THE LANCET

Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

Supplement to: Piel FB, Patil AP, Howes RE, et al. Global epidemiology of sickle haemoglobin in neonates: a contemporary geostatistical model-based map and population estimates. *Lancet* 2012; published online Oct 25. http://dx.doi.org/10.1016/S0140-6736(12)61229-X.

Web Appendix outline

Web Tables

Web Table 3. Sub-national areal prediction summaries and Monte Carlo standard errors (SE) for AS and SS newborn estimates

Web Table 4. **Global, regional and national rates of neonates affected (HbAS and HbSS)** based on median estimates presented in this report (termed MAP) and on data calculated by Modell and Darlison (termed M&D). Births for 2003 and 2010 are shown in thousands and are based on the 2003 UN Demographic Yearbook and the 2010 UN World Population Prospects, respectively.

Web Table 5. MCMC output parameter values

Web Table 6. Summary of data selection and modelling assumptions

Web Figures

Web Figure 1. Temporal distribution of the surveys included in the model

Web Figure 2. Sample size of the HbS surveys

Web Figure 3. Temporal distribution and sample size of the HbS surveys per country within each WHO region. A. AFRO region, B. AMRO region, C. EMRO region, D. EURO region, E. SEARO region and F. WPRO region.

Web Figure 4. Distribution of the validation subsets

Web Figure 5. Validation plots

Web Figure 6. Global human population in 2010

Web Figure 7. Crude birth rate per country

Web Figure 8. WHO and HbS regions

Web Dataset

Web Dataset. List of published and unpublished data sources

Web Appendix 1. HbS database and allele frequency map.

1. Database of HbS allele frequency survey data

Data sources

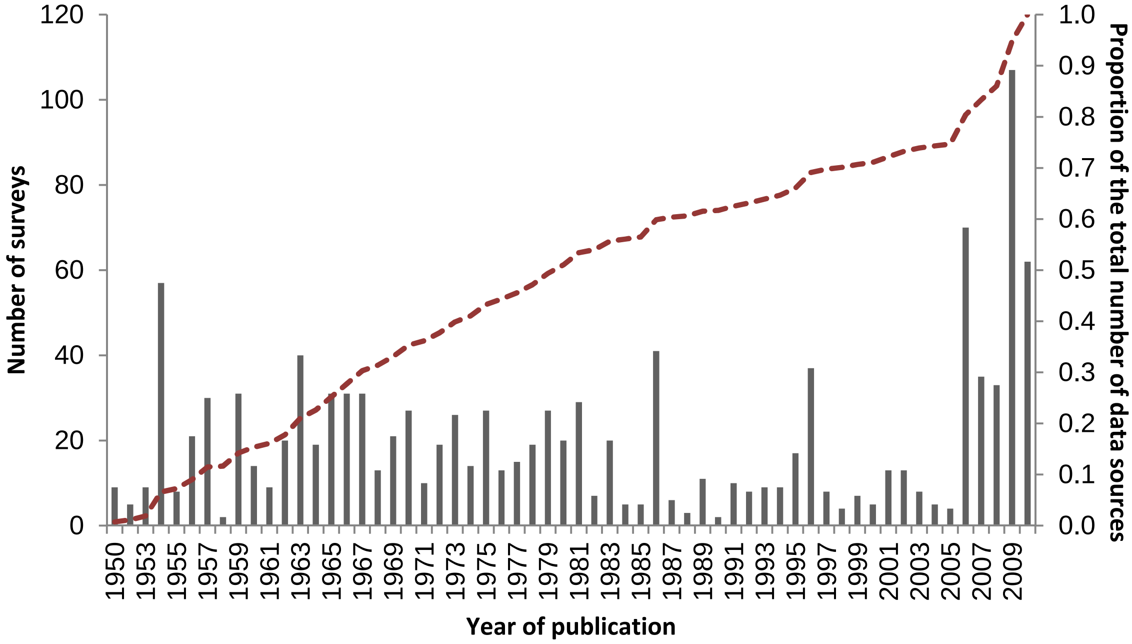
Systematic searches of the literature published since 1950 were undertaken following procedures developed by the Malaria Atlas Project (MAP, http://www.map.ox.ac.uk)[1-3] to create a contemporary database of available sickle haemoglobin (HbS) allele frequency surveys. Preliminary searches were conducted on 12 December 2007, using the following online bibliographic archives: PubMed (http://www.pubmed.gov), ISI Web of Knowledge (http://isiwebofknowledge.com) and Scopus (http://www.scopus.com). The keyword string used was: "sickle cell" or "haemoglobin S" or "hemoglobin S" or "Hb S". Searches were last run on 20 October 2009. A total of 18,336 (in *Text terms*), 28,908 (in *Title/Keywords/Abstract*) and 22,732 (in *Article Title/Abstract/Keywords*) references were found in the three respective databases and exported using bibliographic management software (Endnote X4, Thomson-Reuters, Carlsbad, CA, USA). The 2,220 references from Livingstone's extensive, but out of date, database on frequencies of haemoglobin variants[4] were then merged. Manual duplicate removal and abstract reviews of the amalgamated search results identified 3,531 references likely to contain data allowing calculation of HbS allele frequency. Despite using a conservative approach, the vast majority (91.5%) of the 41,445 unique references identified were irrelevant as they consisted of animal studies, case reports, technical descriptions of new protocols and methods, or reviews and general articles not including any primary data. Full text searches were conducted for each of the relevant references identified. When possible, authors were contacted for additional information concerning their studies in order to obtain missing information necessary to assess the quality of their results. In addition, direct contact with researchers working in Cambodia, Indonesia, Mali, Sri Lanka and Venezuela allowed inclusion of various sets of unpublished data. Finally, data collected by the Malaria Genomic Epidemiology Network Consortium (MalariaGEN, http://www.malariagen.net), representing a valuable source of standardised data from several malaria endemic countries,[5] were also incorporated in the database.

Contributors are acknowledged on the MAP website (http://www.map.ox.ac.uk/inherited-blood-disorders/acknowledgements/). All sources from which data met the criteria for inclusion are listed in Web Dataset. Data are available on the MAP website (http://www.map.ox.ac.uk).

Inclusion criteria

Only population samples representative of the local communities were included. Studies where the sampling method was not explicitly stated to have been random or universal screening could be considered representative so long as other information in the article did not indicate that the sample was biased. Detailed data given for all ethnic groups found in an area (based on the information provided in the original source) were recorded as separate entries but spatial duplicates. Surveys targeting only specific ethnic groups (e.g. African Americans in North America) were excluded as in most cases the proportion of that particular ethnic group in the general population was unknown, as well as the allele frequency in the other ethnic groups present at the sampling site. Surveys focusing on hospital patients (e.g. minor ailments, fever or malaria) were also excluded, as they may represent biased estimates of the frequency in the general population. When several surveys were conducted in the same area, we kept only the most informative one (using a combination of year of survey, sample size and sampling and diagnostic methods criteria). The temporal distribution of surveys (not taken into account in our model due to the limited amount of data available) included in the model is shown in Web Figure 1.

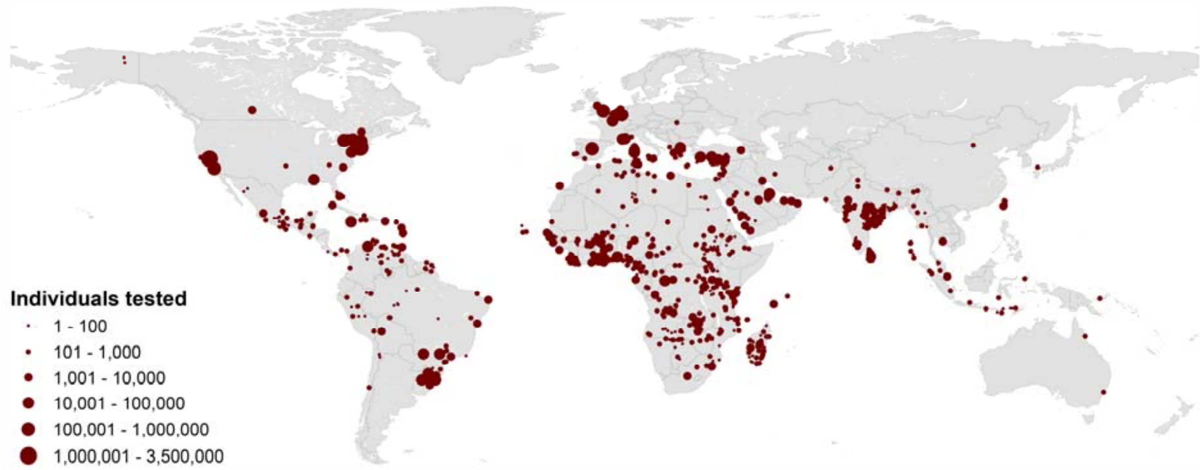
Web Figure 1 Temporal distribution of the surveys included in the model (n=1,211). Vertical grey bars indicate the number of data sources for each year, shown on the left-hand axis. The red dashed line corresponds to a cumulative proportion of the total number of data sources, quantified on the right-hand y-axis of the plot.



No constraints were placed on sample size (Web Figure 2), as there is no rationale for excluding small sample sizes in a model-based geostatistical (MBG) framework (see below). This is because, on one hand the model weighs the information content of each survey in accordance with a binomial sampling model, therefore down-weighting the information from very small samples, and on the other hand the uncertainty in relation to the sample size is explicitly modelled by this technique.[6] Nevertheless, case reports were excluded from this study as they did not match our criterion for representativeness of the local communities. Web Figure 3 shows both the temporal distribution of surveys and their sample size for each country within each WHO region (see Web Figure 8).

The number of normal (HbA or *neg*) and abnormal (HbS or *pos*) alleles observed was used as input for the model. For example, in a sample of N individuals tested in which n_{AA}, n_{AS}, n_{SS} were found to be AA, AS and SS individuals respectively, HbA allele frequency is $p = \frac{(2*n_{AA})+n_{AS}}{2N}$ and HbS allele frequency is $q = \frac{(2*n_{SS})+n_{AS}}{2N}$. Individuals identified as sicklers in earlier studies were all considered as carriers. We assumed all populations were at Hardy-Weinberg equilibrium (HWE).[7, 8]

Web Figure 2. Sample size of the HbS surveys. The size of the circles is proportional to the number of individuals tested.

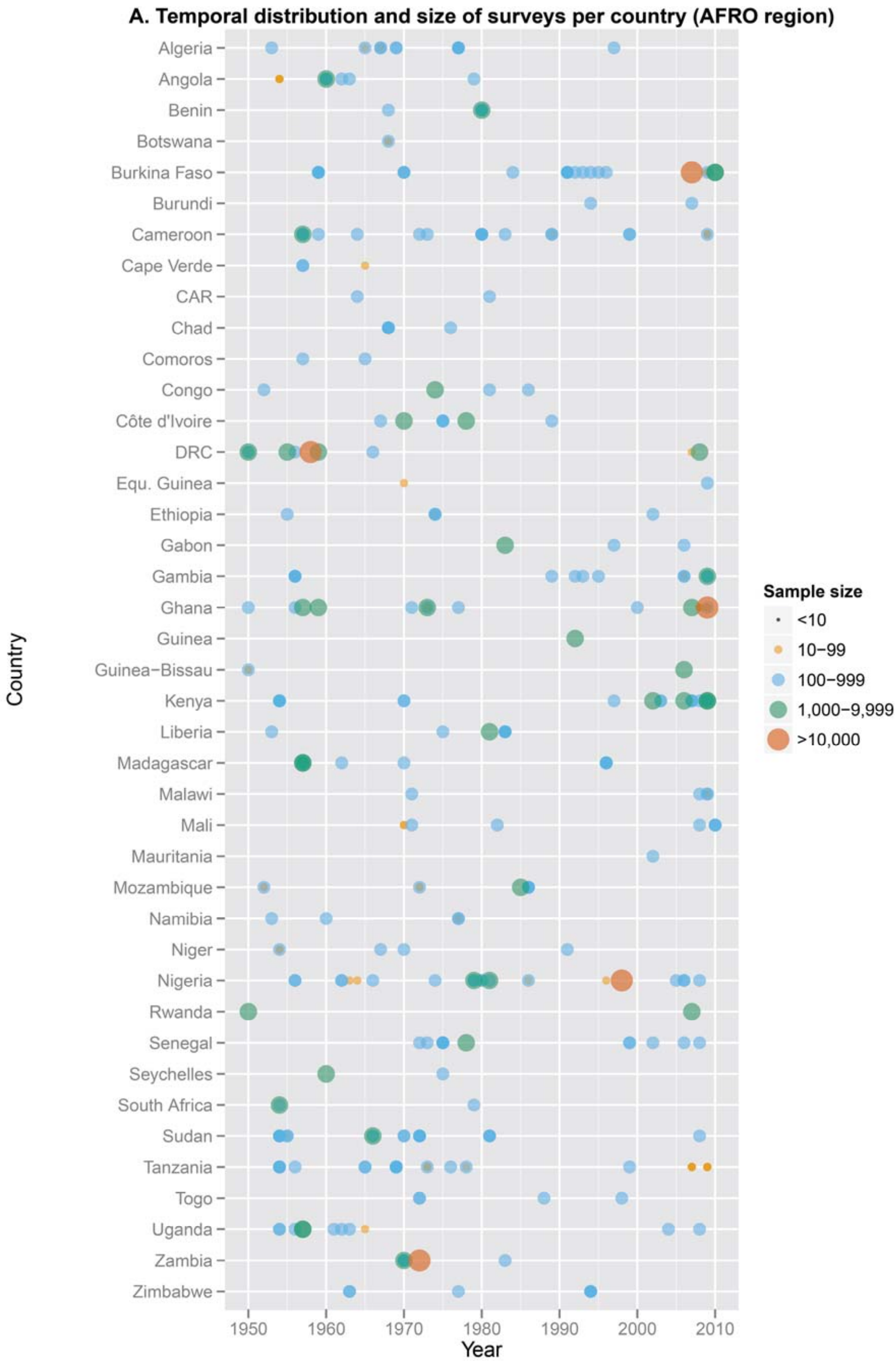


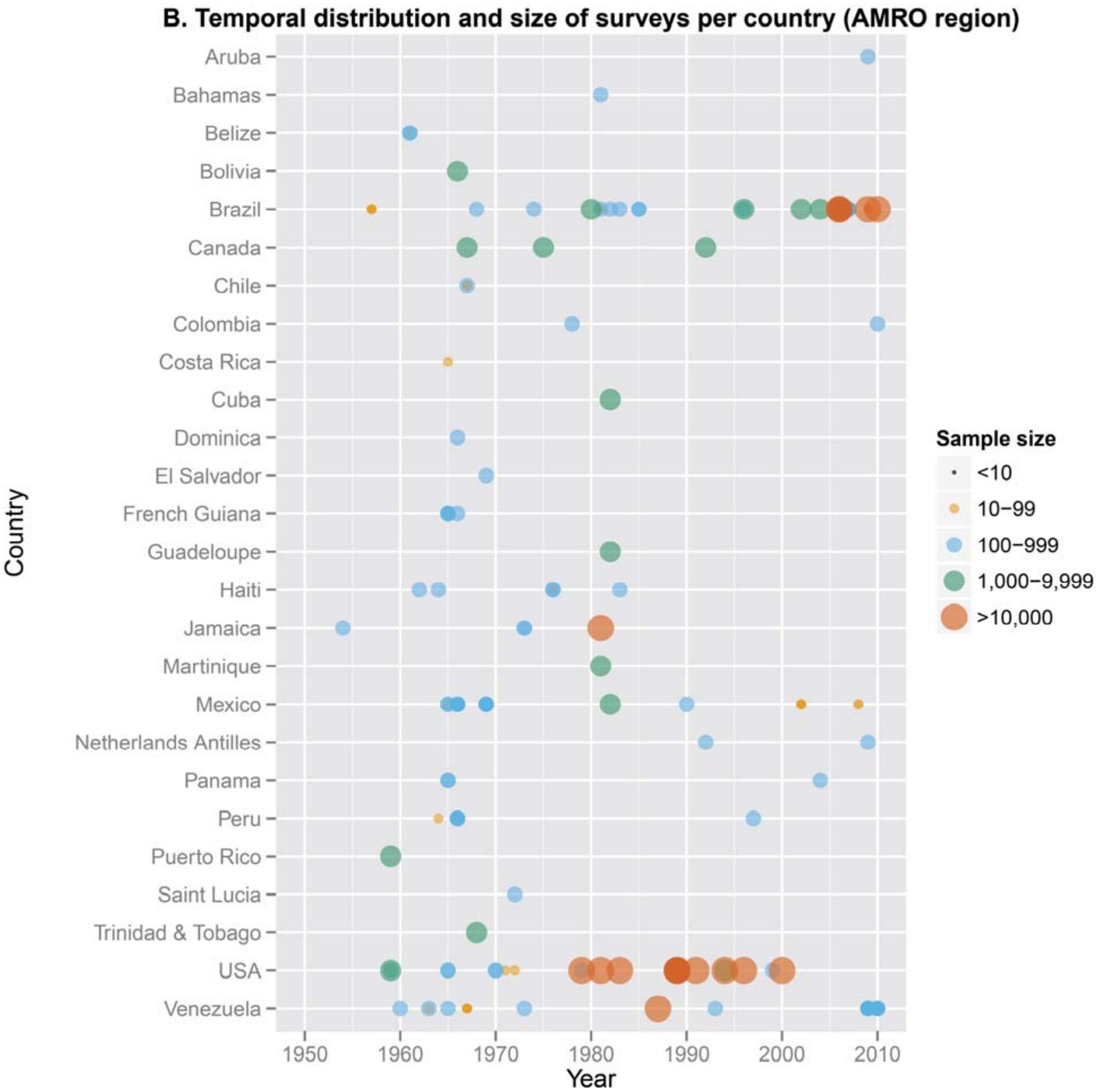
Although compound individuals for haemoglobin C (HbC) and β-thalassaemia[9, 10] are also of clinical and public health significance, we deliberately did not include these data in the present study. Limited data currently available on HbC[11], the complexity of the multiple variants for β-thalassaemias and the small number of individuals affected relative to HbAS, make the inclusion of these conditions difficult in the present modelling framework.

