementation with iron and folic acid on admission to hospital and mortality in preschool children in a high malaria transmission setting: community-based, randomised, placebo-controlled trial. *Lancet* **367**, 133–143.
8. Jaeggi T, Kortman GA, Moretti D et al. (2015) Iron fortification adversely affects the gut microbiome, increases pathogen abundance and induces intestinal inflammation in Kenyan infants. *Gut* **64**, 731–742.
9. Beard JL, Hendricks MK, Perez EM et al. (2005) Maternal iron deficiency anemia affects postpartum emotions and cognition. *J Nutr* **135**, 267–272.
10. Brabin BJ, Hakimi M & Pelletier D (2001) An analysis of anemia and pregnancy-related maternal mortality. *J Nutr* **131**, 604S–615S.
11. Stoltzfus RJ, Chway HM, Montresor A et al. (2004) Low dose daily iron supplementation improves iron status and appetite but not anemia, whereas quarterly anthelminthic treatment improves growth, appetite and anemia in Zanzibari preschool children. *J Nutr* **134**, 348–356.
12. Van Thuy P, Berger J, Davidsson L et al. (2003) Regular consumption of NaFeEDTA-fortified fish sauce improves iron status and reduces the prevalence of anemia in anemic Vietnamese women. *Am J Clin Nutr* **78**, 284–290.
13. Brabin BJ, Premji Z & Verhoeff F (2001) An analysis of anemia and child mortality. *J Nutr* **131**, 636S–648S.
14. Stevens GA, Finucane MM, De-Regil LM et al. (2013) 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* **1**, e16–e25.
15. Prieto-Patron A, Van der Horst K, Hutton Z et al. (2018) Association between anaemia in children 6 to 23 months

old and child, mother, household and feeding indicators. *Nutrients* **10**, 1269.

16. Sudfeld CR & Fawzi WW (2017) Importance of innovations in neonatal and adolescent health in reaching the sustainable development goals by 2030. *JAMA Pediatr* **171**, 521–522.

17. Haddad L, Achadi E, Bendech MA *et al.* (2015) The Global Nutrition Report 2014: actions and accountability to accelerate the world's progress on nutrition. *J Nutr* **145**, 663–671.

18. Kamau MW, Mirie W & Kimani S (2018) Compliance with Iron and folic acid supplementation (IFAS) and associated factors among pregnant women: results from a cross-sectional study in Kiambu County, Kenya. *BMC Public Health* **18**, 1–10.

19. Griffin JT, Bhatt S, Sinka ME *et al.* (2016) Potential for reduction of burden and local elimination of malaria by reducing Plasmodium falciparum malaria transmission: a mathematical modelling study. *Lancet Infect Dis* **16**, 465–472.

20. Yan I, Bendavid E & Korenromp EL (2016) Antiretroviral treatment scale-up and tuberculosis mortality in high TB/HIV burden countries: an econometric analysis. *PLoS One* **11**, e0160481.

21. Zimbabwe National Statistics Agency & ICF International (2016) *Zimbabwe Demographic and Health Survey 2015: Final Report*. Rockville, Maryland: Zimbabwe National Statistics Agency (ZIMSTAT) and ICF International.

22. Central Statistical Office/Zimbabwe & Macro International (2007) *Zimbabwe Demographic and Health Survey 2005–06*. Calverton, Maryland: Central Statistical Office/Zimbabwe and Macro International.

23. United Nations Statistics Division (2013) Standard country or area codes for statistical use (M49). Methodology. https://unstats.un.org/unsd/methodology/m49/ (accessed November 2020).

24. Corsi DJ, Neuman M, Finlay JE *et al.* (2012) Demographic and health surveys: a profile. *Int J Epidemiol* **41**, 1602–1613.

25. Sullivan KM, Mei Z, Grummer-Strawn L *et al.* (2008) Haemoglobin adjustments to define anaemia. *Trop Med Int Health* **13**, 1267–1271.

