Spatial heterogeneity of haemoglobin concentration in preschool-age children in sub-Saharan Africa

Ricardo J Soares Magalhães[a] & Archie CA Clements[a]

Objective To determine whether blood haemoglobin concentration in preschool-age children (< 5 years of age) is geographically heterogeneous in sub-Saharan Africa and describe its association with environmental variables that drive anaemia of different etiologies.
Methods Data were obtained on 24 277 preschool-age children in western Africa (2862 cluster sites) and 25 343 in eastern Africa (2999 cluster sites) from the 2001–2007 *Demographic and Health Surveys* (DHS) for sub-Saharan Africa. Cluster sites were linked to environmental information on distance to perennial water body, elevation, land surface temperature and normalized difference vegetation index (NDVI; a proxy for rainfall) in a geographical information system. Statistical associations with environmental variables were determined using multivariate regression models, and the spatial dependence of haemoglobin concentration unexplained by these factors was quantified using semivariograms.
Findings In eastern Africa, the lowest haemoglobin concentrations (< 70 g/l) occurred in small clusters throughout the region; in western Africa, they occurred in a large cluster straddling the border between Burkina Faso and Mali. Our results show significant continent-wide associations between haemoglobin concentration and environmental variables, particularly in western Africa for land surface temperature and NDVI, and in eastern Africa for elevation. Residual spatial dependence was significant, and the magnitude was greater in western than in eastern Africa.
Conclusion The distribution of anaemia is driven by large-scale environmental factors, and the epidemiological drivers differ in western and eastern Africa. Strategies for anaemia control in preschool-age children in sub-Saharan Africa should be tailored to local conditions, taking into account the specific etiology and prevalence of anaemia.

Abstracts in عربي, 中文, Français, Русский and Español at the end of each article.

Introduction

Over the past five decades many attempts have been made to reduce the burden of anaemia in vulnerable groups, particularly children less than 5 years of age and pregnant women.[1–3] Based on recent estimates from the World Health Organization (WHO),[3] the prevalence of anaemia is 24.8% globally and the highest rates are found in preschool-age children (67.6%) and pregnant women (57.1%) in sub-Saharan Africa. Anaemia is a major public health problem in preschool-age children because it is associated with an increased risk of death and impaired cognitive development,[4,5] growth[6] and immune function.[7]

About 50% of all anaemia cases are due to iron deficiency.[8] Other major contributors include malaria; infection with human immunodeficiency virus (HIV) and with bacteraemia-causing organisms (e.g. *Steptococcus pneumoniae*, non-typhi *Salmonella* species and *Haemophilus influenzae* type b); neglected tropical diseases (especially those caused by *Schistosoma haematobium* – the cause of urinary schistosomiasis – hookworm and, to a lesser extent, *Trichuris trichiura* and *Schistosoma mansoni*), and inherited haemoglobinopathies and thalassemias.[1,9–18]

Currently, the planning of resources required for anaemia control is based on prevalence data from field surveys within a country, which are then extrapolated to the country as a whole.[3] However, efficient allocation of health interventions to control anaemia may require more targeted approaches based on information on the geographical distribution of high-risk communities and on an understanding of the relative contribution of major causes of anaemia.[8] Geographical differences in the causes of anaemia can be partially explained by large-scale variability in environmental drivers, particularly nutritional and infectious causes. The risk of malaria is known to be associated with elevation and land surface temperature.[19] Similarly, nutritional iron deficiency[20] and anaemia-causing helminthic infections[21] are known to be associated with the distance to a perennial water body, land surface temperature and the normalized difference vegetation index (NDVI) – a number derived by remote sensing that indicates the amount of land vegetation and that stands as a proxy for rainfall. Environmental drivers of anaemia tend to show a high degree of spatial dependence (i.e. geographical clustering).[22–24] We therefore hypothesized that the burden of anaemia and perhaps major contributors to anaemia vary geographically, even within high-burden African regions.

In anaemia control, the use of national prevalence estimates of anaemia in the presence of subnational variability is likely to hamper the efficient delivery of control programmes. For control policies to be cost-effective, the geographical variability of anaemia must be quantified. Maps showing geographical variation in anaemia would also be useful in the control of parasitic infections that are highly endemic in sub-Saharan Africa. The prevalence of anaemia has been used as a measurable indicator for evaluating control programmes for malaria, schistosomiasis and soil-transmitted helminthiasis because interventions for these infections aim at controlling morbidity. In highly endemic populations, micronutrients are being distributed as part of parasite control programmes to reduce the burden of anaemia.[2,25–31]

We have used data collected and georeferenced by the *Demographic and Health Surveys* (DHS), together with high-resolution continental maps of selected environmental variables,

[a] School of Population Health, University of Queensland, Herston Road, Herston, Qld., 4006, Australia.
Correspondence to Ricardo J Soares Magalhães (e-mail: r.magalhaes@sph.uq.edu.au).
(*Submitted: 12 October 2010 – Revised version received: 23 March 2011 – Accepted: 24 March 2011*)

to demonstrate geographical clustering in mean blood haemoglobin concentration (a measure of anaemia) in sub-Saharan Africa. Our aim was to quantify the spatial dependence of blood haemoglobin concentration over and above what is accounted for by environmental variables known to contribute to nutritional iron deficiency and infectious causes of anaemia. We also sought to determine the extent to which haemoglobin concentration is associated with these drivers (and whether this differs in different regions of Africa) and to build the foundations of a spatial decision-support tool to inform decision-makers about the most efficient approaches to geographical targeting of interventions for the prevention and control of anaemia.

Methods

Data sources

We searched data from nationally representative household-level DHS programmes for all countries in sub-Saharan Africa.[32] Data for the countries included in the study include remotely-sensed environmental data on distance to perennial water body, elevation, land surface temperature and NDVI (all data available from corresponding author).[7]

Measuring anaemia

The MEASURE DHS Project[32] tests women (15–49 years of age) and children (usually 6 months to 5 years of age) for anaemia. It involves obtaining a capillary blood sample using finger prick or, in the case of young children, a heel prick, and then using the HemoCue® (HemoCue AB, Ängelholm, Sweden) blood haemoglobin testing system.[33] Testing is voluntary and respondents receive the results of their test immediately, along with information about how to prevent anaemia. To determine the level of geographical clustering of blood haemoglobin concentration, we used altitude-adjusted haemoglobin concentration values in children < 5 years of age (data available from corresponding author).