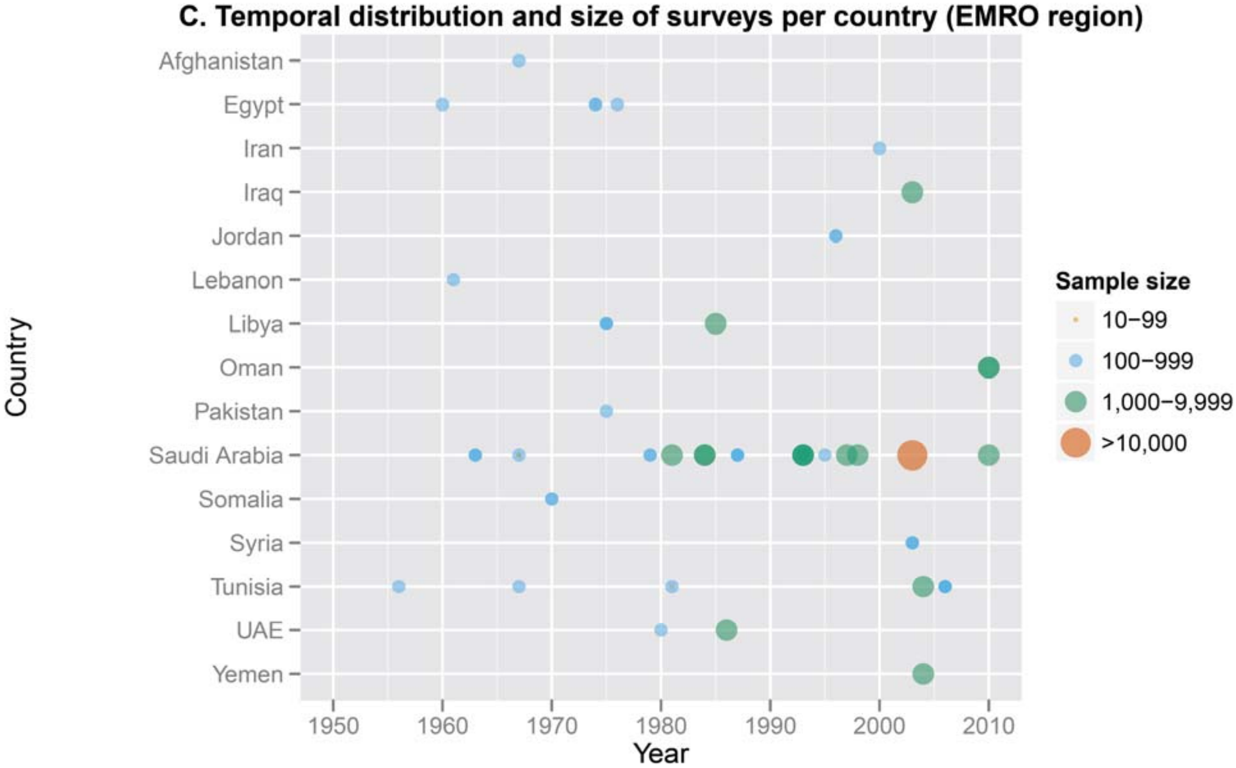
Georeferencing

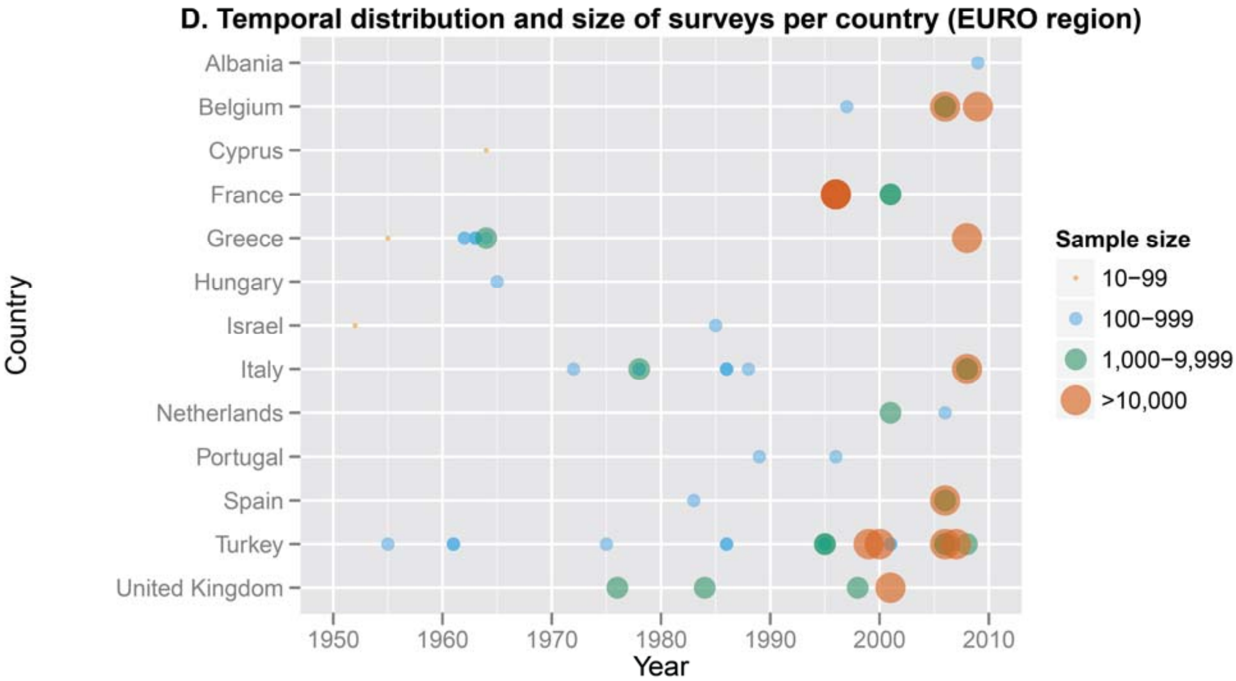
The geographic location of each survey was determined as precisely as possible using a georeferencing protocol adapted from Guerra et al.[3] Authors' descriptions of survey sites were used to locate the sampling sites. Geographic coordinates (in decimal degrees) were identified in various global gazetteers including the Encarta Reference Library 2007 (Microsoft Corporation, Redmond, WA, USA), Geonames (National Geospatial-Intelligence Agency. http://geonames.nga.mil/ggmagaz/) and Global Gazetteer Version 2.2 (Falling Rain Genomics Inc. http://www.fallingrain.com/world/index.html). Surveys were categorised according to the extent of the area that they represented: points (≤10km^2), wide areas (>10 and ≤25km^2), and small (>25 and ≤100km^2) or large polygons (>100km^2). Polygons were digitised and centroids calculated in Geographic Information Systems (GIS) software (ArcView 3.2 and ArcMap 10.0, ESRI Inc., Redlands, CA, USA). A similar method was applied to surveys which could only be georeferenced to the district (admin2 unit) level. Surveys reported only to province (admin1 unit) or country (admin0 unit) level were considered to lack sufficient geographical specificity and were thus excluded. The geographic coordinates (latitude and longitude) were used as input in the model.

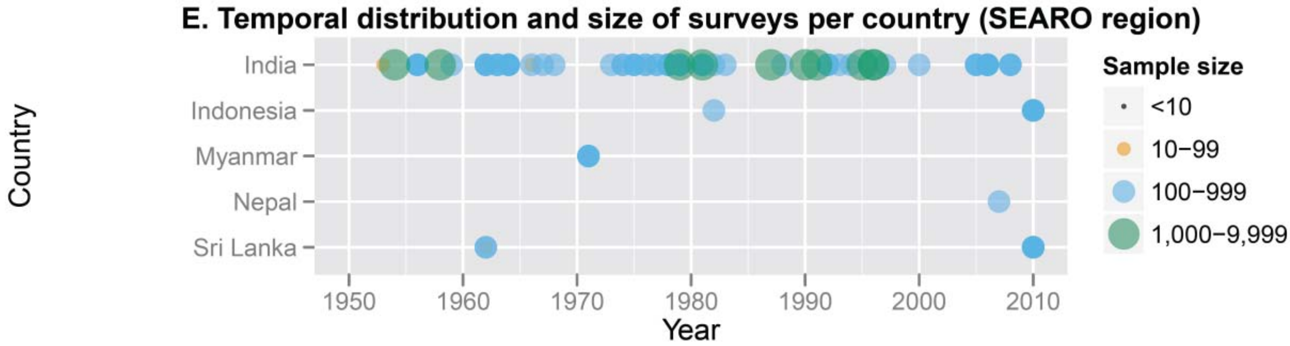
Web Figure 3. Temporal distribution and sample size of the HbS surveys per country within each WHO region. A. AFRO region, B. AMRO region, C. EMRO region, D. EURO region, E. SEARO region and F. WPRO region.

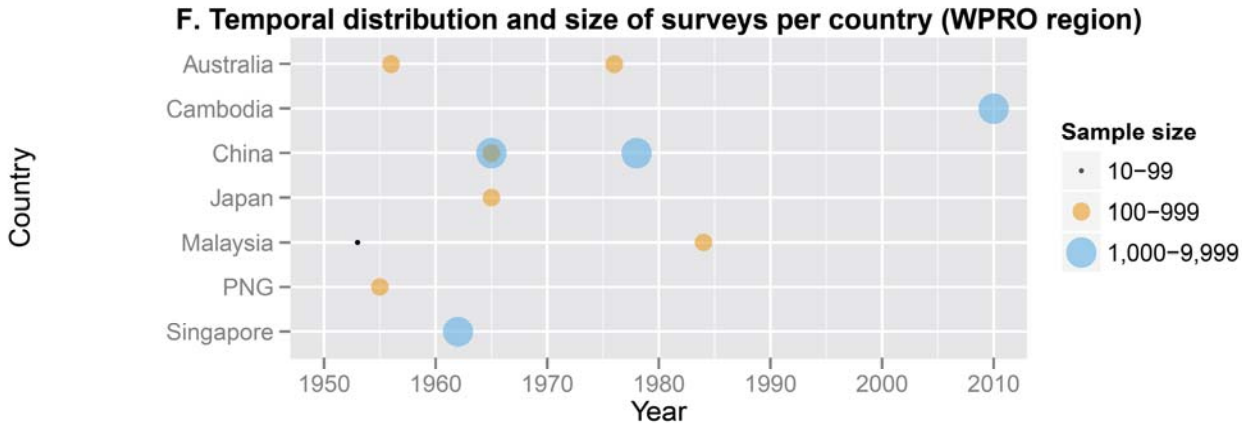

A. Temporal distribution and size of surveys per country (AFRO region)
Algeria
Angola
Benin
Botswana
Burkina Faso
Burundi
Cameroon
Cape Verde
CAR
Chad
Comoros
Congo
Côte d'Ivoire
DRC
Equ. Guinea
Ethiopia
Gabon
Gambia
Ghana
Guinea
Guinea−Bissau
Kenya
Liberia
Madagascar
Malawi
Mali
Mauritania
Mozambique
Namibia
Niger
Nigeria
Rwanda
Senegal
Seychelles
South Africa
Sudan
Tanzania
Togo
Uganda
Zambia
Zimbabwe
Country
1950
1960
1970
1980
1990
2000
2010
Year
Sample size
<10
10−99
100−999
1,000−9,999
>10,000


B. Temporal distribution and size of surveys per country (AMRO region)
Country
Aruba
Bahamas
Belize
Bolivia
Brazil
Canada
Chile
Colombia
Costa Rica
Cuba
Dominica
El Salvador
French Guiana
Guadeloupe
Haiti
Jamaica
Martinique
Mexico
Netherlands Antilles
Panama
Peru
Puerto Rico
Saint Lucia
Trinidad & Tobago
USA
Venezuela
1950
1960
1970
1980
1990
2000
2010
Year
Sample size
<10
10−99
100−999
1,000−9,999
>10,000


C. Temporal distribution and size of surveys per country (EMRO region)
Afghanistan
Egypt
Iran
Iraq
Jordan
Lebanon
Libya
Oman
Pakistan
Saudi Arabia
Somalia
Syria
Tunisia
UAE
Yemen
Country
1950
1960
1970
1980
1990
2000
2010
Year
Sample size
10−99
100−999
1,000−9,999
>10,000


D. Temporal distribution and size of surveys per country (EURO region)
Albania
Belgium
Cyprus
France
Greece
Hungary
Israel
Italy
Netherlands
Portugal
Spain
Turkey
United Kingdom
Country
1950
1960
1970
1980
1990
2000
2010
Year
Sample size
10−99
100−999
1,000−9,999
>10,000





2. Creating a map of HbS allele frequency

Model

In this section, we describe our Bayesian spatial model for the HbS allele frequency surface $S(.)$. S takes as its argument an arbitrary location on the Earth's surface. Because of the scale of this global study, the limited number of datapoints (~1,000) and their relatively good spread, we assumed that the sampling bias towards areas of high-prevalence was reasonable. The posterior $[S]$ induces a posterior $[SS]$ for the SCA frequency surface $SS(.)$ since, using the Hardy-Weinberg assumption[7, 8] that an individual's two copies of each allele are chosen independently from a gene pool, $SS(x) = S(x)^2$. We computed summaries of $[SS(x)]$, such as $E(SS(x))$ and $Var(SS(x))$, at each location x, to produce the maps related to SCA frequency in neonates.

The model differs from the model employed by Piel et al.[1] because, while conducting the analysis for the current study, we diagnosed a lack of fit in our previous model that did not have a substantial effect on the main summaries of interest of $[S]$, but did cause serious errors in $[SS]$. This point is discussed below.

The national-level disease burden $D(A)$ in nation A can be computed from SS, the birth rate b_A in A and the global population density surface N using the areal integral

$$D(A) = \int_A b_A N(x) SS(x) da$$

This is a deterministic transformation of SS and therefore of S, so theoretically the posterior $[S]$ induces the posterior $[D(A)]$. However, for reasons discussed by Patil et al.,[12] it is prohibitively computationally expensive to sample from this posterior. We produce approximate samples using a method described below.

Prior for S

We model S as a nonlinear transformation of a Gaussian random field[12] $f(.)$, plus a random field $\varepsilon(.)$ that associates an independent normally distributed value with each location on the earth's surface. Specifically,

$$S(x) = g(f(x) + \varepsilon(x))$$

The link function g maps the random variable $f(x) + \varepsilon(x)$, which can be any real number, to the interval (0,1), so $S(x)$ can be used as a probability or prevalence. We used a non standard link function, which is described below.

The prior for f is parameterized from the constant mean function $M(x) = m$, and the standard exponential covariance function $C(x, y) = \varphi^2 \exp \frac{|x-y|}{\theta}$ with amplitude parameter φ and range parameter θ, with suitable priors assigned to the scalar parameters m, φ and θ:

$$p(m) \propto 1$$
$$\varphi \sim Exponential(.1)$$
$$\theta \sim Exponential(.1)$$
$$f \sim GP(M, C)$$

GP indicates a Gaussian process. The units of x, y and θ are earth radii, and m and φ are unitless. The unstructured component $\varepsilon(x)$ is modelled as normally distributed with unknown variance V:

$$V \sim Exponential(.1)$$
$$\epsilon(x) \overset{iid}{\sim} Normal(0, V, \alpha)$$

A global approach was preferred to a region-specific version of the model because of the limited number of datapoints available for this study.[13] Furthermore, we privileged model stability over flexibility of the model parameters.

Although distances were calculated across oceans, the range parameter of the model was smaller than typical ocean width. Predictions on the eastern coast of Brazil were therefore not influenced by datapoints from West Africa, but strictly by Central and South American datapoints.

Likelihood

Adopting the assumption of Hardy-Weinberg equilibrium,[7, 8] if n_i individuals are sampled at the *i*'th observation location o_i (for a total of $2n_i$ chromosomes), the probability distribution for the number k_i of copies of the HbS allele that will be found is binomial, with probability $S(o_i)$:

$$k_i \sim Binomial(2n_i, S(o_i))$$

Flexible link function and empirical Bayesian analysis

The link function g for binomial data is usually taken to be the inverse logit function,

$$g(x) = logit^{-1}(x) = \frac{\exp x}{1 + \exp x}$$

Piel et al.[1] employed this model. Applying the change of variables formula,[14] the induced prior for *S(x)* is:

$$p\big(S(x)\big) = \frac{1}{S(x)\big(1 - S(x)\big)} Normal(logit(S(x)); m, \varphi^2 + V)$$

Note that this is essentially a two-parameter family of probability distributions, since φ and V appear only in the sum.

When we initially attempted to fit Piel et al.'s model to the current dataset and predict SS, we found that, when the local distribution above is fitted in areas where datapoints are highly clustered, the best fitting values of m and $\varphi^2 + V$ result in implausibly long right-hand tails for the predictive distribution of prevalence in the next observation at x. Although the standard summary statistics, including the upper 95% credible interval, were consistent with the local dataset, strikingly high allele frequencies $S(x)$ (greater than 40%) were predicted with small but practically significant probability (~0.1%).

This particular type of lack of fit was not a major issue for predictions of $S(x)$ because the bulk of the predictive distribution was roughly consistent with the dataset, but the long right-hand tail translated to an even longer right-hand tail for $SS(x)$, which contained enough mass to skew all of the standard summary statistics. For example, the predicted mean of $SS(x)$ in some areas exceeded 5%, which is higher than all but the observed values in the dataset.

To remedy this problem, we attempted several strategies including employing Stukel's link function[15] in place of the more standard inverse logit, and modelling $f(x) + \epsilon(x)$ as a skew-Gaussian process[16] rather than the standard Gaussian. The skew-Gaussian approach indicated that it could solve the problem, but eliminated the crucial conjugate relationship between $f(x)$ and $f(x) + \epsilon(x)$, and we were unable to devise a successful Markov chain Monte Carlo (MCMC) scheme.

Ultimately, we employed an alternative flexible link function

$$h(x) = \sum_{i=0}^{3} c_i x^i$$

$$g = logit^{-1} \circ h$$

We were unable to infer c_i jointly with the other model parameters in a fully Bayesian manner due to poor MCMC mixing, so we adopted an empirical fitting approach inspired by data pre-processing steps employed in classical geostatistics.

Empirical Bayesian approach to fitting the polynomial coefficients

For each observation (n_i, k_i) where n_i is the sample size and k_i is the number of HbS alleles, we first obtained the posterior expectation of the gene pool-wide prevalence of HbS with uniform prior density on *[0,1]:*

$$\hat{p}_i = \frac{k_i + 1}{2n_i + k_i + 2}$$

We discarded values where $2n_i$ was below 50. Then, we inferred the parameters $\widetilde{m}$ and $\tilde{V}$ of the nonspatial Bayesian model:

$$p(\hat{p}) = \prod_i \frac{1}{\widehat{p}_i(1 - \widehat{p}_i)} Normal\left(logit(\widehat{p}_i); \widetilde{m}, \tilde{V}\right)$$

We then plotted the posterior predictive cumulative distribution function (CDF) of $logit(\hat{p})$ against its empirical CDF, and fitted the coefficients *c* of the cubic polynomial function *h* to the points using least squares, subject to the constraint that *h* must be invertible (or, equivalently, monotone).