26. DHS Program How does DHS collect data on anemia? The Demographic and Health Surveys (DHS). https://dhsprogram.com/topics/Anemia.cfm#:~:text=How%20does%20DHS%20collect%20data,HemoCue%20blood%20hemoglobin%20testing%20system (accessed July 2020).

27. World Health Organization (WHO) (2011) *Haemoglobin Concentration for the Diagnosis of Anaemia and Assessment of Severity. Vitamin and Mineral Nutrition Information System*. Geneva: WHO.

28. International MDI (2013) DHS Methodology Toolkit. https://dhsprogram.com/pubs/pdf/MR18/MR18.pdf (accessed October 2020).

29. Hosmer DW, Lemeshow S & Sturdivant RX (2013) *Applied Logistic Regression*. John Wiley & Sons.

30. Nankinga O & Aguta D (2019) Determinants of anemia among women in Uganda: further analysis of the Uganda demographic and health surveys. *BMC Public Health* **19**, 1757.

31. Ncogo P, Romay-Barja M, Benito A *et al.* (2017) Prevalence of anemia and associated factors in children living in urban and rural settings from Bata District, Equatorial Guinea, 2013. *PLoS One* **12**, e0176613.

32. Adamu AL, Crampin A, Kayuni N *et al.* (2017) Prevalence and risk factors for anemia severity and type in Malawian men and women: urban and rural differences. *Popul Health Metr* **15**, 12.

33. Kawo KN, Asfaw ZG & Yohannes N (2018) Multilevel analysis of determinants of anemia prevalence among children aged 6–59 months in Ethiopia: classical and Bayesian approaches. *Anemia* **2018**, 3087354.

34. Sumbele IU, Nkemnji GB & Kimbi HK (2017) Soil-transmitted helminths and plasmodium falciparum malaria among

individuals living in different agroecosystems in two rural communities in the mount Cameroon area: a cross-sectional study. *Infect Dis Poverty* **6**, 67.

35. Loha E, Deressa W, Gari T *et al.* (2019) Long-lasting insecticidal nets and indoor residual spraying may not be sufficient to eliminate malaria in a low malaria incidence area: results from a cluster randomized controlled trial in Ethiopia. *Malar J* **18**, 141.

36. Kothari MT, Coile A, Huestis A *et al.* (2019) Exploring associations between water, sanitation, and anemia through 47 nationally representative demographic and health surveys. *Ann NY Acad Sci* **1450**, 249–267.

37. Machisa M, Wichmann J & Nyasulu PS (2013) Biomass fuel use for household cooking in Swaziland: is there an association with anaemia and stunting in children aged 6–36 months? *Trans Royal Soc Trop Med Hyg* **107**, 535–544.

38. Derso T, Abera Z & Tariku A (2017) Magnitude and associated factors of anemia among pregnant women in Dera District: a cross-sectional study in northwest Ethiopia. *BMC Res Notes* **10**, 359.

39. Ikeanyi EM & Ibrahim AI (2015) Does antenatal care attendance prevent anemia in pregnancy at term? *Niger J Clin Pract* **18**, 323–327.

40. Woodruff BA, Wirth JP, Ngnie-Teta I *et al.* (2018) Determinants of stunting, wasting, and anemia in guinean preschool-age children: an analysis of DHS data from 1999, 2005, and 2012. *Food Nutr Bull* **39**, 39–53.

41. De Onis M, Onyango AW, Borghi E *et al.* (2006) Comparison of the World Health Organization (WHO) Child Growth Standards and the National Center for Health Statistics/WHO international growth reference: implications for child health programmes. *Public Health Nutr* **9**, 942–947.

42. Bates D, Maechler M, Bolker B *et al.* (2018) Package 'lme4'. Version **1**, 17.

43. Guevarra E zscorer v0. 3.1. https://zenodo.org/record/3510075#.X8FTFGhKg2w28 (accessed October 2020).

44. Hamdan M, Brabin B & Bates I (2014) Implications of inconsistent anaemia policies for children and adolescents in Africa. *Public Health Nutr* **17**, 2587–2594.