Geopositioning

The geopositioning methods used by MEASURE DHS[32] include the identification of all households in enumeration areas or clusters.[34] The information assembled in the current database provides geographical coverage of 35% of administrative areas in sub-Saharan Africa. Coverage was good in western Africa (45% of administrative areas, corresponding to 65% of total area) and eastern Africa (45% of administrative areas, corresponding to 81% of total area). For large areas of central and southern Africa, the only data were from Cameroon and the Democratic Republic of the Congo in central Africa, and Lesotho and Swaziland in southern Africa (data available from corresponding author). Therefore, for analysis, the survey results from Cameroon were included in the western African region and the results from the Democratic Republic of the Congo, Lesotho and Swaziland were included in the eastern African region.

Environmental properties

Relationships between haemoglobin concentration and the environmental variables at each cluster site were investigated using locally-weighted least squares smoothing curves with the gplot package of the R software (R Foundation for Statistical Computing, Vienna, Austria) (data available from corresponding author).[35] Statistical associations between haemoglobin concentration measurements at each cluster site and the environmental variables distance to a perennial water body, elevation, land surface temperature and NDVI were tested using fixed-effects multivariable linear regression models in Stata version 11 (StataCorp. LP, College Station, United States of America).

Analysis of clustering

The extent of geographical clustering in haemoglobin data can be quantified using a semivariogram.[36] This is a plot of the semivariance of all pairs of locations at a series of defined separating distances. It can be characterized by the semivariance due to spatial structure (sill or spatially structured variance, which represents the tendency for geographical clustering), the spatially unstructured semivariance (nugget, which represents natural random variation, very small-scale spatial variability or measurement error) and the distance at which locations can be considered independent (range, which represents the size of geographical clusters).[36] Semivariograms are particularly important in the assessment of spatial variation of spatial point data because they allow for the quantification of the cluster size, the tendency for geographical clustering within a region and the relative contribution for clustering that is explained by a particular modifiable factor.

To investigate geographical clustering in blood haemoglobin concentration measurements, we used empirical semivariograms of the raw haemoglobin data and the residuals of multivariable models, using the geoR package of the R software.[35] The proportion of spatially structured variance in the raw haemoglobin concentration data that is accounted for by environmental covariates was estimated by dividing the partial sill of multivariable models by the partial sill of the raw data; this estimate indicates how well geographical clustering of anaemia is explained by environmental covariates. The proportion of variance that is spatially structured was estimated by dividing the partial sill by the sum of the partial sill and nugget; this measure indicates the role of location in explaining variation in haemoglobin concentration in regions of sub-Saharan Africa.

Results

Haemoglobin concentrations

We included data from 2862 cluster sites in western Africa and 2999 cluster sites in eastern Africa. This included 24 277 children < 5 years of age in western Africa and 25 343 in eastern Africa. Most children (76%) were residing in rural areas and both sexes were equally represented. In both regions, haemoglobin declined towards the end of the first year of life and then increased towards 5 years of age (data available from corresponding author). The mean haemoglobin concentration was significantly lower in western than in eastern Africa (Table 1) and the geographical distribution varied between regions (Fig. 1 and Fig. 2). In western Africa, the geographical distribution of severe anaemia (haemoglobin < 70 g/l) was heterogeneous and was present in a large cluster straddling the border between Burkina Faso and Mali. In eastern Africa, haemoglobin was homogenously low (100–110 g/l) to moderate (70–100 g/l) across the region, and haemoglobin concentrations < 70 g/l were localized in small clusters. The proportion of children with haemoglobin < 110 g/l was highest in western Africa (Table 1). All countries in sub-Saharan Africa had a prevalence of anaemia > 40% (data available from corresponding author); the lowest prevalence was in Swaziland (42%) and the highest was in Burkina Faso (91%).

Table 1. **Blood haemoglobin concentration in 49 620 preschool-age children less than 5 years of age in sub-Saharan Africa, stratified by gender, severity of anaemia and region**

Anaemia severity by region	Males[a]	Females[a]	Total[a]
Western Africa[b]	12 382 (51)	11 895 (49)	24 277
Severe (Hb < 70 g/l)	962 (8)	813 (7)	1 775 (7)
Moderate (Hb 70–99 g/l)	6 202 (50)	5 719 (48)	11 921 (49)
Mild (Hb 100–109 g/l)	2 603 (21)	2 579 (22)	5 182 (21)
No anaemia (Hb ≥ 110 g/l)	2 615 (21)	2 784 (23)	5 399 (22)
Mean haemoglobin, g/l (95% CI)	95.60 (94.47 to 97.12)	96.93 (95.14 to 97.84)	–
Eastern Africa[c]	12 687 (50)	12 656 (50)	25 343
Severe (Hb < 70 g/l)	486 (4)	440 (4)	926 (4)
Moderate (Hb > 70–99 g/l)	4 574 (36)	4 228 (33)	8 802 (34)
Mild (Hb > 100–109 g/l)	3 046 (24)	3 091 (24)	6 137 (24)
No anaemia (Hb ≥ 110 g/l)	4 581 (36)	4 897 (39)	9 478 (37)
Mean haemoglobin, g/l (95% CI)	102.76 (101.13 to 104.21)	103.84 (101.86 to 104.94)	–

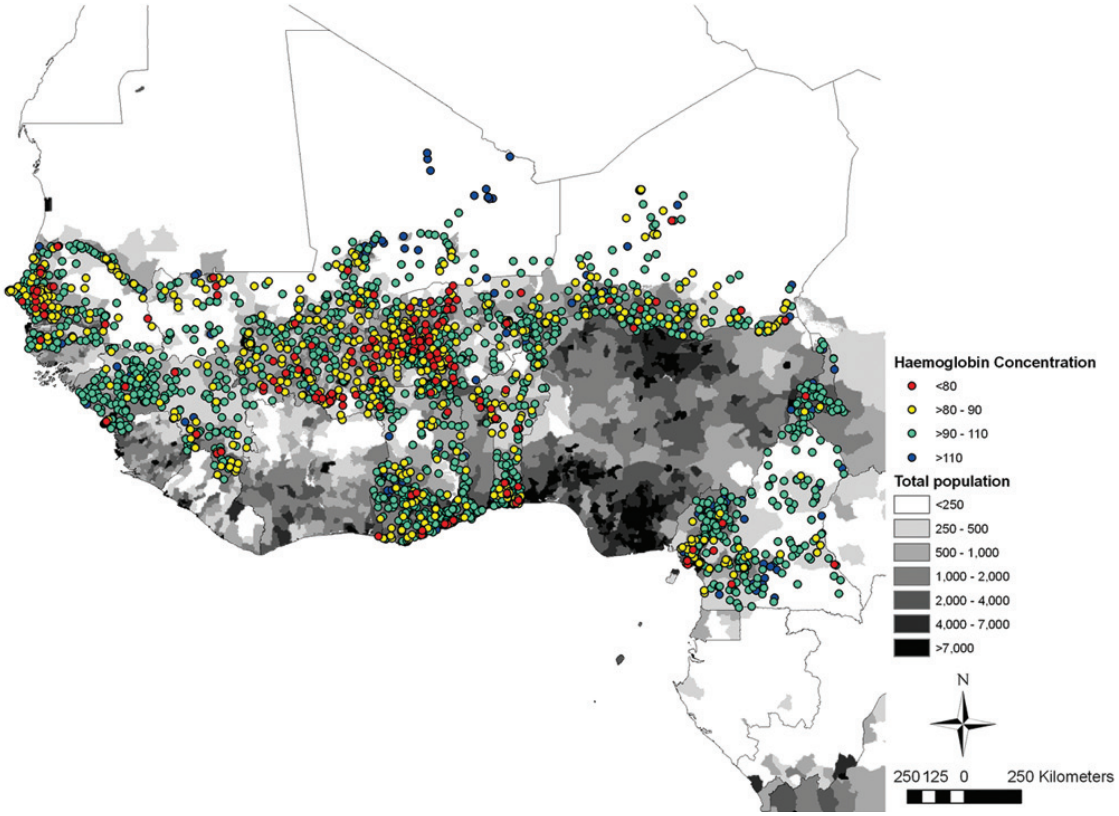
CI, confidence interval; Hb, haemoglobin.