In the Bayesian analysis of the full spatial model, the fitted values of *c* were taken as known and fixed. Although this empirical procedure is admittedly informal, the resulting nonstandard link function did substantially improve the fit of the model to the data.

Prior predictive constraint

Relatively few datapoints are available in areas known to have very low HbS allele frequency, such as the high- and low-latitude regions. The observed allele frequency in these few observations is zero, but more zero observations would be required to rule out the possibility that an occasional area of high allele frequency occurs in these areas. As it happens, the striking local variation in allele frequency in more data-rich and higher-frequency areas in Africa leads the model to conclude that such foci probably *do* occur. Even with the more flexible model for $\varepsilon(x)$, the predictive distribution in areas of low data coverage exhibits long right-hand tails, and the predicted mean value of $S(x)$ in these regions is surprisingly high.

The ideal solution to this problem would be to locate the data behind the common knowledge that HbS allele frequency is low in the high- and low-latitude regions, such as in health service reports, and incorporate it in the model. Given the obvious logistical difficulties associated with this ideal approach, we found it more practical to supplement the dataset with expert opinion (based on authors' and technical advisory group members' knowledge of this gene).

Perhaps the best way to incorporate this expert opinion would be as 'soft data', as described by Christakos [17] among others. However, producing defensible local pseudo-observations of HbS allele frequency all but requires the data collection process we sought to avoid. In addition, using soft datapoints would increase the number of spatial locations at which the Gaussian random field f has to be imputed, increasing the computational expense of fitting the model.

As a compromise, we elected to constrain φ, m, and V in such a way that the prior predictive distribution of $S(x)$, before the data are incorporated, puts probability mass of $1\text{x}10^{-3}$ or less on values in excess of 0.001. This constraint arguably induces a lack of fit by forcing $f(x)$ to depart from its prior mean by many standard deviations in areas where HbS allele frequency is known to be high; but it does remedy the implausibly high predictive values in the polar regions, and does not seem to adversely affect the fit in areas of nonzero allele frequency.

Fitting the model

The model was fitted using a MCMC algorithm[18] implemented in the programming language Python using the Bayesian analysis package PyMC.[19]

The scalar parameters φ, m, θ and V were updated jointly using Haario, Saksman and Tamminen's adaptive Metropolis algorithm,[20] as implemented by PyMC's AdaptiveMetropolis step method. Each value $\varepsilon(o_i)$ at observation location o_i was updated separately using the standard one-at-a-time Metropolis algorithm. The distribution of the Gaussian random field at the observation locations, $\{f(o_i)\}$, is conjugate to the distribution of $\{\epsilon(o_i) + f(o_i)\}$, so we updated $\{f(o_i)\}$ by sampling from its full conditional distribution. MCMC output parameter values based on 1,000,000 iterations are summarised in Web Table 5.

The polynomial coefficients for such a function are specific to the dataset. The set of coefficients used, corresponding to an invertible function and fitting the empirical cumulative distribution function was:

$$y = -1.48556762x^3 + 0.28125179x^2 + 0.02261485\mathrm{x} + 0.02125477$$

The code implementing the analysis is available at http://github.com/malaria-atlas-project/ibd-world and http://github.com/malaria-atlas-project/generic-mbg. Traces for all variables are available upon request.

Mapping procedure

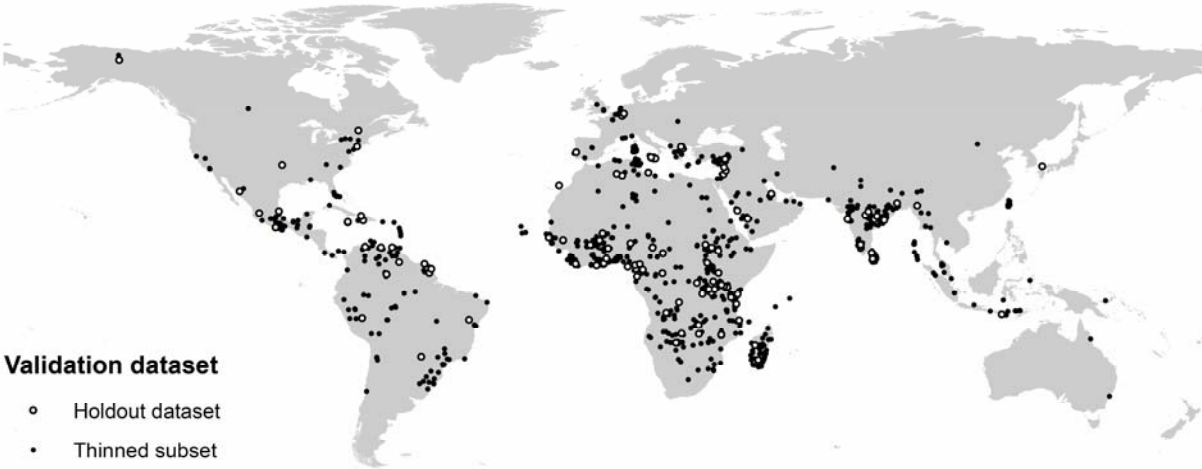
Interpolating spatially sparse survey data to predict an allele frequency across a wide region results in predictions for which the level of certainty (or uncertainty) varies spatially as a function of the density, quality, and sample size of survey data available. The underlying spatial heterogeneity of the frequency of the disorder studied, known to be high in some areas for HbS,[1 4] also influences this uncertainty. A Bayesian MBG framework[21] generates a posterior predictive distribution (PPD) rather than a unique value, therefore allowing estimation of the uncertainty of the prediction for each pixel. In addition to the PPDs of HbS allele frequency, HbAS and HbSS genotype frequencies were also generated directly by the model. Because these are nonlinear functions of the allele frequency, it would be incorrect to produce summary maps of these quantities from those of allele frequency using GIS software.[12] Here, we used the mean as a per-pixel visual summary of the PPD. The summary map is shown at a 5 × 5 km resolution (Figure 2B).

The uncertainty is a crucial measure of the accuracy of the prediction. It is based on the abundance of data, the sample sizes and the homogeneity or heterogeneity of the data around a pixel. From the range of possible uncertainty intervals available from the model's output, we chose here to use the interquartile range (IQR) of the posterior distribution,[22] corresponding to a 50% probability (Figure 2C). This corresponds to the *mbg-map* command of the generic MBG package.

Validation and model performance metrics

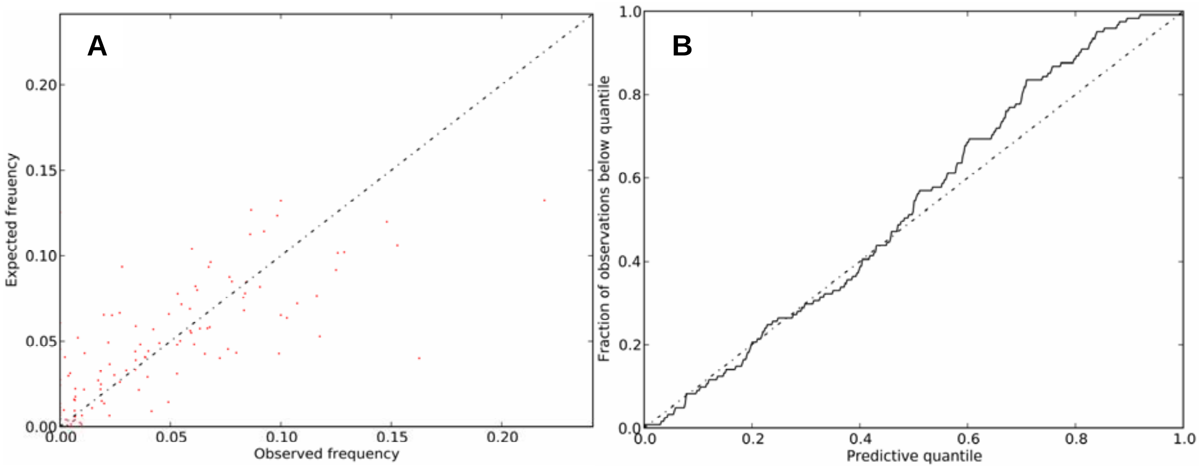
In addition to the model-based representations of prediction uncertainty provided by the MBG framework, the model's predictive ability was quantified by assessing the disparity between the prediction and the observed allele frequency using a validation subset of the data. Ten percent of the data (n=121), randomly selected, were held out from the dataset (Web Figure 4). The model was run in full using the thinned data set (n=1,090) to generate HbS PPD for comparing the mean of the prediction with known values at the locations of the held-out data (Web Figure 5A).

Web Figure 4 Distribution of the validation subsets. Black dots represent datapoints used in the thinned dataset. Circles represent datapoints held out for the model validation.



The prediction's mean error (ME) and mean absolute error (MAE) were used to assess the model's overall bias and overall accuracy respectively. The ME is the average distance between the actual datapoints and the predicted values. The MAE is a measure of the average magnitude of the errors in the predicted values. A procedure was also implemented to test the extent to which PPDs at each location provided a suitable measure of uncertainty.[23, 24] Working through 100 progressively narrower credible intervals (CIs), from the 99% CI to the 1% CI, each was tested by computing the actual proportion of held-out prevalence observations that fell within the predicted CI. In a perfect model, 95% of true values should fall within the 95% CI predicted at each location, 50% within the 50% CI, and so on. Plotting these actual proportions against each predicted CI level allows the overall fidelity of the posterior probability distributions predicted at the held-out data locations to be assessed (Web Figure 5B). This corresponds to the *mbg-validate* command of the generic MBG package.

Web Figure 5 Validation plots comparing the prediction with the observed allele frequency for the datapoints from the hold-out subset of the data (n=121). A. Scatter plot of the observed vs. predicted allele frequency; B. Plot of the observed vs. predicted quantiles.



3. Historical *vs.* contemporary maps

A map of the historical distribution of sickle haemoglobin has been published.[1] Although the methodology used to assemble the dataset, to identify surveys fulfilling inclusion criteria, to georeference the location of the survey and to create a continuous map within a Bayesian geostatistical framework are broadly similar to the methodology described here, fundamental differences exist between these two maps.

The historical map, published in 2010,[1] is based only on population samples which were representative of an indigenous population. We considered populations surveyed to be indigenous, if no information was available from the author(s) to indicate that the population did not evolve locally in relation to the historical prevalence of malaria. Non-native populations surveyed in the Americas or Western Europe, for example, were therefore excluded. A total of 773 surveys were included. This map aims at describing the distribution of sickle haemoglobin as a result of the selection pressure of malaria on the genetics of human populations.

The contemporary map, presented in this paper, is based on all representative population samples, whether indigenous or not. A much larger total of 1,211 surveys were included. This map aims at describing the current distribution of sickle haemoglobin as a result of both malaria selection and human diasporas, in order to estimate the number of individuals affected in 2010 at national, regional and global scales. This map is a continuous global surface of the frequency predictions made within our Bayesian geostatistical framework; frequency predictions combined with demographic data then allowed calculating population estimates and their associated uncertainty.

References

1. 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.
2. Hay SI, Snow RW. The Malaria Atlas Project: developing global maps of malaria risk. PLoS Med. 2006; **3**(12): e473.
3. Guerra C, Hay S, Lucioparedes L, Gikandi P, Tatem A, Noor A, et al. Assembling a global database of malaria parasite prevalence for the Malaria Atlas Project. Malaria J. 2007; **6**(1): 17.
4. Livingstone FB. Frequencies of hemoglobin variants: thalassemia, the glucose-6-phosphate dehydrogenase deficiency, G6Pd variants and ovalocytosis in human populations. New York: Oxford University Press; 1985.
5. Malaria Genomic Epidemiology Network Consortium. A global network for investigating the genomic epidemiology of malaria. Nature. 2008; **456**(7223): 732-7.
6. 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**(3): e1000048.
7. Hardy GH. Mendelian proportions in a mixed population. Science. 1908; **28**(706): 49-50.
8. Weinberg W. Über den Nachweis der Vererbung beim Menschen. Jahresh Wuertt Verh Vaterl Naturkd. 1908; **64**: 369-82.
9. Serjeant GR, Serjeant BE. Sickle cell disease: Oxford University Press; 2001.
10. Weatherall DJ, Clegg JB. The thalassaemia syndromes. Fourth ed. Oxford: Blackwell Science; 2001.
11. Cavalli-Sforza LL, Menozzi P, Piazza A. The history and geography of human genes. Princeton, New Jersey, USA: Princeton University Press; 1994.
12. Patil AP, Gething PW, Piel FB, Hay SI. Bayesian geostatistics in health cartography: the perspective of malaria. Trends Parasitol. 2011; **27**(6): 246-53.
13. Diggle PJ, Menezes R, Su T-l. Geostatistical inference under preferential sampling. Journal of the Royal Statistical Society: Series C (Applied Statistics). 2010; **59**(2): 191-232.
14. Hogg RV, McKean JW, Craig AT. Introduction to mathematical statistics. 6th ed: Pearson; 2005.
15. Stukel TA. Generalized Logistic Models. J Am Stat Assoc. 1988; **83**(402): 426-31.
16. Azzalini A, Capitanio A. Statistical applications of the multivariate skew normal distribution. Journal of the Royal Statistical Society: Series B (Statistical Methodology). 1999; **61**(3): 579-602.
17. Christakos G. Modern spatiotemporal geostatistics. USA: Oxford University Press; 2000.
18. Gilks WR, Richardson S, Spiegelhalter D. Markov chain Monte Carlo in practice: Chapman & Hall/CRC; 1995.
19. Patil AP, Huard D, Fonnesbeck CJ. PyMC: Bayesian stochastic modelling in Python. J Stat Softw. 2010; **35**(4): 1-81.
20. Haario H, Saksman E, Tamminen J. An Adaptive Metropolis Algorithm. Bernoulli. 2001; **7**(2): 223-42.
21. Diggle PJ, Ribeiro Jr PJ. Model-based geostatistics: Springer; 2007.
22. Patil A, Okiro E, Gething P, Guerra C, Sharma S, Snow R, et al. Defining the relationship between *Plasmodium falciparum* parasite rate and clinical disease: statistical models for disease burden estimation. Malaria J. 2009; **8**(1): 186.
23. Gething PW, Noor AM, Gikandi P, Hay SI, Nixon MS, Snow RW, et al. Developing geostatistical space time models to predict outpatient treatment burdens from incomplete national data. Geogr Anal. 2008; **40**: 167-88.
24. Moyeed R, Papritz A. An Empirical Comparison of Kriging Methods for Nonlinear Spatial Point Prediction. Math Geol. 2002; **34**(4): 365-86.

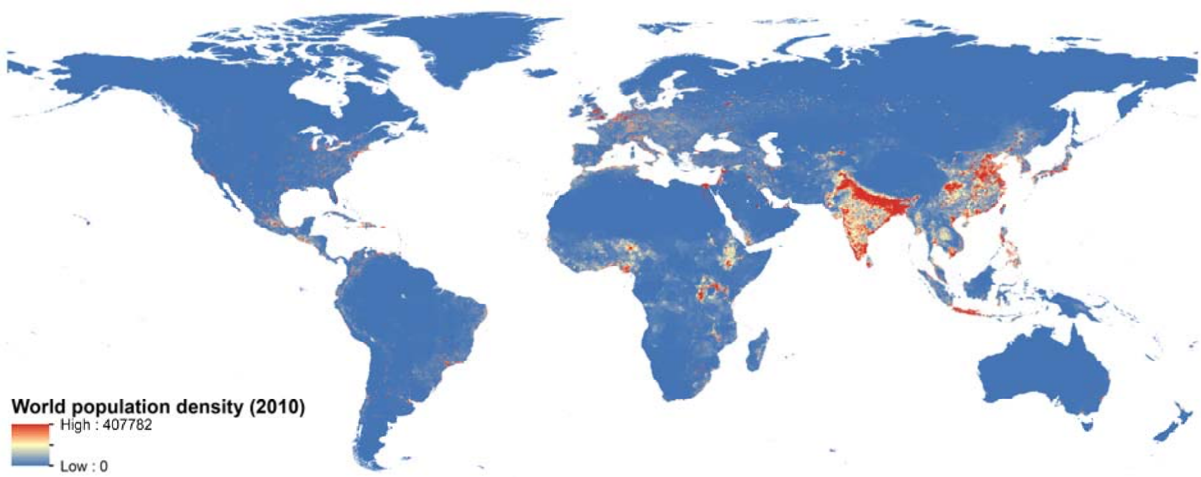
Web Appendix 2. Newborn estimates.

The best way to know with precision the number of neonates affected by a genetic disorder (such as sickle haemoglobin) at the national level is to conduct a universal national screening programme at birth. Although such programmes have proven their benefits,[1-3] they are in place only in a handful of countries, none of which are in Africa where the most affected populations are living.[4] In addition to adding data from recent surveys and refining the modelling methodology (see Web Appendix 1), using the highest resolution available for demographic data can help refining estimates of neonates affected.

1. Demographic data

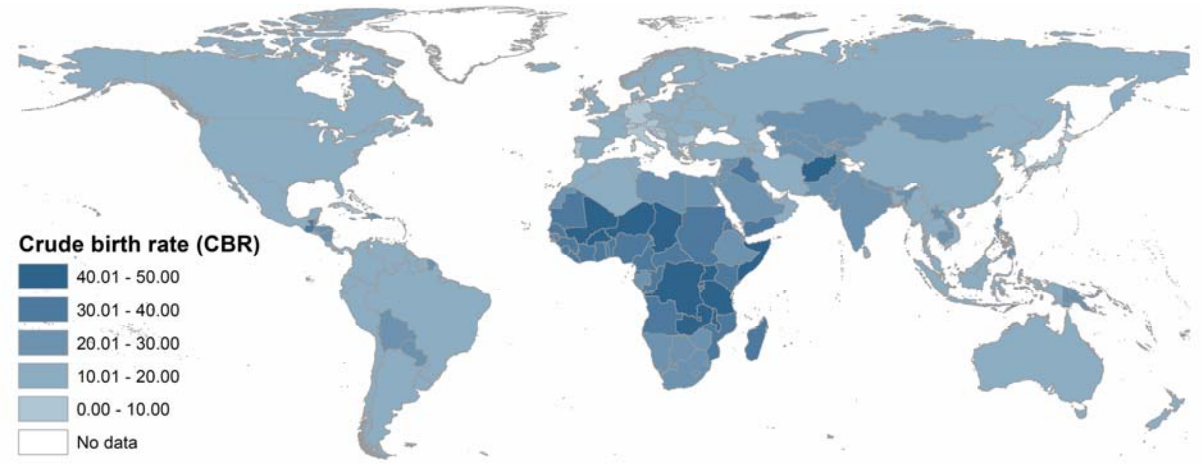
Both HbS allele frequency and population density are highly variable between pixels within countries. The HbS allele frequency map aims to include spatial heterogeneities revealed by population surveys. National estimates therefore depend on whether areas of high or low frequencies are highly populated or not. Rather than using crudely averaged data for each country, we combined our contemporary allele frequency map with high resolution population data to deal with this issue. The Global Rural Urban Mapping Project (GRUMP) *beta* version provides gridded population counts and population density estimates at 1×1 km spatial resolution for the years 1990, 1995 and 2000, both adjusted and unadjusted to the United Nations national population estimates.[5] We used adjusted population counts for the year 2000 projected to 2010 described previously.[6] The urban growth rates were applied to populations residing within the GRUMP-defined urban extents, and the rural rates were applied elsewhere. National 2010 totals were then adjusted to match those estimated by the United Nations.[7] Population density is shown in Web Figure 6.