45. Abioye AI, Aboud S, Premji Z *et al.* (2016) Iron Supplementation affects hematologic biomarker concentrations and pregnancy outcomes among iron deficient Tanzanian women. *J Nutr* **146**, 1162–1171.

46. Arikpo D, Edet ES, Chibuzor MT *et al.* (2018) Educational interventions for improving primary caregiver complementary feeding practices for children aged 24 months and under. *Cochrane Database Systematic Rev* **5**, Cd011768.

47. Estrada JA, Contreras I, Pliego-Rivero FB *et al.* (2014) Molecular mechanisms of cognitive impairment in iron deficiency: alterations in brain-derived neurotrophic factor expression and function in the central nervous system. *Nutr Neurosci* **17**, 193–206.

48. Black RE, Victora CG, Walker SP *et al.* (2013) Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet* **382**, 427–451.

49. Olney DK, Pedehombga A, Ruel MT *et al.* (2015) 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* **145**, 1317–1324.

50. Dush JL (2020) Adolescent food insecurity: a review of contextual and behavioral factors. *Public Health Nurs* **37**, 327–338.

51. Bomela N (2007) Child nutritional status and household patterns in South Africa. *Afr J Food Agric Nutr Dev* **7**(5). https://www.ajol.info/index.php/ajfand/article/view/136156#:~:text=About%2025%25%20of%20all%20children,South%20Africa%20are%20severely%20malnourished.&text=Chronic%20malnutrition%20and%20underweight%20were,

among%20children%20from%20maleheaded%20house holds (accessed December 2020).

52. Walker SP, Grantham-McGregor S, Himes JH *et al.* (1996) Adolescent Kingston girls' school achievement: nutrition, health and social factors. *Proc Nutr Soc* **55**, 333–343.

53. Walker SP, Grantham-McGregor SM, Himes JH *et al.* (1998) School performance in adolescent Jamaican girls: associations with health, social and behavioural characteristics, and risk factors for dropout. *J Adolescence* **21**, 109–122.

54. Buvinic M (1998) The costs of adolescent childbearing: evidence from Chile, Barbados, Guatemala, and Mexico. *Stud Fam Plann* **29**(2), 201–209.

55. Chemouni B (2018) The political path to universal health coverage: power, ideas and community-based health insurance in Rwanda. *World Dev* **106**, 87–98.

56. Bitton A, Ratcliffe HL, Veillard JH *et al.* (2017) Primary health care as a foundation for strengthening health systems in low- and middle-income countries. *J Gen Intern Med* **32**, 566–571.

57. Bhattacharjee NV, Schaeffer LE, Marczak LB *et al.* (2019) Mapping exclusive breastfeeding in Africa between 2000 and 2017. *Nat Med* **25**, 1205–1212.

58. Agho KE, Ezeh OK, Ghimire PR *et al.* (2019) Exclusive breastfeeding rates and associated factors in 13 "Economic Community of West African States" (ECOWAS) countries. *Nutrients* **11**, 3007.

59. Gething PW, Casey DC, Weiss DJ *et al.* (2016) Mapping plasmodium falciparum mortality in Africa between 1990 and 2015. *N Engl J Med* **375**, 2435–2445.

60. Omotayo M (2016) Integrating Strategies for Prevention of Pre-Eclampsia and anemia in Pregnancy into Primary Healthcare Delivery in Kenya. https://oatd.org/oatd/record?record=%22handle%5C%3A1813%2F45282%22 (accessed October 2020).

61. Omotayo MO, Dickin KL, Pelletier DL *et al.* (2018) Feasibility of integrating calcium and iron–folate supplementation to prevent preeclampsia and anemia in pregnancy in primary healthcare facilities in Kenya. *Maternal Child Nutr* **14**, e12437.

62. Omotayo MO, Martin SL, Stoltzfus RJ *et al.* (2018) With adaptation, the WHO guidelines on calcium supplementation for prevention of pre-eclampsia are adopted by pregnant women. *Matern Child Nutr* **14**, e12521.