[a] Unless otherwise indicated, values represent the absolute number followed by the percentage within parentheses.

[b] Includes Cameroon.

[c] Includes the Democratic Republic of the Congo, Lesotho and Swaziland.

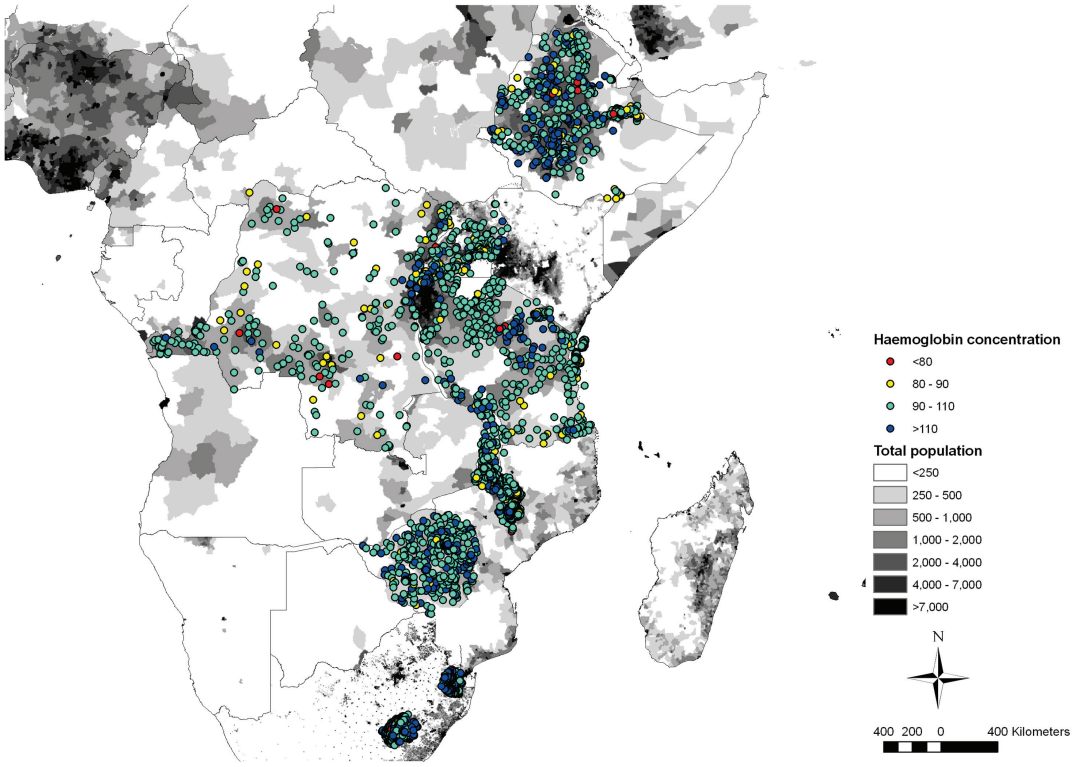
Fig. 1. **The spatial distribution of haemoglobin concentration for cluster sites included for western Africa[a]**



[a] Includes Cameroon.

Map produced using ArcGIS version 10 (ESRI, Redlands, CA, United States of America).

Fig. 2. **Spatial distribution of haemoglobin concentration for cluster sites included for eastern Africa[a]**



[a] Includes the Democratic Republic of the Congo, Lesotho and Swaziland.
Map produced using ArcGIS version 10 (ESRI, Redlands, CA, United States of America).

Environmental properties

Mean haemoglobin concentration in preschool-age children in both regions was negatively associated with land surface temperature and NDVI and positively associated with elevation (Table 2). However, the effect of distance to a perennial water body differed between western and eastern Africa, with mean haemoglobin concentration being negatively associated with it in western Africa and positively associated with it in eastern Africa.

Analysis of clustering

In the raw data on haemoglobin concentration, western Africa showed a greater tendency for geographical clustering (partial sill = 16.33) than eastern Africa (partial sill = 8.42). After taking into account the effect of environmental variables (residual variance), the tendency for clustering of mean haemoglobin values was more pronounced in western Africa than in eastern Africa (Fig. 3 and Fig. 4). Also, clusters of mean haemoglobin concentration were larger in western Africa than in eastern Africa (Fig. 3 and Fig. 4). Our results indicate that environmental variables could account for 13% and 27% of geographical clustering in western and eastern Africa, respectively. In eastern Africa, 100% of the residual variance

Table 2. **Association of environmental variables with blood haemoglobin concentration in children aged less than 5 years in western and eastern Africa**

Environmental variable	Western Africa[a]		Eastern Africa[b]	
	Coefficient (95%CI)	*P*	Coefficient (95%CI)	*P*
DPWB	–0.90 (–1.28 to –0.52)	< 0.001	0.56 (0.19 to 0.93)	0.003
Elevation	0.88 (0.50 to 1.27)	< 0.001	1.58 (1.10 to 2.07)	< 0.001
LST	–4.49 (–5.19 to –3.79)	< 0.001	–1.68 (–2.18 to –1.18)	< 0.001
NDVI	–2.43 (–3.12 to –1.75)	< 0.001	–0.74 (–1.22 to –0.26)	0.002
Intercept	96.90 (96.54 to 97.27)	< 0.001	103.99 (103.63 to 104.35)	< 0.001

CI, confidence interval; DPWB, distance to perennial water body; LST, land surface temperature; NDVI, normalized difference vegetation index.
[a] Includes Cameroon.
[b] Includes the Democratic Republic of the Congo, Lesotho and Swaziland.