Web Figure 6. Global human population in 2010. Number of individuals per pixel (1x1 km) from the Global Rural and Urban Mapping Project, beta version.



Mortality data are currently insufficient for calculating prevalence estimates across whole populations, so we focus here on neonates using Hardy-Weinberg assumptions.[8, 9] Assuming random mating and large population sizes, it is possible to estimate the HbS allele frequency and the proportions of each genotype (AA, AS and SS) from the number of heterozygote individuals observed in the population sample.[10]. Conceptually, the number of AS and SS babies born per year can be obtained by multiplying a function of HbS allele frequency ($2p(1-p)$ and p^2 respectively) by the population living within the area of interest and the crude birth rate (CBR). CBRs are not consistently available globally at a finer resolution than the country level, hence the use of data from the United Nations Population Prospects for the 2010-2015 period[11] (Web Figure 7).

Web Figure 7. Crude birth rate per country. Data from the United Nations World Population Prospects: The 2010 Revision Population Database (http://esa.un.org/unpd/wpp/). The rates are for 2010 and are expressed in neonates per thousand (000s).



2. Areal predictions

As described previously,[12] one needs to be careful when predicting integrals over spatial areas. Using traditional geographic information system (GIS) methods, a researcher having access to a map of HbS allele frequency ($S(x)$) and desiring a national proportion of individuals with the SS genotype ($SS(x)$), would take the square of $S(x)$ and then average the values over the various pixels falling within the country of interest, weighted by population (Web Figure 6). This approach has limitations when the map of allele frequency is uncertain. Squaring the mean map for $S(x)$ does not yield the mean map for $SS(x)$ and it is impossible to produce any assessment of the uncertainty of the areal average from summary maps alone.[12]

To develop a correct procedure for producing predictive distributions for national proportions, we began by considering what we would do if we had the true map of HbS allele frequency in hand. As stated above, the national-level disease burden $D(A)$ in nation A can be computed from S, the birth rate bA in A and the global population density surface N using the areal integral:

$$D(A) = \int_A b_A N(x) S(x)^2 da \qquad (1)$$

In reality, the allele frequency map S is unknown. We do not know its exact value, but we have a posterior distribution $[S]$ for it, from which samples can be drawn. Because applying equation 1 to a sample from $[S]$ generates a sample from $[D(A)]$, many samples from $[S]$ can be used to build up a histogram approximating $[D(A)]$.[12] Summaries such as the mean, median, variance and credible intervals can be approximated using these samples.

Although it is mathematically correct, this procedure is impractical to implement. We have an approximation of $[S]$ in the form of the MCMC trace, but generating samples from it at an appropriately high resolution is extremely computationally expensive.[12] We use an approximate procedure based on the fact that, if z_1 is a single-element binomial process on A with intensity d,

$$\frac{\int_A S(x)^2 d(x) da}{\int_A d(x) da} = E(S(z_1)^2) \qquad (2)$$

Furthermore, if z_i is an l-element binomial process on a with intensity d,

$$E(S(z_1)^2) = \lim_{l \to \infty} \frac{1}{l} \sum_{i=1}^{l} g(S(z_i)^2) \qquad (3)$$

The expectation of the term inside the limit is equal to the left-hand term, but its variance is smaller than that of $S(z_1)$.

The pseudocode for our procedure, based on this approximation, was as follows:

1. Generate an l-element binomial process on A, z_i, with intensity N.
2. For each value in the thinned MCMC trace for the scalar parameters and the Gaussian random field f evaluated at the observation locations $\{o_i\}$, $\{f(o_i)\}$,
    - Draw a value for the *l*-element random vector $\{f(z_i)\}$ from its full conditional distribution.
    - Convert these values to $\{S(z_i)\}$ by applying the inverse-logit link function.

- Square these values to obtain a sample for the value of the desired genotype frequencies $\{S(z_i)^2\}$.
- Compute the arithmetic mean of this sample and store.

To estimate the Monte Carlo standard error (SE) attributable to the use of a set of l spatial locations rather than a high-resolution raster grid, we repeated all computations ten times and recorded the sample standard deviations of all summaries (mean, median, etc.). The point estimates that we report were obtained by aggregating the samples from all repetitions.

This procedure was conducted using l = 30,000, 10,000, 1,000 and 500 spatial points for the global, regional, national and sub-national areal estimates respectively; with 10% of the parameter samples in the dynamic trace, selected at random; and 1,000 iterations. As this resulted in a full PPD for each areal unit of interest, various parameters could be used to summarize the predicted estimates and their uncertainty. Here, we used the median and the interquartile range (IQR).

The modelled surfaces and population estimates presented here are made available in the public domain with the publication of this article via the Malaria Atlas Project (MAP) website (http://www.map.ox.ac.uk), with maps available at the global scale and population estimates at global, regional and national scales. The creation of an interactive online resource for open-access distribution of HbS modelled surfaces and estimates of newborns affected, is part of the ongoing development of the ROAD-MAP online database.

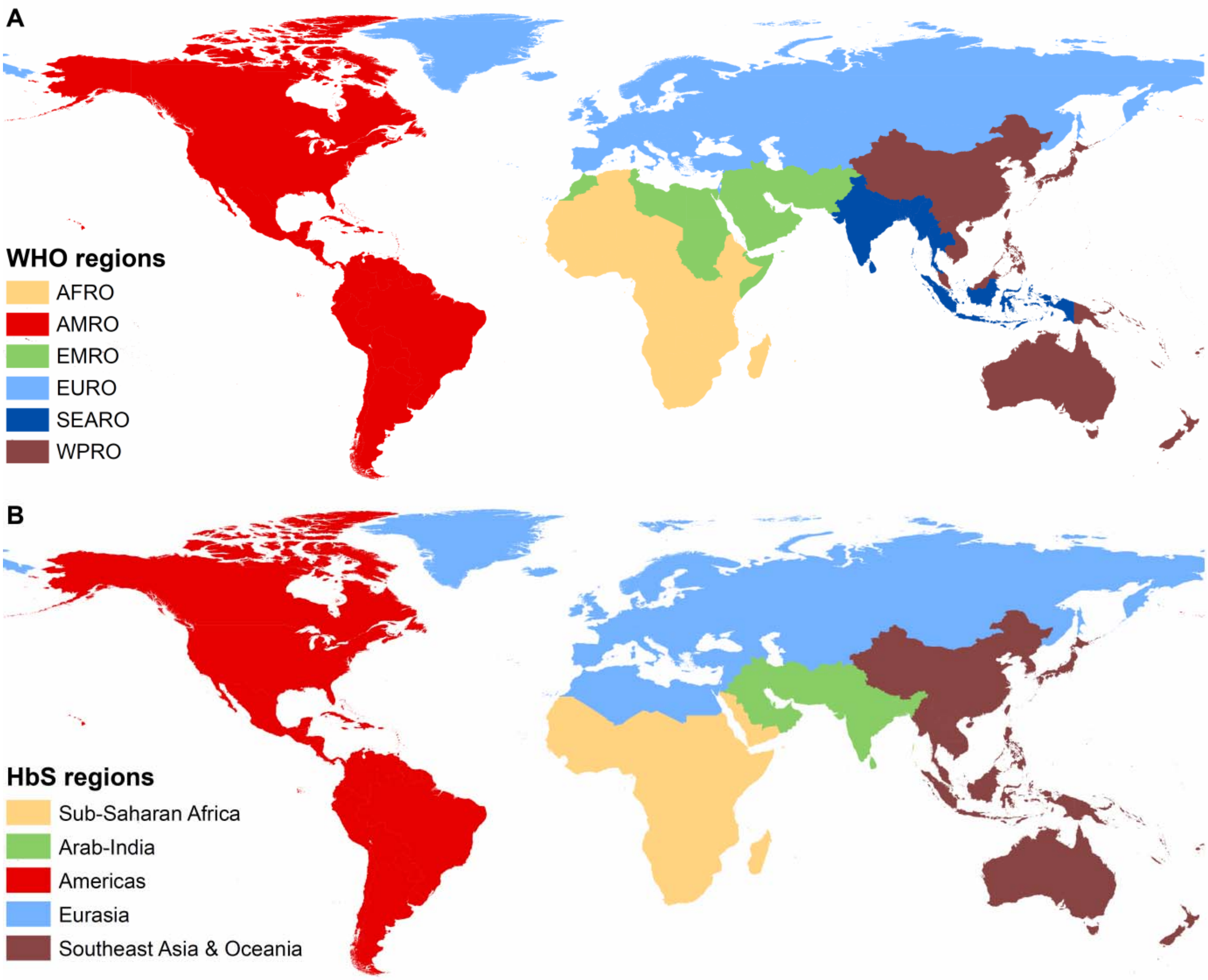
3. Model validation and performance metrics

In order to quantify the error in our areal estimation process, we performed the procedure described above ten times. Each repetition used a different subset of the dynamic tracefile and was therefore independent from previous repetitions. This method allowed us to calculate the Monte Carlo SE[13, 14] for any summary parameter chosen. The results are summarised in Table 1, Web Table 2 and Web Table 3 for the global, national and sub-national estimates respectively.

4. The use of modified WHO regions

The historical distribution of sickle haemoglobin has been explained by the selective advantage that it confers against malaria. Frequency maps of historical malaria and HbS frequencies therefore correlate on a global scale.[15] Recent changes however, are unbalancing this relationship, both in malaria-endemic and non-endemic regions. Many historically malaria endemic regions are undergoing epidemiological shifts, and it is projected that genetic disorders in these regions will have increasingly prominent public health burdens in future years.[16-18] Increases in genetic disorder burdens are also expected in non-malaria endemic regions as human migrations continue to import the sickle gene into these regions. It is important, therefore, to consider estimates of sickle haemoglobin within these epidemiologically-relevant regions. Maps of malaria endemic countries have been recently published by the MAP.[19, 20] In addition, several haplotypes for the HbS mutation have been identified and designated by their geographic area of origin: Senegal, Benin, Cameroon and Arab-Indian.[21-23]. Based on current knowledge, it seems that the Arab-Indian haplotype, which has been observed in India and the eastern part of Saudi Arabia and surrounding countries, has milder clinical severity than the African haplotypes.[21, 24]

Web Figure 8. WHO and HbS regions. A. WHO regions. AFRO: regional office for Africa; AMRO: regional office for the Americas; EMRO: regional office for Eastern Mediterranean; EURO: regional office for Europe; SEARO: regional office for South-East Asia; WPRO: regional office for the Western Pacific. See http://www.who.int/about/regions/en/index.html for further detail. B. HbS regions. WHO modified regions based on sickle cell haplotypes[21-23] and malaria endemicity.[20]



Because of the influence of these two factors on the dynamics, and complications related to HbS respectively, which both have implications for public health policies, we have presented our estimates within modified WHO regions (Web Figure 8) alongside estimates within WHO regions. These regions are: i) the Americas, corresponding exactly to the AMRO region; ii) Eurasia which includes Russia, Mongolia, as well as European and other Mediterranean countries; iii) sub-Saharan Africa which also includes the western part of Saudi Arabia and Yemen; iv) Arab-India which extends from eastern Saudi Arabia and Oman to India; v) Southeast Asia, including China, and Oceania. To allow comparisons with previous estimates,[25] all results are presented within both WHO and modified WHO regions.

5. Comparison of national estimates with Modell and Darlison's (M&D)

We compared our national estimates of SS neonates with unpublished estimates calculated by Modell and Darlison (M&D) in 2008.[25] M&D aimed at presenting "the most conservative [estimates] permitted by the data (i.e. give minimum figures)", based on demographic data from the 2003 UN Demographic Yearbook. In the present study, we aimed at providing the best summary of our current knowledge and of the precision associated with these estimates. It is therefore logical that our national estimates for 2010 tend to be higher than those calculated by M&D as illustrated in Figure 3. This can be explained by various methodological differences including: i) the use of an updated dataset based on strict inclusion criteria; ii) the use of a state-of-the-art modelling geostatistical framework, unconstrained by national boundaries and accounting for spatial heterogeneities; iii) the use of up to date demographic data; and iv) weighting each pixel estimate by population density data, so that, for example, highly populated areas with high frequencies are better represented.

We first compared absolute numbers of neonates affected. Within the AFRO region (Figure 3A), the biggest difference was in the DRC with our median estimate being approximately twice that of M&D. Their estimate for Nigeria fell within our IQR. Important differences appeared for Sudan and Kenya for which relatively large numbers of surveys (32 and 51 respectively) were used in our model. For the AMRO countries (Figure 3B), our median estimates for Brazil and the USA are approximately three times higher than M&D's. Although 47 and 25 surveys respectively were included in our model, they tended to be clustered and targeted areas of high prevalence. This contributes to the large IQR associated with our predictions. Large differences were also observed in Haiti, Mexico, Venezuela and most Central American countries. Within the EMRO region (Figure 3C), M&D's estimate for Saudi Arabia was more than five times higher than ours which has a small IQR. For Egypt, the Syrian Arab Republic and Iran, our median estimates are higher, and the IQRs were relatively large. In the EURO countries (Figure 3D), our median estimates are higher for most Western

European countries, as well as for Turkey and Israel, but IQRs are large. Within the SEARO region (Figure 3E), the only difference appeared in India for which our median estimate is 1.6 times higher than M&D's. For the WPRO countries (Figure 3F), numbers are low but differences appeared for Australia and New Zealand.

We also looked at the rate of affected neonates per thousand overall conceptions as a relative comparison measure. This rate, calculated as the ratio between the number of affected neonates (AS or SS) and the product of the population and crude birth rate within the area considered, given in per thousand (Web Table 4), can facilitate comparisons with previous and future estimates, as well as with estimates for other disorders. M&D global and regional rates were calculated using the sum of regional and national estimates respectively. MAP global and regional estimates are based on our areal predictions. These rates have also been included in Web Table 4.

6. National newborn screening programme data

Worldwide, only a few high-income, non-malarious countries, with relatively low haemoglobinopathy prevalence, have implemented a national universal newborn screening for sickle haemoglobin. These countries include the United States of America (USA), England and the French Overseas Departments and Territories. A targeted screening programme focussing on populations at risk is in place in France. Some African countries (e.g. Ghana)[26] have recently started to implement pilot screening programmes for haemoglobinopathies but no screening-based national estimates were available for this study.

In the USA, universal newborn screening for sickle cell homozygotes (SS), sickle cell carriers (AS) and compound heterozygotes with HbS and HbC (SC) is now either required by law, by an official rule or fully implemented in all states.[27] Since 2005, part of this data is centralized into the National Newborn Screening Information System (NNSIS, http://nnsis.uthscsa.edu/) on a voluntary reporting basis. Although incomplete, due to the absence of any reports from some states and the lack of spatial resolution, this is the only national resource currently available. Haemoglobin reports from the NNSIS included the total number of cases detected per year. Such data were available for most states from 2001 to 2010. Based on reported data, the annual number of SS neonates in the USA was 1,213 in 2001 (50 states/territories), 1,166 in 2002 (47 states/territories), 1,141 in 2003 (48 states/territories), 1,056 in 2004 (58 states/territories), 1,047 in 2005 (50 states/territories), 1,057 in 2006 (49 states/territories), 988 in 2007 (44 states/territories), 1,029 in 2008 (42 states/territories), 883 in 2009 (36 states/territories), and 783 in 2010 (32 states/territories). Using all data available, the annual average number of SS neonates over that period was 1,123. Based on the 25 population representative surveys used in our model, our estimate for the USA was 2,843 SS (IQR: 2,038-

3,968) neonates. Our estimate is therefore at least twice as high as suggested by the NNSIS reported data. Potential explanations for this include i) the relatively small number of surveys available for such a large country; ii) the heterogeneous distribution of ethnic groups mostly affected (not included in our model); and iii) potential discrepancies between data collected locally and data reported in the NNSIS data.

In England, the National Health System (NHS) Sickle Cell and Thalassaemia Screening Programme was launched in 2001. It collects data from 152 antenatal laboratories and 13 newborn laboratories.[28] Based on data from April 2005 to March 2007, 10,000 AS neonates were identified amongst 1,069,173 babies screened (89% of all babies born in England).[1] The report estimates that this represents 90% of the total actual number of carriers. Considering 748,990 neonates for 2010,[11] applying the same ratio would result in 7,783 AS neonates. No number for SS neonates was available. Based on the four population surveys included in our global model, our estimate for England was 14,509 (IQR: 10,263-20,013) AS and 269 (IQR: 150-466) SS neonates. Our estimate of AS neonates appeared therefore slightly higher than what could be expected from national screening programme data. This probably results from the opportunistic sampling of published surveys used in our model, which focus mostly on populations at risk.

In France and the French Overseas Departments and Territories, there is currently no central database to give precise figures on the number of neonates affected by HbS. Cumulative data from 1996 to 2007, based on the screening of 2,622,870 neonates, identified 64,269 AS and 2,917 SS or Sβ^0 thalassaemia babies respectively.[29] Using the total number of neonates in 2010 (n=832,799),[30] the annual number of AS neonates based on the above ratio would be 20,416 which is consistent with our estimate of 22,040 (IQR: 15,621-30,597) AS neonates. For Guadeloupe, Martinique and Réunion, our estimates were 459 (IQR: 343-594) AS and 14 (IQR: 8-22) SS; 391 (IQR: 300-496) AS and 12 (IQR: 8-19) SS; 6 (IQR: 0-110) AS and 0 (IQR: 0-1) SS neonates respectively. No detailed data from the universal screening programme in place in these French Overseas Departments and Territories could be accessed for comparison.

The inclusion of the complete data from national screening programmes for each maternity or testing centre would obviously result in much better estimates, but collecting these data was beyond the scope of the present study. Moreover, it appeared that existing infrastructures do not allow optimal management and centralisation of data collected locally. Further work on improving the management of these data would therefore be useful, particularly for developing countries aiming at launching a national screening programme.

References

1. Streetly A, Latinovic R, Henthorn J. Positive screening and carrier results for the England-wide universal newborn sickle cell screening programme by ethnicity and area for 2005-07. J Clin Pathol. 2010; **63**(7): 626-9.
2. Bouva MJ, Mohrmann K, Brinkman HBJM, Kemper-Proper EA, Elvers B, Loeber JG, et al. Implementing neonatal screening for haemoglobinopathies in the Netherlands. J Med Screen. 2010; **17**(2): 58-65.
3. van Heyningen AM, Levenston MJ, Tamminga N, Scoop-Martijn EG, Wever RM, Verhagen AA, et al. Estimated incidence of sickle-cell disease in Aruba and St. Maarten suggests cost-effectiveness of a universal screening programme for St. Maarten. The West Indian medical journal. 2009; **58**(4): 301-4.
4. Weatherall D, Akinyanju O, Fucharoen S, Olivieri N, Musgrove P. Inherited disorders of hemoglobin. Disease control priorities in developing countries (2nd Edition). New York: Oxford University Press; 2006. p. 663-80.
5. Balk DL, Deichmann U, Yetman G, Pozzi F, Hay SI, Nelson A. Determining global population distribution: methods, applications and data. Adv Parasitol. 2006; **62**: 119-56.
6. Guerra CA, Howes RE, Patil AP, Gething PW, Van Boeckel TP, Temperley WH, et al. The international limits and population at risk of *Plasmodium vivax* transmission in 2009. PLoS Negl Trop Dis. 2010; **4**(8): e774.
7. Gething PW, Patil AP, Guerra CA, Elyazar IR, Tatem AJ, Smith DL, et al. A Revised World Malaria Map: *Plasmodium falciparum* Endemicity in 2010. Malaria J. **Under review**.
8. Hardy GH. Mendelian proportions in a mixed population. Science. 1908; **28**(706): 49-50.
9. Weinberg W. Über den Nachweis der Vererbung beim Menschen. Jahresh Wuertt Verh Vaterl Naturkd. 1908; **64**: 369-82.
10. Grosse SD, Odame I, Atrash HK, Amendah D, Piel FB, Williams TN. Sickle cell disease in Africa: a neglected cause of early childhood mortality. Am J Prev Med. 2011; **41**(6S4): S398-S405.
11. World population prospects: The 2010 revision. http://esa.un.org/unpp. Date accessed: July 15, 2011.
12. Patil AP, Gething PW, Piel FB, Hay SI. Bayesian geostatistics in health cartography: the perspective of malaria. Trends Parasitol. 2011; **27**(6): 246-53.
13. Gilks WR, Richardson S, Spiegelhalter D. Markov chain Monte Carlo in practice: Chapman & Hall/CRC; 1995.
14. Diggle PJ, Ribeiro Jr PJ. Model-based geostatistics: Springer; 2007.
15. 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.
16. Weatherall DJ, Clegg JB. Inherited haemoglobin disorders: an increasing global health problem. Bull World Health Organ. 2001; **79**(8): 704-12.
17. Weatherall DJ. The challenge of haemoglobinopathies in resource-poor countries. Br J Haematol. 2011; **154**(6): 736-44.
18. Weatherall DJ. The inherited diseases of hemoglobin are an emerging global health burden. Blood. 2010; **115**(22): 4331-6.
19. 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**(3): e1000048.
20. Hay SI, Okiro EA, Gething PW, Patil AP, Tatem AJ, Guerra CA, et al. Estimating the global clinical burden of *Plasmodium falciparum* malaria in 2007. PLoS Med. 2010; **7**(6): e1000290.
21. Flint J, Harding RM, Boyce AJ, Clegg JB. The population genetics of the haemoglobinopathies. Baillieres Clin Haematol. 1993; **6**(1): 215-62.
22. Gabriel A, Przybylski J. Sickle-cell anemia: a look at global haplotype distribution. Nature Education. 2010; **3**(3): 2.
23. Ragusa A, Lombardo M, Sortino G, Lombardo T, Nagel RL, Labie D. Beta S gene in Sicily is in linkage disequilibrium with the Benin haplotype: implications for gene flow. Am J Hematol. 1988; **27**(2): 139-41.

24. Oner C, Dimovski AJ, Olivieri NF, Schiliro G, Codrington JF, Fattoum S, et al. Beta S haplotypes in various world populations. Hum Genet. 1992; **89**(1): 99-104.
25. Modell B, Darlison M. Global epidemiology of haemoglobin disorders and derived service indicators. Bull World Health Organ. 2008; **86**(6): 480-7.
26. Ohene-Frempong K, Oduro J, Tetteh H, Nkrumah F. Screening newborns for sickle cell disease in Ghana. Pediatrics. 2008; **121**: S120-S1.
27. National Newborn Screening Status Report. genes-r-us.uthscsa.edu/nbsdisorders.pdf. Date accessed: 26/09/2011.
28. Streetly A. A national screening policy for sickle cell disease and thalassaemia major for the United Kingdom. Br Med J. 2000; **320**(7246): 1353-4.
29. Bardakdjian-Michau J, Bahuau M, Hurtrel D, Godart C, Riou J, Mathis M, et al. Neonatal screening for sickle cell disease in France. J Clin Pathol. 2009; **62**(1): 31-3.
30. National Institute of Statistics and Economic Studies (INSEE). [cited 24/10/2011]; Available from: http://www.insee.fr

Web Tables

Web Table 1: National demographic indicators and estimates of HbS allele frequency and neonates affected. The color code indicates high uncertainty (IQR>1.5*median) in red; medium-high uncertainty (IQR>median) in orange; medium low uncertainty (IQR>0.5*median) in blue; and low uncertainty (IQR<0.5*median) in green. An asterisk (*) indicates Modell and Darlison's 2008 (M&D) estimates falling outside our 50% credible interval (IQR). A double asterisk (**) indicates M&D estimat+C237es falling outside our 90% credible interval. The full legend is shown at the bottom of the Table (p.33).

Country[1]	Population[2]	CBR[3]	WHO/HbS region[4]	Surveys	HbS AF (IQR[5])	AS neonates/year (IQR5)	SS neonates/year (IQR5)	M&D[6]
Afghanistan	29,117	0.0423	EMRO/Arab-India	1	0.000 (0.000-0.001)	144 (13-1,078)	0 (0-8)	0
Albania	3,158	0.0128	EURO/Eurasia	1	0.014 (0.009-0.022)	1,391 (863-2,112)	30 (14-58)	11 *
Algeria	35,423	0.0192	AFRO/Eurasia	18	0.007 (0.005-0.010)	10,486 (7,351-15,100)	191 (115-332)	50 **
Angola	18,994	0.0399	AFRO/Sub-Saharan Africa	18	0.137 (0.097-0.192)	112,443 (90,764-135,659)	8,364 (5,880-11,735)	9,560
Argentina	40,668	0.0168	AMRO/Americas	0	0.000 (0.000-0.001)	444 (131-1,273)	4 (1-22)	0 **
Armenia	3,093	0.0150	EURO/Eurasia	0	0.000 (0.000-0.001)	0 (0-8)	0 (0-0)	0
Aruba	107	0.0111	AMRO/Americas	1	0.016 (0.010-0.024)	48 (30-72)	1 (0-2)	0 **
Australia	21,510	0.0135	WPRO/Southeast Asia	2	0.001 (0.001-0.002)	663 (281-1,415)	5 (1-18)	0 *
Austria	8,403	0.0086	EURO/Eurasia	0	0.002 (0.000-0.005)	143 (19-691)	1 (0-10)	0 *
Azerbaijan	8,932	0.0195	EURO/Eurasia	0	0.000 (0.000-0.001)	4 (0-92)	0 (0-0)	4 *
Bahamas	346	0.0152	AMRO/Americas	1	0.024 (0.011-0.054)	287 (130-559)	8 (3-24)	34 *
Bahrain	807	0.0179	EMRO/Arab-India	0	0.050 (0.031-0.076)	1,548 (1,104-2,016)	59 (32-98)	81
Bangladesh	164,424	0.0195	SEAR/Arab-India	0	0.001 (0.001-0.002)	3,459 (847-11,777)	16 (2-101)	0 **
Barbados	257	0.0109	AMRO/Americas	0	0.025 (0.010-0.063)	179 (66-350)	4 (1-15)	4
Belarus	9,579	0.0112	EURO/Eurasia	0	0.000 (0.000-0.000)	0 (0-7)	0 (0-0)	0
Belgium	10,715	0.0114	EURO/Eurasia	18	0.008 (0.006-0.011)	2,302 (1,695-3,094)	29 (17-49)	5 **
Belize	313	0.0240	AMRO/Americas	3	0.075 (0.051-0.112)	937 (719-1,178)	47 (31-70)	5 **
Benin	9,219	0.0383	AFRO/Sub-Saharan Africa	9	0.159 (0.130-0.191)	64,207 (58,876-69,623)	4,543 (3,808-5,362)	3,561 *
Bhutan	723	0.0196	SEAR/Southeast Asia	0	0.001 (0.000-0.002)	4 (0-26)	0 (0-0)	0
Bolivia (Plurinational State of)	9,995	0.0258	AMRO/Americas	0	0.000 (0.000-0.000)	6 (0-45)	0 (0-0)	0
Bosnia and Herzegovina	3,746	0.0082	EURO/Eurasia	0	0.003 (0.001-0.007)	120 (18-509)	1 (0-8)	0 *
Botswana	1,977	0.0229	AFRO/Sub-Saharan Africa	4	0.003 (0.002-0.007)	300 (120-693)	4 (1-15)	0 **
Brazil	195,453	0.0150	AMRO/Americas	47	0.017 (0.013-0.022)	101,138 (81,605-124,941)	3,244 (2,312-4,570)	764 **
Brunei Darussalam	410	0.0182	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Bulgaria	7,491	0.0100	EURO/Eurasia	0	0.007 (0.003-0.015)	1,076 (377-2,510)	17 (4-64)	0 **
Burkina Faso	16,250	0.0424	AFRO/Sub-Saharan Africa	51	0.056 (0.049-0.064)	71,083 (65,562-76,864)	3,124 (2,681-3,609)	1,065 **
Burundi	8,519	0.0333	AFRO/Sub-Saharan Africa	2	0.040 (0.029-0.057)	24,365 (19,070-30,317)	889 (577-1,322)	2,449 **
Cambodia	15,056	0.0216	WPRO/Southeast Asia	1	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Cameroon	19,957	0.0349	AFRO/Sub-Saharan Africa	34	0.120 (0.105-0.138)	109,857 (102,502-117,187)	6,915 (6,069-7,853)	5,906 *
Canada	33,871	0.0113	AMRO/Americas	3	0.004 (0.002-0.006)	3,004 (1,678-5,163)	45 (17-104)	43
Cape Verde	513	0.0199	AFRO/Sub-Saharan Africa	3	0.026 (0.018-0.036)	625 (463-800)	18 (11-28)	6 *
Central African Republic	4,506	0.0345	AFRO/Sub-Saharan Africa	2	0.077 (0.052-0.113)	18,315 (14,060-22,742)	976 (638-1,437)	677
Chad	11,509	0.0434	AFRO/Sub-Saharan Africa	6	0.051 (0.038-0.069)	43,553 (35,604-52,360)	2,045 (1,459-2,788)	908 *
Chile	17,135	0.0140	AMRO/Americas	4	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
China	1,381,710	0.0119	WPRO/Southeast Asia	8	0.000 (0.000-0.000)	43 (3-384)	0 (0-1)	0
Colombia	46,305	0.0189	AMRO/Americas	2	0.008 (0.004-0.014)	14,464 (7,675-25,504)	321 (126-742)	537
Comoros	691	0.0357	AFRO/Sub-Saharan Africa	2	0.018 (0.011-0.031)	1,105 (660-1,736)	25 (10-56)	0 **
Congo	3,760	0.0346	AFRO/Sub-Saharan Africa	4	0.145 (0.112-0.190)	22,773 (19,572-25,999)	1,560 (1,218-2,008)	2,042 *

Country[1]	Population[2]	CBR[3]	WHO/HbS region[4]	Surveys	HbS AF (IQR[5])	AS neonates/year (IQR5)	SS neonates/year (IQR5)	M&D[6]
Congo, the Democratic Republic of the	67,829	0.0421	AFRO/Sub-Saharan Africa	11	0.165 (0.142-0.191)	489,745 (455,733-524,014)	38,217 (32,838-44,870)	20,113 **
Costa Rica	4,640	0.0153	AMRO/Americas	1	0.016 (0.008-0.033)	2,731 (1,211-5,281)	60 (18-173)	8 *
Côte d'Ivoire	21,571	0.0330	AFRO/Sub-Saharan Africa	7	0.062 (0.047-0.082)	74,168 (61,560-88,026)	3,567 (2,648-4,773)	1,564 **
Croatia	4,410	0.0098	EURO/Eurasia	0	0.002 (0.001-0.006)	137 (22-572)	1 (0-10)	0 *
Cuba	11,204	0.0096	AMRO/Americas	1	0.030 (0.017-0.054)	6,578 (4,194-9,570)	240 (111-465)	259
Cyprus	846	0.0115	EURO/Eurasia	1	0.007 (0.004-0.013)	147 (61-308)	2 (0-6)	0 *
Czech Republic	10,410	0.0109	EURO/Eurasia	0	0.001 (0.000-0.003)	59 (4-512)	0 (0-5)	0
Denmark	5,482	0.0113	EURO/Eurasia	0	0.000 (0.000-0.002)	11 (0-136)	0 (0-1)	2 *
Djibouti	879	0.0284	EMRO/Sub-Saharan Africa	0	0.001 (0.000-0.001)	3 (0-29)	0 (0-0)	0
Dominican Republic	10,225	0.0209	AMRO/Americas	0	0.019 (0.009-0.040)	9,461 (4,334-17,804)	247 (78-672)	722 *
Ecuador	13,775	0.0198	AMRO/Americas	0	0.000 (0.000-0.001)	45 (3-389)	0 (0-3)	12 *
Egypt	84,472	0.0223	EMRO/Eurasia	5	0.012 (0.006-0.024)	47,754 (21,874-92,324)	1,196 (395-3,096)	19 **
El Salvador	6,201	0.0200	AMRO/Americas	1	0.014 (0.008-0.022)	4,039 (2,370-6,240)	80 (33-168)	8 *
Equatorial Guinea	693	0.0359	AFRO/Sub-Saharan Africa	2	0.192 (0.144-0.253)	5,059 (4,441-5,668)	385 (297-493)	182 **
Eritrea	5,204	0.0344	AFRO/Sub-Saharan Africa	0	0.003 (0.001-0.006)	767 (265-2,109)	9 (2-34)	0 **
Estonia	1,340	0.0121	EURO/Eurasia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Ethiopia	84,996	0.0300	AFRO/Sub-Saharan Africa	8	0.003 (0.002-0.004)	11,197 (6,431-18,883)	137 (60-294)	1 **
Fiji	854	0.0206	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Finland	5,346	0.0114	EURO/Eurasia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
France	62,618	0.0124	EURO/Eurasia	7	0.013 (0.009-0.018)	22,040 (15,621-30,597)	520 (290-915)	79 **
French Guiana	231	0.0240	AMRO/Americas	6	0.015 (0.011-0.021)	186 (133-251)	5 (3-8)	4
French Polynesia	272	0.0164	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Gabon	1,501	0.0270	AFRO/Sub-Saharan Africa	3	0.280 (0.223-0.342)	9,342 (8,503-10,189)	864 (705-1,059)	736
Gambia	1,751	0.0369	AFRO/Sub-Saharan Africa	29	0.075 (0.065-0.087)	8,657 (7,977-9,355)	418 (359-487)	305 *
Georgia	4,221	0.0115	EURO/Eurasia	0	0.000 (0.000-0.000)	0 (0-4)	0 (0-0)	0
Germany	82,014	0.0087	EURO/Eurasia	0	0.004 (0.002-0.008)	5,940 (2,480-12,680)	85 (22-267)	23
Ghana	24,339	0.0303	AFRO/Sub-Saharan Africa	52	0.087 (0.079-0.097)	102,229 (96,569-107,899)	5,474 (4,924-6,051)	4,847 *
Greece	11,194	0.0101	EURO/Eurasia	31	0.026 (0.020-0.037)	6,667 (5,142-8,664)	206 (142-322)	1 **
Grenada	104	0.0193	AMRO/Americas	0	0.037 (0.016-0.079)	174 (84-284)	6 (2-14)	5
Guadeloupe	467	0.0132	AMRO/Americas	1	0.031 (0.022-0.044)	459 (343-594)	14 (8-22)	16
Guam	180	0.0176	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Guatemala	14,378	0.0315	AMRO/Americas	0	0.011 (0.006-0.020)	10,285 (5,208-19,137)	252 (105-570)	0 **
Guinea	10,324	0.0376	AFRO/Sub-Saharan Africa	1	0.168 (0.128-0.213)	70,965 (62,302-79,040)	5,232 (4,063-6,564)	4,325
Guinea-Bissau	1,647	0.0374	AFRO/Sub-Saharan Africa	4	0.041 (0.029-0.057)	5,011 (3,938-6,175)	192 (123-284)	0 **
Guyana	761	0.0174	AMRO/Americas	0	0.021 (0.009-0.049)	622 (251-1,247)	17 (5-53)	11
Haiti	10,189	0.0257	AMRO/Americas	8	0.051 (0.038-0.069)	26,801 (21,627-32,317)	1,088 (756-1,531)	622 *
Honduras	7,609	0.0258	AMRO/Americas	0	0.049 (0.027-0.092)	17,783 (11,179-25,925)	772 (368-1,473)	0 **
Hong Kong	7,288	0.0088	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Hungary	9,979	0.0101	EURO/Eurasia	1	0.001 (0.000-0.003)	59 (4-406)	0 (0-4)	0
Iceland	329	0.0147	EURO/Eurasia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
India	1,196,940	0.0213	SEAR/Arab-India	113	0.023 (0.020-0.027)	996,563 (883,210-1,135,290)	42,016 (35,347-50,919)	25,768 **
Indonesia	232,546	0.0174	SEAR/Southeast Asia	14	0.000 (0.000-0.000)	328 (79-1,206)	1 (0-7)	0 *
Iran, Islamic Republic of	75,084	0.0162	EMRO/Arab-India	0	0.011 (0.007-0.018)	25,768 (16,613-39,359)	862 (444-1,581)	96 **