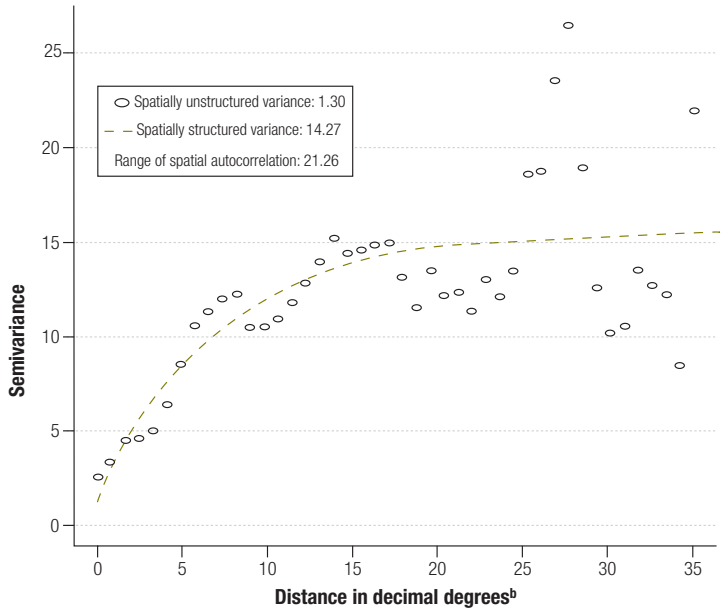
in haemoglobin concentration can be explained by location (i.e. the separating distance between cluster sites); in western Africa, only 91% of residual variance in haemoglobin concentration can be explained by location.

Discussion

The raw DHS data indicate that anaemia in preschool-age children is a severe public health problem in sub-Saharan Africa countries, with most national prevalence estimates exceeding 40% (data available from corresponding author). These statistics underline the failure of national programmes and interventions to reduce the burden of anaemia in young children. One reason for the lack of success is that anaemia-control interventions are designed on the assumption that nutritional iron deficiency is the major cause of anaemia.[1] In targeting communities with the highest prevalence of childhood anaemia within sub-Saharan Africa, it is useful to identify and geographically position anaemia-control resources, based on the relative importance of different anaemia contributors. Our approach addresses important operational constraints for anaemia control in the African continent by shedding new light on the distribution of anaemia severity within the countries studied. It also highlights the role of known environmental drivers of anaemia related to nutrition and infection, thus adding value to national-level summary statistics of the DHS data. We found considerable geographical variation in haemoglobin concentration in sub-Saharan Africa. Western Africa should receive priority, particularly those areas straddling the border between Burkina Faso and Mali, where most anaemia cases are moderate to severe.

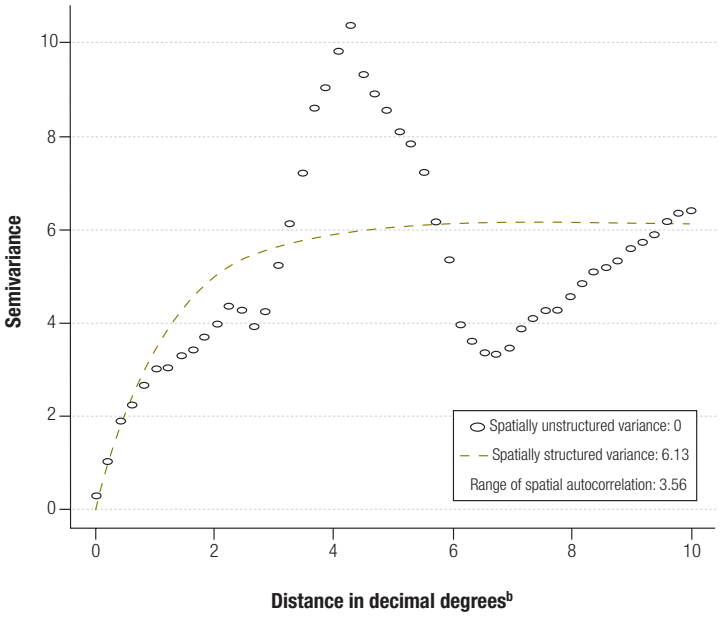
Most DHS surveys include the collection of empirical information on factors that may contribute to childhood nutritional anaemia (e.g. micronutrient measurements, maternal haemoglobin concentration and place of residence). However, information on infectious causes of anaemia is not routinely collected. The collection of stool, urine and blood samples in the design of DHS surveys would make it possible to gather important epidemiological information on infectious and hereditary causes of anaemia. In the absence of comparable

Fig. 3. **Residual geographical clustering of haemoglobin concentration in western Africa,[a] based on a multivariable linear regression model**



[a] Includes Cameroon.
[b] One decimal degree at the equator is approximately 111 km.

Fig. 4. **Residual geographical clustering of haemoglobin concentration in eastern Africa,[a] based on a multivariable linear regression model**



[a] Includes the Democratic Republic of the Congo, Lesotho and Swaziland.
[b] One decimal degree at the equator is approximately 111 km.

individual-level clinical data on these contributors, we adopted an ecological approach, using existing remotely-sensed environmental data as proxies of anaemia contributors. Nevertheless, we found that haemoglobin concentration is significantly associated with known environmental drivers of anaemia-causing parasitic infections and nutritional iron deficiency, such as distance to a perennial water body, elevation, land surface temperature and NDVI (Table 2). These effects were estimated to be greater in western Africa for NDVI and land surface temperature, and in eastern Africa for elevation. The results suggest that different environmental factors play varying roles in the anaemia burden in different geographical regions. This situation is exemplified by the different relationships between haemoglobin concentrations and the environmental variables distance to a perennial water body and elevation in western and eastern Africa (data available from corresponding author). These findings suggest that strategies for anaemia control should be tailored to local conditions while taking into account the specific etiology in a given location.