Country[1]	Population[2]	CBR[3]	WHO/HbS region[4]	Surveys	HbS AF (IQR[5])	AS neonates/year (IQR5)	SS neonates/year (IQR5)	M&D[6]
Iraq	31,443	0.0341	EMRO/Arab-India	1	0.010 (0.005-0.022)	23,488 (11,617-47,957)	629 (255-1,595)	499
Ireland	4,588	0.0156	EURO/Eurasia	0	0.001 (0.000-0.003)	60 (5-447)	0 (0-4)	0
Italy	60,119	0.0091	EURO/Eurasia	41	0.005 (0.003-0.009)	5,635 (3,028-10,363)	91 (37-236)	3 **
Jamaica	2,730	0.0179	AMRO/Americas	4	0.037 (0.029-0.048)	3,998 (3,282-4,820)	137 (99-189)	172
Japan	126,995	0.0085	WPRO/Southeast Asia	1	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Jordan	6,461	0.0237	EMRO/Eurasia	2	0.017 (0.012-0.026)	6,365 (4,245-9,313)	145 (80-260)	4 **
Kazakhstan	15,758	0.0206	EURO/Eurasia	0	0.000 (0.000-0.000)	1 (0-11)	0 (0-0)	0
Kenya	40,835	0.0369	AFRO/Sub-Saharan Africa	51	0.038 (0.034-0.043)	98,471 (89,175-108,467)	4,475 (3,879-5,137)	7,872 **
Korea, Democratic People's Republic of	23,963	0.0142	SEAR/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Korea, Republic of	48,517	0.0099	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Kuwait	3,050	0.0174	EMRO/Arab-India	0	0.031 (0.014-0.065)	3,824 (1,878-6,476)	116 (36-293)	37
Kyrgyzstan	5,545	0.0240	EURO/Eurasia	0	0.000 (0.000-0.000)	0 (0-1)	0 (0-0)	0
Lao People's Democratic Republic	6,434	0.0218	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Latvia	2,241	0.0110	EURO/Eurasia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Lebanon	4,237	0.0149	EMRO/Eurasia	1	0.049 (0.033-0.071)	6,382 (4,808-8,044)	251 (152-382)	6 **
Lesotho	2,064	0.0271	AFRO/Sub-Saharan Africa	0	0.001 (0.000-0.003)	40 (4-244)	0 (0-2)	0
Liberia	4,102	0.0376	AFRO/Sub-Saharan Africa	15	0.046 (0.038-0.057)	13,217 (11,487-14,919)	562 (443-714)	105 **
Libyan Arab Jamahiriya	6,546	0.0217	EMRO/Eurasia	4	0.021 (0.015-0.027)	6,020 (4,673-7,559)	188 (128-267)	34 **
Lithuania	3,256	0.0108	EURO/Eurasia	0	0.000 (0.000-0.000)	0 (0-1)	0 (0-0)	0
Luxembourg	493	0.0118	EURO/Eurasia	0	0.005 (0.003-0.008)	48 (20-105)	0 (0-1)	0
Madagascar	20,146	0.0346	AFRO/Sub-Saharan Africa	37	0.061 (0.053-0.070)	69,295 (63,138-75,644)	3,379 (2,902-3,915)	2,084 **
Malawi	15,690	0.0445	AFRO/Sub-Saharan Africa	15	0.033 (0.023-0.050)	47,370 (35,308-61,509)	1,688 (1,029-2,765)	917 *
Malaysia	27,949	0.0198	WPRO/Southeast Asia	6	0.000 (0.000-0.000)	1 (0-14)	0 (0-0)	0
Maldives	314	0.0165	SEAR/Eurasia	0	0.000 (0.000-0.000)	0 (0-1)	0 (0-0)	0 *
Mali	13,362	0.0450	AFRO/Sub-Saharan Africa	8	0.057 (0.044-0.072)	56,236 (47,355-65,909)	2,701 (2,068-3,509)	4,421 *
Malta	410	0.0091	EURO/Eurasia	0	0.015 (0.007-0.031)	143 (61-284)	2 (1-8)	0 **
Martinique	406	0.0116	AMRO/Americas	1	0.035 (0.025-0.049)	391 (300-496)	12 (8-19)	9
Mauritania	3,359	0.0327	AFRO/Sub-Saharan Africa	1	0.050 (0.030-0.085)	9,505 (6,585-12,929)	433 (240-748)	159 *
Mauritius	1,297	0.0125	AFRO/Sub-Saharan Africa	0	0.000 (0.000-0.001)	0 (0-19)	0 (0-0)	1 *
Mayotte	199	0.0326	AFRO/Sub-Saharan Africa	0	0.027 (0.010-0.070)	447 (168-863)	12 (2-40)	0 *
Mexico	110,567	0.0185	AMRO/Americas	34	0.007 (0.005-0.009)	31,120 (23,289-41,145)	641 (422-975)	105 **
Micronesia, Federated States of	112	0.0242	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Moldova, Republic of	3,538	0.0121	*/Eurasia	0	0.000 (0.000-0.001)	1 (0-22)	0 (0-0)	0
Mongolia	2,706	0.0227	WPRO/Eurasia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Montenegro	654	0.0120	EURO/Eurasia	0	0.005 (0.002-0.012)	72 (16-226)	1 (0-4)	0 *
Morocco	31,943	0.0187	EMRO/Eurasia	0	0.003 (0.001-0.008)	3,202 (824-10,051)	40 (6-215)	118
Mozambique	23,418	0.0363	AFRO/Sub-Saharan Africa	14	0.027 (0.021-0.035)	42,588 (34,837-51,562)	1,645 (1,193-2,235)	170 **
Myanmar	50,503	0.0167	SEAR/Southeast Asia	6	0.000 (0.000-0.000)	40 (5-222)	0 (0-1)	0
Namibia	2,212	0.0252	AFRO/Sub-Saharan Africa	8	0.010 (0.006-0.015)	1,138 (730-1,806)	30 (17-55)	10 *
Nepal	29,950	0.0232	SEAR/Arab-India	1	0.002 (0.001-0.004)	1,558 (357-4,805)	11 (1-67)	0 **
Netherlands	16,649	0.0108	EURO/Eurasia	2	0.011 (0.008-0.016)	4,759 (3,163-6,819)	82 (43-149)	10 **
Netherlands Antilles	201	0.0131	AMRO/Americas	2	0.023 (0.016-0.032)	150 (105-203)	4 (2-6)	9 *
New Caledonia	254	0.0159	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
New Zealand	4,303	0.0143	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	9 **

Country[1]	Population[2]	CBR[3]	WHO/HbS region[4]	Surveys	HbS AF (IQR[5])	AS neonates/year (IQR5)	SS neonates/year (IQR5)	M&D[6]
Nicaragua	5,822	0.0228	AMRO/Americas	0	0.023 (0.009-0.054)	6,514 (2,641-12,964)	204 (53-576)	4 *
Niger	15,885	0.0477	AFRO/Sub-Saharan Africa	7	0.080 (0.058-0.111)	90,671 (73,050-109,417)	4,965 (3,543-6,894)	6,046
Nigeria	158,255	0.0393	AFRO/Sub-Saharan Africa	24	0.171 (0.153-0.192)	1,136,909 (1,070,320-1,200,907)	85,186 (76,413-94,945)	77,192
Norway	4,856	0.0123	EURO/Eurasia	0	0.000 (0.000-0.000)	0 (0-13)	0 (0-0)	2 *
Oman	2,962	0.0169	EMRO/Arab-India	2	0.001 (0.000-0.001)	32 (9-94)	0 (0-1)	222 **
Pakistan	184,754	0.0263	EMRO/Arab-India	1	0.002 (0.001-0.005)	18,962 (7,260-47,537)	228 (53-892)	101
Panama	3,508	0.0191	AMRO/Americas	3	0.030 (0.019-0.046)	4,457 (3,053-6,176)	140 (77-244)	8 **
Papua New Guinea	6,886	0.0290	WPRO/Southeast Asia	1	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Paraguay	6,462	0.0237	AMRO/Americas	0	0.003 (0.001-0.006)	664 (178-2,093)	7 (1-36)	0 **
Peru	29,493	0.0196	AMRO/Americas	10	0.000 (0.000-0.000)	2 (0-22)	0 (0-0)	25 **
Philippines	93,617	0.0245	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Poland	38,049	0.0109	EURO/Eurasia	0	0.000 (0.000-0.001)	59 (3-590)	0 (0-4)	0
Portugal	10,229	0.0088	EURO/Eurasia	2	0.010 (0.007-0.017)	2,170 (1,303-3,598)	41 (19-90)	3 **
Puerto Rico	3,998	0.0129	AMRO/Americas	1	0.004 (0.002-0.006)	326 (127-710)	2 (1-8)	23 *
Qatar	1,508	0.0116	EMRO/Arab-India	0	0.032 (0.015-0.068)	1,365 (668-2,262)	41 (12-104)	7 *
Réunion	837	0.0169	*/	0	0.001 (0.000-0.004)	6 (0-110)	0 (0-1)	1 *
Romania	21,209	0.0103	EURO/Eurasia	0	0.001 (0.000-0.004)	320 (45-1,500)	2 (0-21)	0 *
Russian Federation	140,324	0.0118	EURO/Eurasia	0	0.000 (0.000-0.000)	14 (1-135)	0 (0-0)	0
Rwanda	10,277	0.0406	AFRO/Sub-Saharan Africa	2	0.023 (0.018-0.029)	22,857 (18,400-28,098)	601 (423-846)	125 **
Saint Lucia	174	0.0169	AMRO/Americas	1	0.049 (0.031-0.074)	311 (223-402)	12 (6-19)	7
Saint Vincent and the Grenadines	109	0.0164	AMRO/Americas	0	0.045 (0.022-0.086)	176 (99-262)	6 (2-13)	2
Samoa	530	0.0237	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Saudi Arabia	26,207	0.0214	EMRO/Arab-India	28	0.018 (0.016-0.021)	19,447 (17,012-22,221)	691 (572-842)	5,397 **
Sao Tome and Principe	165	0.0299	AFRO/Sub-Saharan Africa	0	0.094 (0.033-0.236)	763 (376-1,132)	41 (12-92)	49
Senegal	12,866	0.0359	AFRO/Sub-Saharan Africa	20	0.067 (0.054-0.082)	53,002 (46,123-60,123)	2,535 (1,998-3,163)	1,895 *
Serbia	9,842	0.0110	EURO/Eurasia	0	0.004 (0.002-0.010)	830 (225-2,417)	10 (1-49)	0 **
Sierra Leone	5,837	0.0365	AFRO/Sub-Saharan Africa	0	0.164 (0.108-0.240)	39,530 (31,971-47,084)	2,838 (1,906-4,018)	3,243
Singapore	4,777	0.0095	WPRO/Southeast Asia	1	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Slovakia	5,406	0.0107	EURO/Eurasia	0	0.001 (0.000-0.002)	12 (0-125)	0 (0-1)	0
Slovenia	2,027	0.0099	EURO/Eurasia	0	0.001 (0.000-0.005)	22 (2-176)	0 (0-2)	0
Solomon Islands	536	0.0304	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Somalia	9,359	0.0430	EMRO/Sub-Saharan Africa	2	0.002 (0.001-0.005)	1,192 (321-3,777)	13 (2-69)	0 *
South Africa	50,523	0.0205	AFRO/Sub-Saharan Africa	3	0.003 (0.002-0.004)	4,946 (2,617-8,872)	73 (28-177)	0 **
Spain	45,322	0.0106	EURO/Eurasia	4	0.007 (0.004-0.012)	7,324 (4,253-12,071)	149 (64-341)	0 **
Sri Lanka	20,410	0.0170	SEAR/Arab-India	28	0.001 (0.001-0.002)	425 (295-590)	2 (1-3)	0 **
Sudan	43,182	0.0319	AFRO/Sub-Saharan Africa	32	0.043 (0.034-0.055)	98,244 (84,697-113,554)	4,567 (3,527-5,894)	483 **
Suriname	524	0.0178	AMRO/Americas	0	0.030 (0.013-0.066)	653 (300-1,162)	19 (6-53)	13
Swaziland	1,195	0.0287	AFRO/Sub-Saharan Africa	0	0.006 (0.003-0.010)	398 (173-813)	4 (1-13)	1
Sweden	9,292	0.0120	EURO/Eurasia	0	0.000 (0.000-0.001)	2 (0-41)	0 (0-0)	4 *
Switzerland	7,597	0.0100	EURO/Eurasia	0	0.004 (0.002-0.011)	622 (145-1,907)	6 (1-36)	0 *
Syrian Arab Republic	22,627	0.0219	EMRO/Eurasia	4	0.025 (0.019-0.033)	24,448 (19,056-31,267)	901 (664-1,261)	66 **
Tajikistan	7,078	0.0277	EURO/Eurasia	0	0.000 (0.000-0.000)	0 (0-6)	0 (0-0)	0
Tanzania, United Republic of	45,028	0.0410	AFRO/Sub-Saharan Africa	57	0.074 (0.063-0.087)	203,747 (185,237-222,866)	11,022 (9,327-12,897)	8,655 *
Thailand	68,141	0.0115	SEAR/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-10)	0 (0-0)	0

Country[1]	Population[2]	CBR[3]	WHO/HbS region[4]	Surveys	HbS AF (IQR[5])	AS neonates/year (IQR5)	SS neonates/year (IQR5)	M&D[6]
Timor-Leste	1,167	0.0376	SEAR/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Togo	6,774	0.0310	AFRO/Sub-Saharan Africa	4	0.125 (0.105-0.149)	34,057 (31,180-36,958)	2,175 (1,846-2,540)	1,746 *
Trinidad and Tobago	1,344	0.0143	AMRO/Americas	1	0.038 (0.026-0.056)	1,648 (1,207-2,154)	56 (33-91)	30 *
Tonga	104	0.0257	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Tunisia	10,374	0.0165	EMRO/Eurasia	12	0.011 (0.009-0.013)	4,420 (3,623-5,372)	81 (58-113)	63
Turkey	75,699	0.0169	EURO/Eurasia	45	0.005 (0.004-0.007)	12,852 (9,281-20,051)	330 (248-526)	116 **
Turkmenistan	5,178	0.0212	EURO/Eurasia	0	0.000 (0.000-0.001)	4 (0-54)	0 (0-0)	0
Uganda	33,798	0.0439	AFRO/Sub-Saharan Africa	11	0.082 (0.067-0.100)	189,801 (169,157-210,719)	10,143 (8,223-12,325)	8,216 *
Ukraine	45,454	0.0109	EURO/Eurasia	0	0.000 (0.000-0.001)	33 (2-293)	0 (0-2)	0
United Arab Emirates	4,647	0.0123	EMRO/Arab-India	2	0.004 (0.002-0.007)	402 (189-827)	4 (1-11)	24 *
United Kingdom	61,900	0.0121	EURO/Eurasia	4	0.009 (0.007-0.013)	15,746 (10,982-21,949)	296 (163-517)	108 *
United States of America	317,736	0.0137	AMRO/Americas	25	0.011 (0.009-0.014)	100,150 (82,111-122,520)	2,843 (2,038-3,968)	838 **
Uruguay	3,373	0.0145	AMRO/Americas	0	0.001 (0.001-0.003)	82 (26-231)	1 (0-3)	0 **
Uzbekistan	27,790	0.0208	EURO/Eurasia	0	0.000 (0.000-0.000)	1 (0-24)	0 (0-0)	0
Vanuatu	246	0.0287	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-0)	0 (0-0)	0
Venezuela, Bolivarian Republic of	29,044	0.0198	AMRO/Americas	40	0.014 (0.012-0.017)	19,272 (16,150-22,799)	435 (325-591)	108 **
Viet Nam	89,009	0.0159	WPRO/Southeast Asia	0	0.000 (0.000-0.000)	0 (0-4)	0 (0-0)	0
Virgin Islands, U.S.	109	0.0121	*/	0	0.008 (0.004-0.018)	25 (8-59)	0 (0-1)	4 *
Western Sahara	441	0.0213	*/	0	0.007 (0.003-0.017)	144 (51-330)	3 (1-10)	2
Yemen	24,325	0.0372	EMRO/Sub-Saharan Africa	1	0.004 (0.002-0.006)	6,411 (3,355-12,043)	80 (29-207)	119
Zambia	13,254	0.0465	AFRO/Sub-Saharan Africa	11	0.112 (0.095-0.133)	88,801 (80,963-96,982)	5,652 (4,801-6,632)	3,346 **
Zimbabwe	12,645	0.0287	AFRO/Sub-Saharan Africa	7	0.021 (0.016-0.028)	16,345 (12,706-20,982)	483 (326-704)	162 **

1. Official country names consistent with ISO 3166-1. The following countries are not shown: Åland Islands; Aksai Chin; American Samoa; Andorra; Anguilla; Antarctica; Antigua and Barbuda; Arunachal Pradesh; Ashmore and Cartier Islands; Azores Islands; Baker Island; Bassas da India; Bermuda; Bird Island; Bonaire; Sint Eustatius and Saba; Bouvet Island; British Indian Ocean Territory; British Virgin Islands; Cayman Islands; China/India; Christmas Island; Clipperton Island; Cocos (Keeling) Islands; Cook Islands; Curaçao; Dhekelia and Akrotiri SBA; Dominica; Europa Island; Falkland Islands (Malvinas); Faroe Islands; French Southern Territories; Gaza Strip; Gibraltar; Glorioso Island; Greenland; Guernsey; Hala'ib triangle; Heard Island and McDonald Islands; Holy See (Vatican City State); Howland Island; Ilemi triangle; Isle of Man; Jammu Kashmir; Jarvis Island; Jersey; Johnston Atoll; Juan de Nova Island; Kashmir; Kingman Reef; Kiribati; Kuril islands; Liancourt Rock; Liechtenstein; Madeira Islands; Marshall Islands; Ma'tan al-Sarra; Midway Island; Monaco; Montserrat; Nauru; Navassa Island; Niue; Norfolk Island; Northern Mariana Islands; Palau; Palestinian Territory, Occupied; Palmyra Atoll; Paracel Islands; Pitcairn; Saint Bathélemy; Saint Helena, Ascension and Tristan de Cunha; Saint Kitts and Nevis; Saint Martin (French Part); Saint Pierre and Miquelon; San Marino; Scarborough Reef; Senkaku Islands; Seychelles; Sint Maarten (Dutch part); South Georgia and the South Sandwich Islands; Svalbard and Jan Mayen; Taiwan, Province of China; Tokelau; Trinidad and Tobago; Tromelin Island; Turks and Caicos islands; Tuvalu; United States Minor Outlying Islands; Virgin Islands, British; Wake Island; Wallis and Futuna; West Bank.

2. In thousands. Population data were obtained for the year 2000 from the Global Rural Urban Mapping Project (GRUMP) alpha version and projected to 2010 by applying United Nations national, medium variant, inter-censal growth rates by country [24].

3. CBR = Crude birth rate. Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2010 Revision, http://esa.un.org/unpd/wpp/index.htm,Monday, July 25, 2011.

4. World Health Organisation Regional Offices: AFRO, African; SEARO, South East Asian; WPRO, Western Pacific; EMRO, Eastern Mediterranean; AMRO, American; EURO, European.

5. IQR: interquartile range of the posterior predictive distribution for each population at risk estimate. The color code indicates high uncertainty (IQR>1.5*median) in red; medium-high uncertainty (IQR>median) in orange; medium low uncertainty (IQR>0.5*median) in blue; and low uncertainty (IQR<0.5*median) in green.

6. SS neonate estimates from Modell B, Darlison M (2008) Global epidemiology of haemoglobin disorders and derived service indicators. Bull World Health Organ 86: 480-487 [7]. C54

Web Table 2: National areal prediction summaries and Monte Carlo standard errors (SE) for AS and SS neonate estimates

	HbS heterozygote neonates (AS)								HbS homozygote neonates (SS)							
COUNTRY[1]	**Mean**	***SE***	**Median**	***SE***	**Q25%**	***SE***	**Q75%**	***SE***	**Mean**	***SE***	**Median**	***SE***	**Q25%**	***SE***	**Q75%**	***SE***
Afghanistan	1,889	*37*	144	*8*	13	*1*	1,078	*39*	40	*2*	0	*0*	0	*0*	8	*0*
Albania	1,619	*6*	1,391	*8*	863	*9*	2,112	*12*	44	*0*	30	*0*	14	*0*	58	*1*
Algeria	11,939	*84*	10,486	*88*	7,351	*94*	15,100	*113*	267	*3*	191	*3*	115	*2*	332	*5*
Angola	114,473	*451*	112,443	*369*	90,764	*554*	135,659	*578*	9,761	*73*	8,364	*51*	5,880	*49*	11,735	*76*
Argentina	1,436	*32*	444	*20*	131	*7*	1,273	*38*	38	*2*	4	*0*	1	*0*	22	*1*
Armenia	60	*4*	0	*0*	0	*0*	8	*1*	1	*0*	0	*0*	0	*0*	0	*0*
Aruba	54	*0*	48	*0*	30	*0*	72	*0*	1	*0*	1	*0*	0	*0*	2	*0*
Australia	1,101	*20*	663	*14*	281	*9*	1,415	*27*	17	*0*	5	*0*	1	*0*	`	*0*
Austria	727	*11*	143	*3*	19	*1*	691	*18*	23	*1*	1	*0*	0	*0*	10	*0*
Azerbaijan	398	*13*	4	*0*	0	*0*	92	*8*	10	*1*	0	*0*	0	*0*	0	*0*
Bahamas	376	*3*	287	*4*	130	*2*	559	*6*	19	*0*	8	*0*	3	*0*	24	*0*
Bahrain	2,468	*8*	1,548	*13*	1,104	*16*	2,016	*9*	71	*0*	59	*1*	32	*1*	98	*1*
Bangladesh	10,409	*234*	3,459	*113*	847	*32*	11,777	*323*	195	*8*	16	*1*	2	*0*	101	*4*
Barbados	243	*2*	179	*2*	66	*1*	350	*5*	12	*0*	4	*0*	1	*0*	15	*0*
Belarus	94	*5*	0	*0*	0	*0*	7	*0*	3	*0*	0	*0*	0	*0*	0	*0*
Belgium	2,499	*9*	2,302	*8*	1,695	*8*	3,094	*17*	38	*0*	29	*0*	17	*0*	49	*1*
Belize	950	*2*	937	*3*	719	*3*	1,178	*3*	54	*0*	47	*0*	31	*0*	70	*0*
Benin	61,586	*149*	64,207	*138*	58,876	*181*	69,623	*145*	4,637	*17*	4,543	*21*	3,808	*22*	5,362	*19*
Bhutan	33	*1*	4	*0*	0	*0*	26	*1*	0	*0*	0	*0*	0	*0*	0	*0*
Bolivia (Plurinational State of)	136	*5*	6	*0*	0	*0*	45	*2*	3	*0*	0	*0*	0	*0*	0	*0*
Bosnia and Herzegovina	487	*12*	120	*5*	18	*1*	509	*16*	16	*1*	1	*0*	0	*0*	8	*0*
Botswana	557	*6*	300	*5*	120	*3*	693	*11*	16	*0*	4	*0*	1	*0*	15	*0*
Brazil	105,051	*455*	101,138	*532*	81,605	*771*	124,941	*488*	3,697	*25*	3,244	*28*	2,312	*28*	4,570	*38*
Brunei Darussalam	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Bulgaria	1,840	*30*	1,076	*29*	377	*12*	2,510	*38*	61	*1*	17	*1*	4	*0*	64	*1*
Burkina Faso	72,279	*126*	71,083	*100*	65,562	*96*	76,864	*214*	3,179	*9*	3,124	*8*	2,681	*8*	3,609	*15*
Burundi	24,599	*52*	24,365	*56*	19,070	*65*	30,317	*108*	1,017	*5*	889	*2*	577	*4*	1,322	*8*
Cambodia	21	*2*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Cameroon	107,877	*219*	109,857	*203*	102,502	*238*	117,187	*268*	7,033	*24*	6,915	*24*	6,069	*24*	7,853	*37*
Canada	3,971	*50*	3,004	*50*	1,678	*32*	5,163	*68*	90	*2*	45	*1*	17	*0*	104	*2*
Cape Verde	622	*2*	625	*2*	463	*2*	800	*3*	21	*0*	18	*0*	11	*0*	28	*0*
Central African Republic	18,179	*67*	18,315	*79*	14,060	*97*	22,742	*59*	1,126	*7*	976	*8*	638	*7*	1,437	*10*
Chad	43,331	*156*	43,553	*189*	35,604	*150*	52,360	*191*	2,224	*14*	2,045	*14*	1,459	*9*	2,788	*18*
Chile	4	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
China	941	*48*	43	*6*	3	*1*	384	*43*	19	*2*	0	*0*	0	*0*	1	*0*
Colombia	18,814	*58*	14,464	*175*	7,675	*109*	25,504	*207*	591	*3*	321	*5*	126	*3*	742	*8*
Comoros	1,364	*7*	1,105	*12*	660	*8*	1,736	*9*	44	*0*	25	*0*	10	*0*	56	*0*

COUNTRY[1]	Mean	SE	Median	SE	Q25%	SE	Q75%	SE	Mean	SE	Median	SE	Q25%	SE	Q75%	SE
Congo	24,627	*38*	22,773	*58*	19,572	*60*	25,999	*77*	1,729	*10*	1,560	*6*	1,218	*4*	2,008	*11*
Costa Rica	3,685	*22*	2,731	*27*	1,211	*32*	5,281	*46*	141	*2*	60	*1*	18	*1*	173	*3*
Côte d'Ivoire	69,104	*194*	74,168	*243*	61,560	*194*	88,026	*221*	3,890	*20*	3,567	*16*	2,648	*19*	4,773	*27*
Croatia	542	*7*	137	*3*	22	*1*	572	*12*	18	*0*	1	*0*	0	*0*	10	*0*
Cuba	7,187	*35*	6,578	*29*	4,194	*40*	9,570	*56*	345	*3*	240	*2*	111	*2*	465	*3*
Cyprus	296	*2*	147	*3*	61	*1*	308	*5*	5	*0*	2	*0*	0	*0*	6	*0*
Czech Republic	748	*18*	59	*3*	4	*0*	512	*22*	22	*1*	0	*0*	0	*0*	5	*0*
Democratic Republic of the Congo	477,016	*1,714*	489,745	*2,002*	455,733	*1,504*	524,014	*2,012*	39,965	*271*	38,217	*286*	32,838	*235*	44,870	*371*
Denmark	318	*8*	11	*0*	0	*0*	136	*6*	10	*0*	0	*0*	0	*0*	1	*0*
Djibouti	62	*2*	3	*0*	0	*0*	29	*1*	1	*0*	0	*0*	0	*0*	0	*0*
Dominican Republic	12,092	*71*	9,461	*79*	4,334	*47*	17,804	*121*	540	*7*	247	*3*	78	*1*	672	*10*
Ecuador	877	*28*	45	*1*	3	*0*	389	*16*	23	*1*	0	*0*	0	*0*	3	*0*
Egypt	64,466	*478*	47,754	*751*	21,874	*287*	92,324	*703*	2,570	*34*	1,196	*31*	395	*9*	3,096	*41*
El Salvador	4,668	*20*	4,039	*28*	2,370	*17*	6,240	*60*	129	*1*	80	*1*	33	*1*	168	*2*
Equatorial Guinea	5,099	*7*	5,059	*13*	4,441	*8*	5,668	*9*	409	*1*	385	*2*	297	*1*	493	*2*
Eritrea	1,799	*34*	767	*19*	265	*5*	2,109	*46*	42	*1*	9	*0*	2	*0*	34	*1*
Estonia	6	*1*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Ethiopia	14,263	*106*	11,197	*113*	6,431	*71*	18,883	*148*	259	*3*	137	*2*	60	*1*	294	*3*
Fiji	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Finland	18	*2*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
France	24,435	*104*	22,040	*175*	15,621	*124*	30,597	*208*	727	*5*	520	*5*	290	*3*	915	*11*
French Guiana	201	*2*	186	*2*	133	*2*	251	*2*	6	*0*	5	*0*	3	*0*	8	*0*
French Polynesia	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Gabon	9,374	*16*	9,342	*16*	8,503	*18*	10,189	*21*	905	*2*	864	*2*	705	*2*	1,059	*4*
Georgia	38	*2*	0	*0*	0	*0*	4	*0*	1	*0*	0	*0*	0	*0*	0	*0*
Germany	9,880	*143*	5,940	*88*	2,480	*58*	12,680	*156*	265	*6*	85	*2*	22	*1*	267	*5*
Ghana	102,545	*248*	102,229	*264*	96,569	*261*	107,899	*250*	5,519	*19*	5,474	*21*	4,924	*20*	6,051	*23*
Greece	7,187	*40*	6,667	*51*	5,142	*47*	8,664	*46*	259	*2*	206	*2*	142	*2*	322	*3*
Grenada	196	*1*	174	*2*	84	*2*	284	*2*	10	*0*	6	*0*	2	*0*	14	*0*
Guadeloupe	469	*1*	459	*2*	343	*1*	594	*2*	16	*0*	14	*0*	8	*0*	22	*0*
Guam	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Guatemala	14,159	*184*	10,285	*172*	5,208	*96*	19,137	*258*	470	*9*	252	*6*	105	*3*	570	*14*
Guinea	68,464	*115*	70,965	*124*	62,302	*156*	79,040	*176*	5,518	*19*	5,232	*24*	4,063	*16*	6,564	*29*
Guinea-Bissau	4,708	*19*	5,011	*23*	3,938	*11*	6,175	*32*	218	*2*	192	*2*	123	*1*	284	*3*
Guyana	837	*7*	622	*7*	251	*5*	1,247	*18*	43	*1*	17	*0*	5	*0*	53	*1*
Haiti	26,659	*38*	26,801	*75*	21,627	*72*	32,317	*57*	1,197	*3*	1,088	*5*	756	*5*	1,531	*6*
Honduras	19,204	*100*	17,783	*182*	11,179	*171*	25,925	*104*	1,083	*8*	772	*11*	368	*8*	1,473	*10*
China, Hong Kong SAR	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Hungary	553	*16*	59	*3*	4	*0*	406	*9*	14	*1*	0	*0*	0	*0*	4	*0*
Iceland	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*

COUNTRY[1]	Mean	*SE*	Median	*SE*	Q25%	*SE*	Q75%	*SE*	Mean	*SE*	Median	*SE*	Q25%	*SE*	Q75%	*SE*
India	1,044,394	*10,547*	996,563	*11,472*	883,210	*10,488*	1,135,290	*10,399*	44,252	*671*	42,016	*706*	35,347	*616*	50,919	*770*
Indonesia	1,907	*140*	328	*23*	79	*8*	1,206	*76*	32	*6*	1	*0*	0	*0*	7	*1*
Iran (Islamic Republic of)	30,617	*411*	25,768	*441*	16,613	*353*	39,359	*433*	1,252	*21*	862	*18*	444	*11*	1,581	*19*
Iraq	36,723	*386*	23,488	*420*	11,617	*176*	47,957	*761*	1,532	*27*	629	*14*	255	*6*	1,595	*35*
Ireland	526	*13*	60	*2*	5	*0*	447	*13*	15	*1*	0	*0*	0	*0*	4	*0*
Israel	7,856	*48*	7,117	*58*	5,302	*36*	9,248	*83*	252	*2*	218	*3*	136	*2*	324	*6*
Italy	8,051	*67*	5,635	*48*	3,028	*45*	10,363	*107*	209	*4*	91	*2*	37	*1*	236	*4*
Jamaica	4,128	*13*	3,998	*16*	3,282	*14*	4,820	*18*	152	*1*	137	*1*	99	*1*	189	*1*
Japan	3	*1*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Jordan	6,850	*28*	6,365	*37*	4,245	*22*	9,313	*50*	202	*1*	145	*1*	80	*1*	260	*3*
Kazakhstan	63	*2*	1	*0*	0	*0*	11	*1*	1	*0*	0	*0*	0	*0*	0	*0*
Kenya	98,657	*956*	98,471	*1,055*	89,175	*915*	108,467	*1,039*	4,566	*63*	4,475	*63*	3,879	*59*	5,137	*68*
Dem. People's Republic of Korea	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Republic of Korea	3	*2*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Kuwait	3,982	*30*	3,824	*34*	1,878	*39*	6,476	*71*	212	*3*	116	*2*	36	*1*	293	*7*
Kyrgyzstan	52	*3*	0	*0*	0	*0*	1	*0*	1	*0*	0	*0*	0	*0*	0	*0*
Lao People's Democratic Republic	17	*1*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Latvia	15	*2*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Lebanon	6,502	*37*	6,382	*41*	4,808	*37*	8,044	*46*	290	*3*	251	*3*	152	*2*	382	*3*
Lesotho	343	*8*	40	*2*	4	*0*	244	*13*	7	*0*	0	*0*	0	*0*	2	*0*
Liberia	12,890	*54*	13,217	*60*	11,487	*50*	14,919	*59*	594	*3*	562	*4*	443	*3*	714	*4*
Libyan Arab Jamahiriya	6,087	*29*	6,020	*41*	4,673	*37*	7,559	*36*	210	*1*	188	*2*	128	*1*	267	*2*
Lithuania	32	*2*	0	*0*	0	*0*	1	*0*	1	*0*	0	*0*	0	*0*	0	*0*
Luxembourg	83	*1*	48	*1*	20	*0*	105	*1*	1	*0*	0	*0*	0	*0*	1	*0*
China, Macao SAR	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
TFYR Macedonia	736	*5*	510	*6*	230	*5*	1,016	*14*	22	*0*	9	*0*	3	*0*	25	*0*
Madagascar	71,583	*336*	69,295	*362*	63,138	*282*	75,644	*372*	3,457	*28*	3,379	*28*	2,902	*23*	3,915	*33*
Malawi	47,002	*194*	47,370	*249*	35,308	*251*	61,509	*264*	2,133	*16*	1,688	*18*	1,029	*14*	2,765	*25*
Malaysia	56	*2*	1	*0*	0	*0*	14	*0*	1	*0*	0	*0*	0	*0*	0	*0*
Maldives	6	*0*	0	*0*	0	*0*	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Mali	65,849	*235*	56,236	*231*	47,355	*268*	65,909	*301*	2,904	*18*	2,701	*20*	2,068	*17*	3,509	*20*
Malta	197	*2*	143	*2*	61	*1*	284	*4*	7	*0*	2	*0*	1	*0*	8	*0*
Martinique	403	*1*	391	*1*	300	*1*	496	*1*	14	*0*	12	*0*	8	*0*	19	*0*
Mauritania	10,335	*47*	9,505	*72*	6,585	*50*	12,929	*109*	573	*5*	433	*5*	240	*3*	748	*10*
Mauritius	105	*4*	0	*0*	0	*0*	19	*1*	4	*0*	0	*0*	0	*0*	0	*0*
Mayotte	575	*3*	447	*7*	168	*3*	863	*8*	30	*0*	12	*0*	2	*0*	40	*1*
Mexico	34,594	*214*	31,120	*235*	23,289	*256*	41,145	*242*	800	*10*	641	*9*	422	*7*	975	*10*
Micronesia (Fed. States of)	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Republic of Moldova	124	*5*	1	*0*	0	*0*	22	*1*	3	*0*	0	*0*	0	*0*	0	*0*
Mongolia	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*