Previous approaches to describing the anaemia burden in Africa have typically been made at the national level with haemoglobin data from the field surveys available within a country, which are then extrapolated to the country as a whole. While such estimates are useful for advocacy and resource estimation at the national level, they are of limited practical relevance to the targeting of control efforts. Our results demonstrate that haemoglobin concentration is highly clustered geographically in both western and eastern Africa (Fig. 3 and Fig. 4). The size of the clusters and the tendency to cluster differ considerably between western (Fig. 3) and eastern Africa (Fig. 4), after taking into account the effect of environmental covariates. These findings highlight the non-stationary nature (i.e. spatial variation in spatial dependence) of the spatial processes leading to anaemia in preschool-age children throughout sub-Saharan Africa. Non-stationary spatial variation may occur because of human-induced environmental transformations, geographical variation of climate or topography, implementation of disease control, or the presence of different species or strains of parasites, intermediate hosts and vectors. Our results suggest that environmental drivers of anaemia-causing factors play differing roles in different regions of Africa.

The environmental variables in the haemoglobin concentration model account for only 13% of the geographical clustering in western Africa, but for 27% in eastern Africa. This result supports the suggestion that drivers of anaemia differ in these regions and that haemoglobin concentration, particularly in western Africa, is being driven by factors not accounted for in our models. Our results also indicate that, in western Africa, 9% of haemoglobin variance unexplained by environmental covariates is not related to location. Haemoglobinopathies and thalassemias are important inherited haematological conditions, particularly in western Africa,[37] and could, in part, account for the remainder of haemoglobin variability. In addition, the difference in spatial effects presented in this study potentially reflects differences in food systems or possibly deterioration in food production driven by socioeconomic factors at smaller spatial scales. Overall, our findings reinforce the need for further studies to understand how different factors (hereditary, nutritional or infectious) affect anaemia burden at smaller spatial scales.

Our approach generated new knowledge of use for the design and implementation of more cost-effective control programmes for childhood anaemia, including nutrient supplementation and infectious disease control. First, we identified significant geographical variability in the severity of anaemia. This information will inform resource allocation for control of severe forms of anaemia, which requires strategies different from those needed for milder cases.[38–41] Second, we found that the effect of environmental drivers (e.g. anaemia-causing parasite infections and nutritional iron deficiency) on the burden of anaemia varies by region. This information will allow the identification of areas where micronutrient supplementation is likely to have side-effects.[42–44] An example is the increased severity of infectious disease linked to the delivery of iron supplementation in areas where parasitic infection is highly endemic. Third, we quantified geographical clustering within regions of sub-Saharan Africa; this is paramount for the development of modern cartographic resources that could be used as operational tools for targeting anaemia control. This information could be incorporated into anaemia risk maps that control for the major contributors to anaemia, to predict haemoglobin concentration (and possibly the prevalence of anaemia) in unsurveyed areas, potentially across the continent. To date, such maps have been created at subnational, national, regional and continental scales for malaria;[22] at subnational, national and regional scales for neglected tropical diseases;[23] at national level for malnutrition;[45] and at continental level for thalassemias,[24] but have yet to be produced for anaemia.

Our findings should be viewed in the light of the study's assumptions and limitations. Environmental covariates were used as proxies for contributors to anaemia in preschool-age children. This approach provides a somewhat imprecise measurement of exposure to possible anaemia contributors and may therefore result in regression dilution bias, which can lead to underestimation of the observed effects.[46] Although the observed relationships are biologically plausible, in the absence of individually collected data it is not possible to know to what extent the magnitude of the relationships represent an artefact introduced by ecological fallacy. Next, although the collated information on anaemia in preschool-age children is extensive in western (65% coverage) and eastern Africa (80% coverage), our maps suggest that for many areas of the continent little or no georeferenced data are available via the DHS. This is particularly the case in the central and southern African regions, including 5 countries (Kenya, Mozambique, Nigeria, South Africa and the Sudan) that are among the 10 most populated countries in sub-Saharan Africa (Fig. 1 and Fig. 2). As a way to provide meaningful estimates of geographical clustering across sub-Saharan Africa, we allocated available DHS data for central and southern Africa into the western and eastern African regions. This means that the estimates of geographical clustering are not necessarily representative of administrative divisions within the central and southern African regions. Nevertheless, those countries for which DHS data are currently unavailable con-

stitute priority countries for obtaining more haemoglobin concentration data in future iterations of our approach, which could include literature searches. To facilitate studies such as this one, all future DHS should include georeferencing of communities.

The quantification of geographical variation in anaemia burden and in region-specific relationships with known drivers of major contributors to anaemia has allowed us to review the rationale underpinning the design and implementation of programmes for reducing anaemia in preschool-age children. Knowledge about the relative contribution of nutritional, infectious and hereditary causes of anaemia in different regions can help in the design of more cost-effective delivery of programmes that target these causes. Such programmes might include micronutrient supplementation, provision of fortified food, infectious disease control and transfusion services in sub-Saharan Africa. ■

Acknowledgements

We thank MEASURE DHS for granting permission to use the African DHS data sets under the project Spatial heterogeneity of anaemia in Sub-Saharan Africa.

Funding: RJSM is funded by an International Research Award from the University of Queensland (#41795457). ACC is funded by an Australian National Health and Medical Research Council Career Development Award (#631619).

Competing interests: None declared.

ملخص

التغاير الحيّزي لتركيز الهيموغلوبين لدى الأطفال دون عمر المدرسة في البلدان الواقعة جنوب الصحراء الأفريقية

الغرض تحديد ما إذا كان تركيز هيموغلوبين الدم لدى الأطفال دون عمر المدرسة (أقل من عمر 5 سنوات) له تغاير جغرافي في البلدان الواقعة جنوب الصحراء الأفريقية ووصف ارتباطه بالمتغيّرات البيئية المفضية إلى فقر الدم نتيجة لمختلف السببيّات.

الطريقة جمعت المعطيات من 24277 طفلاً دون عمر المدرسة في غرب أفريقيا (2862 موقعاً عنقودياً) ومن 25343 طفلاً في شرق أفريقيا (2999 موقعاً عنقودياً) من المسوحات الديموغرافية الصحية للأعوام 2001-2007 للبلدان الواقعة جنوب الصحراء الأفريقية. ارتبطت المواقع العنقودية بالمعلومات البيئية عن المسافات إلى كتل المياه المستديمة، والارتفاعات، ودرجات حرارة سطح الأرض، والاختلافات الطبيعية في مؤشر النوابت (كمؤشر لهطول الأمطار) في نظام المعلومات البيئية. وجرى تحديد الارتباطات الإحصائية مع المتغيرات البيئية باستخدام نماذج تحوّف متعددة المتغيرات، وجرى تقدير كمية الاعتماد الحيزي على تركيز الهيموغلوبين غير المفسر بهذه العوامل باستخدام مبيان شبه التغيّر.

النتائج في شرق أفريقيا، حدث أقل تركيز للهيموغلوبين (أقل من 70 غرام في الديسي لتر) في مواقع عنقودية صغيرة في الإقليم؛ بينما حدث ذلك في غرب أفريقيا في مواقع عنقودية كبيرة في الحدود المتاخمة لبوركينا فاسو ومالي. وأظهرت النتائج ارتباطات يعتد بها على نطاق القارة بين تركيز الهيموغلوبين والمتغيرات البيئية، ولاسيما في غرب أفريقيا من حيث درجة الحرارة على سطح الأرض، والاختلاف الطبيعي في مؤشر النوابت، وفي شرق أفريقيا من حيث الارتفاعات. وكان الاعتماد الحيزي المتبقي يعتد به. وكان المقدار أكبر في غرب أفريقيا عنه في شرق أفريقيا.

الاستنتاج يعتمد توزيع فقر الدم على العوامل البيئية على نطاق واسع، وتختلف العوامل الوبائية في غرب أفريقيا عنها في شرق أفريقيا. ويتعين تفصيل استراتيجيات مكافحة فقر الدم بين الأطفال دون سن المدرسة في البلدان الواقعة جنوب الصحراء الأفريقية حسب الظروف المحلية، مع الأخذ بعين الاعتبار السببيّات النوعية وانتشار فقر الدم.

摘要

撒哈拉沙漠以南的非洲地区学龄前儿童血红蛋白浓度的空间异质性

目的 旨在确定撒哈拉沙漠以南的非洲地区学龄前儿童血红蛋白浓度是否呈地理异质性,并描述其与造成不同病因贫血症的环境变量间的关联。

方法 从2001至2007年间撒哈拉沙漠以南非洲地区的“人口和健康调查”项目,得到西部非洲24 277名(2862 集群)学龄前儿童和东部非洲25 343名(2999集群)学龄前儿童的数据。在地理信息系统中,聚集性与非季节性水源距离、海拔、地表温度和归一化植被指数(NDVI;降雨量代替物)等环境信息相关联。与环境变量的统计关联运用多元回归模型确定,而用这些因素无法解释的血红蛋白浓度的空间相关性则运用半方差进行量化。

结果 在东部非洲,最低血红蛋白浓度(<70克/分升)在此区域内出现小聚集;而在西部非洲,最低血红蛋白浓度则在布基纳法索和马里边境出现大聚集。结果表明,血红蛋白浓度和环境变量之间存在显著性关联,特别是西部非洲的地表温度和归一化植被指数和东部非洲的海拔。剩余空间相关性也很显著,西部非洲的相关显著性高于东部非洲。

结论 贫血症的分布受到大规模环境因素的影响,而流行病学因素在西部和东部非洲并不相同。撒哈拉以南非洲地区学龄前儿童中的贫血症控制策略应该适合当地条件,考虑贫血症的特定病因和患病情况。

Résumé

Hétérogénéité spatiale de la concentration en hémoglobine chez les enfants d'âge préscolaire en Afrique subsaharienne

Objectif Déterminer si la concentration sanguine en hémoglobine chez les enfants d'âge préscolaire (moins de 5 ans) est géographiquement hétérogène en Afrique subsaharienne et décrire son association avec les variables environnementales à la base de l'anémie de différentes étiologies.

Méthodes Les données, recueillies auprès de 24 277 enfants d'âge préscolaire en Afrique occidentale (2862 emplacements de grappes) et 25 243 en Afrique orientale (2999 emplacements de grappes), proviennent de l'étude 2001–2007 *Demographic and Health Surveys* (DHS) pour l'Afrique subsaharienne. Les emplacements des grappes ont été reliés dans un système d'informations géographiques aux informations environnementales relatives à la distance de points d'eau pérennes, à l'altitude, à la température à la surface du sol et à l'indice de végétation par différence normalisée (IVDN, un indicateur de pluviosité). Des associations statistiques avec des variables environnementales ont été établies à l'aide de modèles de régression multidimensionnelle, et la dépendance spatiale de la concentration en hémoglobine inexpliquée par ces facteurs a été quantifiée à l'aide de semi-variogrammes.

Résultats En Afrique orientale, les plus faibles concentrations en hémoglobine (<70 g/l) ont été trouvées dans des petites grappes disséminées ; en Afrique occidentale, elles ont été trouvées dans une grappe importante à cheval sur la frontière entre le Burkina Faso et le Mali. Nos résultats montrent des associations significatives à l'échelon du continent entre la concentration en hémoglobine et les variables environnementales, en particulier en Afrique occidentale, pour la température de la surface du sol et l'IVDN, et, en Afrique orientale, pour l'altitude. La dépendance résiduelle spatiale était significative, et son importance était plus forte en Afrique occidentale qu'en Afrique orientale.

Conclusion La répartition de l'anémie est déterminée par des facteurs environnementaux à grande échelle, et les agents épidémiologiques diffèrent en Afrique occidentale et orientale. Les stratégies pour contrôler l'anémie chez les enfants en âge préscolaire en Afrique subsaharienne devraient être adaptées aux conditions locales, pour prendre en compte l'étiologie et la prévalence spécifiques de l'anémie.

Резюме

Пространственная гетерогенность содержания гемоглобина в крови детей дошкольного возраста в странах Африки к югу от Сахары

Цель Определить, является ли содержание гемоглобина в крови детей дошкольного возраста (в возрасте до пяти лет) гетерогенным в географическом отношении в странах Африки к югу от Сахары, и описать корреляцию этого показателя по отношению к экологическим переменным, способствующим развитию анемии с различной этиологией.

Методы Использованы данные по 24 277 детям дошкольного возраста из стран Западной Африки (2 862 кластерных участка) и 25 343 детям из стран Восточной Африки (2999 кластерных участков), взятые из «Обследований в области народонаселения и здравоохранения» за 2001–2007 годы по странам Африки к югу от Сахары. Для кластерных участков была определена связь с экологическими данными о расстоянии до водоема, не пересыхающего в летний период, высоте над уровнем моря, температуре земной поверхности и значении нормализованного разностного вегетационного индекса (NDVI; замещающий показатель для уровня осадков) в системе географической информации. Статистические корреляции с экологическими переменными определялись с использованием моделей мультивариантной регрессии, а пространственная зависимость содержания гемоглобина, не объясняемая этими факторами, определялась в количественном выражении с использованием семивариограмм.

Результаты В Восточной Африке самые низкие показатели содержания гемоглобина (менее 70 г/л) наблюдались в мелких кластерах по всему региону; в Западной Африке они наблюдались в крупном кластере, протянувшемся вдоль границы между Буркина-Фасо и Мали. Наши результаты демонстрируют по всему континенту статистически значимые корреляции между содержанием гемоглобина и экологическими переменными, особенно в Западной Африке для показателей температуры земной поверхности и NDVI, и в Восточной Африке для высоты над уровнем моря. Остаточная пространственная зависимость была статистически значимой, а ее масштабы были более значительны в Западной, чем в Восточной Африке.

Вывод Распределение анемии определяется воздействием масштабных экологических факторов, а эпидемиологические драйверы в Западной и Восточной Африке различаются. Стратегии борьбы с анемией среди детей дошкольного возраста в странах Африки к югу от Сахары должны определяться местными условиями, с учетом конкретной этиологии и распространенности анемии.

Resumen

Heterogeneidad espacial de la concentración de hemoglobina en niños de edad preescolar en el África Subsahariana

Objetivo Determinar si la concentración de hemoglobina en sangre en niños de edad preescolar (< 5 años de edad) es geográficamente heterogénea en África Subsahariana y describir su relación con variables ambientales que causen anemia de diferentes etiologías.

Métodos Se obtuvieron datos en 24 277 niños de edad preescolar en África Occidental (2862 sitios agrupados) y 25 343 en África Oriental (2999 sitios agrupados) de las *Encuestas Demográficas y de Salud* (DHS) de 2001-2007 para el África Subsahariana. Los sitios agrupados fueron vinculados a información medioambiental sobre la distancia a una masa acuífera perenne, la cota, la temperatura de la superficie de la tierra y el índice de vegetación de diferencia normalizada (NDVI, una representación de las precipitaciones) en un sistema de información geográfica. Las asociaciones estadísticas con variables medioambientales fueron determinadas utilizando modelos de regresión multivariados, y la dependencia espacial de la concentración de hemoglobina no explicada por estos factores fue cuantificada utilizando semivariogramas.

Resultados En África Oriental, las concentraciones más bajas de hemoglobina (< 70 g/l) se dieron en pequeñas agrupaciones por toda la región; en África Occidental, se dieron en una gran agrupación ubicada sobre la frontera entre Burkina Faso y Mali. Nuestros resultados muestran asociaciones significativas en todo el continente entre la concentración de hemoglobina y las variables medioambientales, especialmente en África Occidental, para la temperatura de la superficie de la tierra y NDVI, y en África Oriental para la cota. La dependencia espacial residual fue significativa, y la magnitud fue mayor en África Occidental que Oriental.

Conclusión La distribución de la anemia es causada por factores medioambientales a gran escala, y los causantes epidemiológicos difieren entre África Occidental y Oriental. Las estrategias para el control de la anemia en niños de edad preescolar en el África Subsahariana han de ser adaptadas a las condiciones locales, teniendo en cuenta la etiología y la prevalencia específicas de la anemia.

References

1. *Iron deficiency anaemia: assessment prevention and control.* Geneva: World Health Organization; 2001.
2. *Iron supplementation of young children in regions where malaria transmission is intense and infectious disease highly prevalent.* Geneva: World Health Organization; 2006.
3. *Worldwide prevalence of anaemia 1993–2005* Geneva: World Health Organization; 2008.
4. Grantham-McGregor S, Ani C. A review of studies on the effect of iron deficiency on cognitive development in children. *J Nutr* 2001;131(2S-2):649S–66S, discussion 666S-8S. PMID:11160596
5. Nelson M. Anaemia in adolescent girls: effects on cognitive function and activity. *Proc Nutr Soc* 1996;55(1B):359–67. doi:10.1079/PNS19960035 PMID:8832806
6. Lawless JW, Latham MC, Stephenson LS, Kinoti SN, Pertet AM. Iron supplementation improves appetite and growth in anemic Kenyan primary school children. *J Nutr* 1994;124:645–54. PMID:8169656
7. Haas JD, Brownlie T 4th. Iron deficiency and reduced work capacity: a critical review of the research to determine a causal relationship. *J Nutr* 2001;131(2S-2):676S–88S, discussion 688S-90S. PMID:11160598
8. Crawley J. Reducing the burden of anemia in infants and young children in malaria-endemic countries of Africa: from evidence to action. *Am J Trop Med Hyg* 2004;71(Suppl):25–34. PMID:15331816
9. Williams TN, Uyoga S, Macharia A, Ndila C, McAuley CF, Opi DH et al. Bacteraemia in Kenyan children with sickle-cell anaemia: a retrospective cohort and case-control study. *Lancet* 2009;374:1364–70. doi:10.1016/S0140-6736(09)61374-X PMID:19747721
10. Means RT Jr. The anaemia of infection. *Best Pract Res Clin Haematol* 2000;13:151–62. doi:10.1053/beha.1999.0065 PMID:10942618
11. Morris CR, Singer ST, Walters MC. Clinical hemoglobinopathies: iron, lungs and new blood. *Curr Opin Hematol* 2006;13:407–18. PMID:17053452
12. Wambua S, Mwangi TW, Kortok M, Uyoga SM, Macharia AW, Mwacharo JK et al. The effect of alpha+-thalassaemia on the incidence of malaria and other diseases in children living on the coast of Kenya. *PLoS Med* 2006;3:e158. doi:10.1371/journal.pmed.0030158 PMID:16605300
13. Bates I, McKew S, Sarkinfada F. Anaemia: a useful indicator of neglected disease burden and control. *PLoS Med* 2007;4:e231. doi:10.1371/journal.pmed.0040231 PMID:17696641
14. Friedman JF, Kanzaria HK, McGarvey ST. Human schistosomiasis and anemia: the relationship and potential mechanisms. *Trends Parasitol* 2005;21:386–92. doi:10.1016/j.pt.2005.06.006 PMID:15967725
15. Hotez PJ, Brooker S, Bethony JM, Bottazzi ME, Loukas A, Xiao S. Hookworm infection. *N Engl J Med* 2004;351:799–807. doi:10.1056/NEJMra032492 PMID:15317893
16. Stoltzfus RJ, Dreyfuss ML, Chwaya HM, Albonico M. Hookworm control as a strategy to prevent iron deficiency. *Nutr Rev* 1997;55:223–32. doi:10.1111/j.1753-4887.1997.tb01609.x PMID:9279058
17. Ezeamama AE, McGarvey ST, Acosta LP, Zierler S, Manalo DL, Wu HW et al. The synergistic effect of concomitant schistosomiasis, hookworm, and trichuris infections on children's anemia burden. *PLoS Negl Trop Dis* 2008;2:e245. doi:10.1371/journal.pntd.0000245 PMID:18523547
18. Albonico M, Stoltzfus RJ, Savioli L, Tielsch JM, Chwaya HM, Ercole E et al. Epidemiological evidence for a differential effect of hookworm species, Ancylostoma duodenale or Necator americanus, on iron status of children. *Int J Epidemiol* 1998;27:530–7. doi:10.1093/ije/27.3.530 PMID:9698148
19. Guerra CA, Snow RW, Hay SI. Defining the global spatial limits of malaria transmission in 2005. *Adv Parasitol* 2006;62:157–79. doi:10.1016/S0065-308X(05)62005-2 PMID:16647970
20. Schmidhuber J, Tubiello FN. Global food security under climate change. *Proc Natl Acad Sci USA* 2007;104:19703–8. doi:10.1073/pnas.0701976104 PMID:18077404
21. Pietrock M, Marcogliese DJ. Free-living endohelminth stages: at the mercy of environmental conditions. *Trends Parasitol* 2003;19:293–9. doi:10.1016/S1471-4922(03)00117-X PMID:12855379
22. Hay SI, Guerra CA, Gething PW, Patil AP, Tatem AJ, Noor AM et al. A world malaria map: Plasmodium falciparum endemicity in 2007. *PLoS Med* 2009;6:e48. doi:10.1371/journal.pmed.1000048 PMID:19323591
23. Magalhães RJ, Clements AC, Patil AP, Gething PW, Brooker S. The applications of model-based geostatistics in helminth epidemiology and control. *Adv Parasitol* 2011;74:267–96. doi:10.1016/B978-0-12-385897-9.00005-7 PMID:21295680
24. Piel FB, Patil AP, Howes RE, Nyangiri OA, Gething PW, Williams TN et al. Global distribution of the sickle cell gene and geographical confirmation of the malaria hypothesis. *Nat Commun* 2010;1:104. doi:10.1038/ncomms1104 PMID:21045822
25. Koukounari A, Fenwick A, Whawell S, Kabatereine NB, Kazibwe F, Tukahebwa EM et al. Morbidity indicators of Schistosoma mansoni: relationship between infection and anemia in Ugandan schoolchildren before and after praziquantel and albendazole chemotherapy. *Am J Trop Med Hyg* 2006;75:278–86. PMID:16896133
26. Koukounari A, Gabrielli AF, Toure S, Bosque-Oliva E, Zhang Y, Sellin B et al. Schistosoma haematobium infection and morbidity before and after large-scale administration of praziquantel in Burkina Faso. *J Infect Dis* 2007;196:659–69. doi:10.1086/520515 PMID:17674306

27. Kabatereine NB, Brooker S, Koukounari A, Kazibwe F, Tukahebwa EM, Fleming FM et al. Impact of a national helminth control programme on infection and morbidity in Ugandan schoolchildren. *Bull World Health Organ* 2007;85:91–9. doi:10.2471/BLT.06.030353 PMID:17308729
28. Guyatt HL, Brooker S, Kihamia CM, Hall A, Bundy DA. Evaluation of efficacy of school-based anthelmintic treatments against anaemia in children in the United Republic of Tanzania. *Bull World Health Organ* 2001;79:695–703. PMID:11545325
29. Brooker S, Whawell S, Kabatereine NB, Fenwick A, Anderson RM. Evaluating the epidemiological impact of national control programmes for helminths. *Trends Parasitol* 2004;20:537–45. doi:10.1016/j.pt.2004.08.012 PMID:15471706
30. Stoltzfus RJ, Albonico M, Chwaya HM, Tielsch JM, Schulze KJ, Savioli L. Effects of the Zanzibar school-based deworming program on iron status of children. *Am J Clin Nutr* 1998;68:179–86. PMID:9665112
31. International Nutritional Anaemia Consultative Group. *Safety of iron supplementation programs in malaria-endemic regions*. Washington: International Life Sciences Institute; 1999.
32. Demographic and Health Surveys [Internet]. Calverton: Measure DHS; 2011. Available from: http://www.measuredhs.com/start.cfm [accessed 1 April 2011].
33. Sharman A. *Anemia testing in population-based surveys: general information and guidelines for country monitors and program managers*. Calverton: ORC Macro; 2000.
34. Montana L, Spencer J. *Incorporating geographic information into MEASURE surveys: a field guide to GPS data collection* (Macro International Publication). Calverton: 2004.
35. R Development Core Team. R: *A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing; 2008.
36. Cressie N. *Statistics for spatial data*. New York: Wiley; 1993.
37. Weatherall DJ, Clegg JB. Inherited haemoglobin disorders: an increasing global health problem. *Bull World Health Organ* 2001;79:704–12. PMID:11545326
38. Bates I, Chapotera GK, McKew S, van den Broek N. Maternal mortality in sub-Saharan Africa: the contribution of ineffective blood transfusion services. *BJOG* 2008;115:1331–9. doi:10.1111/j.1471-0528.2008.01866.x PMID:18823485
39. Hassall O, Ngina L, Kongo W, Othigo J, Mandaliya K, Maitland K et al. The acceptability to women in Mombasa, Kenya, of the donation and transfusion of umbilical cord blood for severe anaemia in young children. *Vox Sang* 2008;94:125–31. doi:10.1111/j.1423-0410.2007.01012.x PMID:18067489
40. Lackritz EM, Hightower AW, Zucker JR, Ruebush TK 2nd, Onudi CO, Steketee RW et al. Longitudinal evaluation of severely anemic children in Kenya: the effect of transfusion on mortality and hematologic recovery. *AIDS* 1997;11:1487–94. doi:10.1097/00002030-199712000-00013 PMID:9342071
41. English M, Ahmed M, Ngando C, Berkley J, Ross A. Blood transfusion for severe anaemia in children in a Kenyan hospital. *Lancet* 2002;359:494–5. doi:10.1016/S0140-6736(02)07666-3 PMID:11853798
42. Sazawal S, Black RE, Ramsan M, Chwaya HM, Stoltzfus RJ, Dutta A et al. 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* 2006;367:133–43. doi:10.1016/S0140-6736(06)67962-2 PMID:16413877
43. *How to add deworming to vitamin A distribution*. Geneva: World Health Organization & United Nations Children's Fund; 2004.
44. Miller RK, Hendrickx AG, Mills JL, Hummler H, Wiegand UW. Periconceptional vitamin A use: how much is teratogenic? *Reprod Toxicol* 1998;12:75–88. doi:10.1016/S0890-6238(97)00102-0 PMID:9431575
45. Margai FM. Geographic targeting of risk zones for childhood stunting and related health outcomes in Burkina Faso. *World Health Popul* 2007;9:64–82. PMID:18270507
46. Hutcheon JA, Chiolero A, Hanley JA. Random measurement error and regression dilution bias. *BMJ* 2010;340:c2289.