COUNTRY[1]	Mean	SE	Median	SE	Q25%	SE	Q75%	SE	Mean	SE	Median	SE	Q25%	SE	Q75%	SE
Montenegro	170	*3*	72	*1*	16	*0*	226	*3*	5	*0*	1	*0*	0	*0*	4	*0*
Morocco	8,269	*92*	3,202	*54*	824	*23*	10,051	*139*	278	*6*	40	*1*	6	*0*	215	*7*
Mozambique	43,902	*241*	42,588	*253*	34,837	*195*	51,562	*312*	1,818	*19*	1,645	*19*	1,193	*13*	2,235	*30*
Myanmar	305	*12*	40	*2*	5	*0*	222	*7*	4	*0*	0	*0*	0	*0*	1	*0*
Namibia	1,442	*11*	1,138	*8*	730	*8*	1,806	*22*	46	*0*	30	*1*	17	*0*	55	*1*
Nepal	4,150	*77*	1,558	*33*	357	*16*	4,805	*80*	105	*4*	11	*0*	1	*0*	67	*2*
Netherlands	5,281	*19*	4,759	*19*	3,163	*22*	6,819	*41*	115	*1*	82	*1*	43	*0*	149	*2*
Netherlands Antilles	159	*0*	150	*1*	105	*1*	203	*1*	5	*0*	4	*0*	2	*0*	6	*0*
New Caledonia	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
New Zealand	3	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Nicaragua	8,715	*57*	6,514	*77*	2,641	*40*	12,964	*125*	471	*7*	204	*4*	53	*1*	576	*10*
Niger	89,801	*231*	90,671	*325*	73,050	*326*	109,417	*469*	5,503	*24*	4,965	*32*	3,543	*25*	6,894	*38*
Nigeria	1,138,493	*1,665*	1,136,909	*1,640*	1,070,320	*2,018*	1,200,907	*1,719*	86,420	*211*	85,186	*247*	76,413	*272*	94,945	*190*
Norway	77	*4*	0	*0*	0	*0*	13	*1*	2	*0*	0	*0*	0	*0*	0	*0*
Oman	81	*3*	32	*1*	9	*0*	94	*2*	2	*0*	0	*0*	0	*0*	1	*0*
Pakistan	37,554	*616*	18,962	*275*	7,260	*92*	47,537	*540*	1,123	*42*	228	*6*	53	*2*	892	*9*
Panama	4,793	*16*	4,457	*23*	3,053	*16*	6,176	*30*	184	*1*	140	*1*	77	*1*	244	*2*
Papua New Guinea	4	*1*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Paraguay	1,878	*40*	664	*19*	178	*4*	2,093	*57*	55	*2*	7	*0*	1	*0*	36	*1*
Peru	80	*5*	2	*0*	0	*0*	22	*1*	1	*0*	0	*0*	0	*0*	0	*0*
Philippines	55	*9*	0	*0*	0	*0*	0	*0*	1	*0*	0	*0*	0	*0*	0	*0*
Poland	1,110	*26*	59	*3*	3	*0*	590	*12*	28	*1*	0	*0*	0	*0*	4	*0*
Portugal	2,921	*21*	2,170	*14*	1,303	*13*	3,598	*34*	81	*1*	41	*0*	19	*0*	90	*1*
Puerto Rico	498	*4*	326	*4*	127	*1*	710	*11*	8	*0*	2	*0*	1	*0*	8	*0*
Qatar	1,809	*13*	1,365	*28*	668	*11*	2,262	*26*	74	*1*	41	*1*	12	*0*	104	*2*
Réunion	193	*4*	6	*0*	0	*0*	110	*7*	8	*1*	0	*0*	0	*0*	1	*0*
Romania	1,543	*33*	320	*7*	45	*2*	1,500	*48*	44	*2*	2	*0*	0	*0*	21	*1*
Russian Federation	381	*22*	14	*1*	1	*0*	135	*9*	9	*1*	0	*0*	0	*0*	0	*0*
Rwanda	24,532	*75*	22,857	*103*	18,400	*58*	28,098	*124*	680	*4*	601	*6*	423	*2*	846	*7*
Saint Lucia	317	*1*	311	*2*	223	*1*	402	*1*	14	*0*	12	*0*	6	*0*	19	*0*
Saint Vincent and the Grenadines	187	*1*	176	*1*	99	*2*	262	*1*	9	*0*	6	*0*	2	*0*	13	*0*
Samoa	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Sao Tome and Principe	783	*6*	763	*11*	376	*7*	1,132	*7*	72	*1*	41	*1*	12	*0*	92	*1*
Saudi Arabia	20,767	*187*	19,447	*190*	17,012	*181*	22,221	*213*	723	*9*	691	*9*	572	*8*	842	*10*
Senegal	51,572	*142*	53,002	*154*	46,123	*146*	60,123	*205*	2,652	*15*	2,535	*16*	1,998	*14*	3,163	*22*
Serbia	1,891	*28*	830	*20*	225	*9*	2,417	*59*	59	*2*	10	*0*	1	*0*	49	*2*
Sierra Leone	39,730	*128*	39,530	*197*	31,971	*123*	47,084	*116*	3,170	*21*	2,838	*23*	1,906	*15*	4,018	*24*
Singapore	4	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Slovakia	221	*7*	12	*1*	0	*0*	125	*7*	5	*0*	0	*0*	0	*0*	1	*0*
Slovenia	228	*5*	22	*1*	2	*0*	176	*5*	7	*0*	0	*0*	0	*0*	2	*0*

COUNTRY[1]	Mean	SE	Median	SE	Q25%	SE	Q75%	SE	Mean	SE	Median	SE	Q25%	SE	Q75%	SE
Solomon Islands	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Somalia	3,423	*51*	1,192	*37*	321	*12*	3,777	*70*	109	*2*	13	*1*	2	*0*	69	*2*
South Africa	6,803	*58*	4,946	*39*	2,617	*43*	8,872	*109*	157	*3*	73	*1*	28	*1*	177	*3*
Spain	9,231	*45*	7,324	*47*	4,253	*43*	12,071	*103*	281	*2*	149	*2*	64	*1*	341	*5*
Sri Lanka	479	*5*	425	*6*	295	*4*	590	*6*	2	*0*	2	*0*	1	*0*	3	*0*
Sudan	100,612	*596*	98,244	*714*	84,697	*688*	113,554	*511*	4,921	*40*	4,567	*52*	3,527	*43*	5,894	*43*
Suriname	783	*7*	653	*10*	300	*7*	1,162	*13*	39	*1*	19	*0*	6	*0*	53	*1*
Swaziland	605	*4*	398	*3*	173	*2*	813	*7*	12	*0*	4	*0*	1	*0*	13	*0*
Sweden	186	*10*	2	*0*	0	*0*	41	*2*	5	*0*	0	*0*	0	*0*	0	*0*
Switzerland	1,510	*24*	622	*20*	145	*5*	1,907	*51*	46	*1*	6	*0*	1	*0*	36	*1*
Syrian Arab Republic	23,406	*124*	24,448	*123*	19,056	*163*	31,267	*71*	1,030	*10*	901	*9*	664	*11*	1,261	*8*
Tajikistan	109	*8*	0	*0*	0	*0*	6	*0*	2	*0*	0	*0*	0	*0*	0	*0*
United Republic of Tanzania	203,814	*696*	203,747	*685*	185,237	*738*	222,866	*831*	11,304	*71*	11,022	*77*	9,327	*68*	12,897	*82*
Thailand	108	*11*	0	*0*	0	*0*	10	*0*	2	*0*	0	*0*	0	*0*	0	*0*
Gambia	8,557	*6*	8,657	*12*	7,977	*9*	9,355	*10*	427	*1*	418	*1*	359	*1*	487	*1*
Timor-Leste	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Togo	30,324	*89*	34,057	*93*	31,180	*109*	36,958	*92*	2,211	*10*	2,175	*8*	1,846	*9*	2,540	*12*
Tonga	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Trinidad and Tobago	1,713	*5*	1,648	*9*	1,207	*6*	2,154	*9*	68	*0*	56	*1*	33	*0*	91	*1*
Tunisia	4,619	*17*	4,420	*20*	3,623	*16*	5,372	*25*	90	*1*	81	*1*	58	*0*	113	*1*
Turkey	16,384	*449*	12,852	*363*	9,281	*327*	20,051	*656*	519	*20*	330	*17*	248	*14*	526	*23*
Turkmenistan	173	*7*	4	*0*	0	*0*	54	*3*	5	*0*	0	*0*	0	*0*	0	*0*
Uganda	187,866	*618*	189,801	*754*	169,157	*604*	210,719	*728*	10,454	*54*	10,143	*65*	8,223	*51*	12,325	*65*
Ukraine	600	*16*	33	*1*	2	*0*	293	*11*	14	*1*	0	*0*	0	*0*	2	*0*
United Arab Emirates	1,043	*16*	402	*10*	189	*7*	827	*22*	11	*0*	4	*0*	1	*0*	11	*0*
United Kingdom	17,273	*41*	15,746	*79*	10,982	*52*	21,949	*114*	395	*2*	296	*1*	163	*2*	517	*5*
United States of America	102,887	*512*	100,150	*600*	82,111	*505*	122,520	*631*	3,289	*25*	2,843	*20*	2,038	*16*	3,968	*34*
Uruguay	263	*3*	82	*2*	26	*1*	231	*6*	7	*0*	1	*0*	0	*0*	3	*0*
Uzbekistan	255	*23*	1	*0*	0	*0*	24	*2*	5	*1*	0	*0*	0	*0*	0	*0*
Vanuatu	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Venezuela (Bolivarian Republic of)	19,721	*107*	19,272	*104*	16,150	*93*	22,799	*156*	485	*4*	435	*4*	325	*2*	591	*6*
Viet Nam	190	*19*	0	*0*	0	*0*	4	*0*	3	*1*	0	*0*	0	*0*	0	*0*
United States Virgin Islands	42	*0*	25	*0*	8	*0*	59	*0*	1	*0*	0	*0*	0	*0*	1	*0*
Western Sahara	295	*4*	144	*3*	51	*1*	330	*8*	10	*0*	3	*0*	1	*0*	10	*0*
Yemen	9,318	*58*	6,411	*77*	3,355	*41*	12,043	*78*	194	*2*	80	*1*	29	*1*	207	*2*
Zambia	87,955	*297*	88,801	*344*	80,963	*327*	96,982	*344*	5,806	*29*	5,652	*32*	4,801	*28*	6,632	*34*
Zimbabwe	17,166	*50*	16,345	*48*	12,706	*57*	20,982	*70*	560	*4*	483	*4*	326	*4*	704	*4*

1. Official country names consistent with ISO 3166-1. See Supplementary Table S1 for list of countries not shown.

Web Table 3: Sub-national areal prediction summaries and Monte Carlo standard errors (SE) for HbAS and HbSS neonate estimates

AFRICA						HbAS								HbSS							
Country	**Admin1 unit**	**GAUL**	**Surveys**	**Population**	**CBR**	**Mean**	**SE**	**Median**	**SE**	**Q25**	**SE**	**Q75**	**SE**	**Mean**	**SE**	**Median**	**SE**	**Q25**	**SE**	**Q75**	**SE**
Algeria	Illizi	362	7	47,940	0.0192	60	0	56	1	43	1	74	1	2	0	2	0	1	0	3	0
Algeria	Ouargla	373	2	636,715	0.0192	416	7	387	3	266	2	530	18	10	0	8	0	4	0	14	1
Angola	Cuando Cubango	402	5	220,749	0.0399	249	4	230	2	166	3	313	8	7	0	6	0	3	0	9	0
Angola	Lunda Norte	409	7	530,093	0.0399	4,550	3	4,553	10	4,250	9	4,846	21	388	0	381	1	334	0	434	1
Angola	Lunda Sul	410	2	262,521	0.0399	1,659	10	1,656	23	1,397	13	1,928	17	105	1	98	3	73	1	133	2
Angola	Malanje	411	4	1,453,300	0.0399	14,035	8	14,033	4	12,783	34	15,344	95	1,471	6	1,364	4	1,096	10	1,722	35
Benin	Atakora	610	7	737,962	0.0383	2,989	16	2,969	18	2,553	11	3,413	17	128	2	122	2	92	0	157	2
Botswana	Ngamiland	660	2	139,642	0.0229	17	0	10	1	4	0	22	0	0	0	0	0	0	0	0	0
Burkina Faso	Boucle Du Mouhoun	40276	3	1,795,040	0.0424	5,474	42	5,355	44	4,403	43	6,438	18	192	2	177	2	128	2	242	1
Burkina Faso	Cascades	40277	3	546,281	0.0424	2,768	11	2,757	27	2,189	0	3,312	4	135	1	124	3	81	1	173	2
Burkina Faso	Centre-est	40279	2	1,353,980	0.0424	6,155	9	6,121	26	5,083	30	7,131	3	267	0	251	3	182	0	335	0
Burkina Faso	Centre-sud	40282	8	799,269	0.0424	3,313	9	3,287	21	2,896	8	3,712	12	128	1	123	2	97	1	153	1
Burkina Faso	Hauts-bassins	40284	26	1,663,650	0.0424	5,326	1	5,305	5	4,822	0	5,803	6	167	0	163	0	139	0	190	0
Burkina Faso	Nord	40285	2	1,520,520	0.0424	7,267	67	7,237	41	5,746	101	8,666	76	338	5	311	2	209	4	436	8
Burkina Faso	Sahel	40287	4	1,008,040	0.0424	5,405	49	5,385	44	4,594	51	6,203	33	284	4	271	1	201	3	353	1
Burundi	Bujumbura-Mairie	40543	2	498,769	0.0333	1,440	5	1,395	6	1,089	8	1,743	12	49	0	43	0	27	0	64	1
Cote d'Ivoire	Lagunes	1044	3	5,733,330	0.0330	19,069	48	18,876	95	15,669	64	22,253	75	756	2	704	5	502	1	946	3
Cote d'Ivoire	Zanzan	1053	4	928,182	0.0330	4,976	36	4,996	34	4,416	57	5,574	18	314	4	304	6	242	6	375	1
Cameroon	Centre	816	2	3,394,960	0.0349	23,598	12	23,650	57	21,407	15	25,981	44	1,731	1	1,687	13	1,373	8	2,060	13
Cameroon	Est	817	2	877,748	0.0349	4,618	41	4,604	28	3,321	36	5,818	105	319	7	272	0	151	0	426	16
Cameroon	Extreme-Nord	818	6	3,170,660	0.0349	11,777	142	11,722	121	10,244	155	13,211	142	532	12	512	9	401	8	642	13
Cameroon	Littoral	819	4	3,257,190	0.0349	18,928	63	19,112	121	16,178	86	21,801	89	1,175	7	1,122	11	808	4	1,482	14
Cameroon	Ouest	822	2	2,365,110	0.0349	12,515	53	12,531	49	10,704	68	14,365	11	725	2	691	1	510	7	897	2
Cameroon	Sud	823	2	650,268	0.0349	4,224	1	4,219	6	3,742	3	4,732	12	303	1	290	3	229	2	367	1
Cameroon	Sud-Ouest	824	15	1,590,850	0.0349	10,125	35	10,159	19	9,400	42	10,831	25	682	2	676	2	580	6	774	2
Chad	Mandoul	12925	2	422,971	0.0434	1,466	1	1,453	0	1,084	5	1,815	4	56	0	49	0	30	0	74	1
Comoros	Ngazidja	969	2	360,557	0.0357	518	1	472	2	298	3	682	1	12	0	8	0	4	0	15	0
Congo	Pool	978	3	1,664,670	0.0346	10,867	54	10,920	25	9,907	69	11,894	79	736	4	725	1	598	5	863	12
DRC	Equateur	1068	2	7,264,900	0.0421	52,038	84	51,681	524	43,694	183	60,396	40	4,082	16	3,730	47	2,805	7	5,019	34
DRC	Katanga	1071	2	8,788,270	0.0421	70,148	581	69,811	596	59,978	21	79,793	1,259	6,215	117	5,514	144	4,175	8	7,350	151
DRC	Province Orientale	1075	3	8,980,980	0.0421	56,452	277	56,200	157	48,710	357	63,712	266	3,922	27	3,711	9	2,945	15	4,687	43

Country	Admin1 unit	GAUL	Surveys	Population	CBR	Mean	SE	Median	SE	Q25	SE	Q75	SE	Mean	SE	Median	SE	Q25	SE	Q75	SE
Egypt	Al Wadi/al Jadid	1169	2	1,147,300	0.0223	1,427	29	1,171	12	680	20	1,969	22	62	2	40	1	18	1	82	1
Ethiopia	Addis Ababa	1227	2	3,923,150	0.0300	489	5	282	5	99	1	670	5	3	0	1	0	0	0	3	0
Ethiopia	Amhara	1229	3	21,959,100	0.0300	3,153	5	1,917	26	829	6	4,052	18	46	0	17	0	5	0	48	2
Gambia	Kombo Saint Mary	1286	5	492,564	0.0369	2,456	1	2,447	1	2,194	10	2,710	1	116	0	113	1	91	0	135	1
Gambia	Q25er River	1287	13	87,850	0.0369	432	2	433	1	384	1	482	2	21	0	20	0	16	0	25	0
Gambia	North Bank	1288	4	209,418	0.0369	1,056	0	1,055	1	970	4	1,141	2	52	0	50	0	43	0	59	0
Gambia	Western	1290	4	464,194	0.0369	2,185	3	2,169	11	1,905	13	2,459	19	101	0	96	1	77	1	122	2
Ghana	Ashanti	1324	18	4,872,310	0.0303	20,087	15	19,982	16	18,179	49	21,934	23	1,006	4	969	2	812	8	1,165	6
Ghana	Central	1326	4	1,928,780	0.0303	9,172	19	9,176	17	8,122	58	10,248	14	531	2	513	1	409	3	637	3
Ghana	Eastern	1327	4	2,693,720	0.0303	13,261	3	13,263	39	11,897	3	14,664	14	790	0	767	3	624	2	945	1
Ghana	Greater Accra	1328	3	4,345,450	0.0303	19,670	2	19,689	35	17,716	44	21,647	36	1,044	0	1,021	3	829	1	1,231	5
Ghana	Upper East	1330	16	1,069,720	0.0303	2,779	16	2,737	6	2,303	7	3,229	22	100	1	91	0	67	0	125	1
Ghana	Volta	1332	2	2,034,190	0.0303	10,257	88	10,263	103	9,279	93	11,213	53	647	6	635	9	526	5	755	4
Guinea-Bissau	Biombo	1386	3	103,423	0.0374	187	0	180	1	138	1	228	1	4	0	4	0	2	0	5	0
Kenya	Coast	51326	28	3,507,020	0.0369	16,124	78	16,142	83	14,764	78	17,487	128	840	7	817	11	690	8	969	7
Kenya	Nairobi	51328	2	3,501,660	0.0369	2,808	18	2,532	11	1,610	2	3,689	27	38	0	26	0	12	0	51	0
Kenya	Nyanza	51330	8	6,161,510	0.0369	33,401	129	33,319	68	29,437	142	37,418	251	1,934	12	1,865	4	1,491	18	2,291	24
Kenya	Rift Valley	51331	6	9,919,120	0.0369	16,861	293	15,967	266	11,894	408	20,726	413	533	6	436	10	288	8	683	0
Kenya	Western	51332	4	4,689,570	0.0369	21,830	24	21,742	40	19,229	34	24,485	24	1,069	3	1,030	1	829	3	1,278	3
Liberia	Grand Bassa	1817	3	303,787	0.0376	977	1	964	1	797	2	1,143	6	35	0	32	0	23	0	44	0
Liberia	Grand Cape Mount	1818	2	319,087	0.0376	1,772	0	1,765	11	1,388	15	2,150	28	102	1	90	1	57	0	133	2
Liberia	Lofa	1821	2	159,054	0.0376	1,019	9	1,023	9	885	7	1,149	11	67	1	65	0	50	1	82	1
Liberia	Nimba	1825	2	355,946	0.0376	777	6	743	6	560	3	959	6	24	0	20	0	12	0	31	1
Liberia	Sinoe	1828	2	424,039	0.0376	882	4	832	4	606	5	1,105	5	26	0	20	0	12	0	33	0
Libya	Banghazi	1839	2	888,002	0.0217	896	10	823	1	561	12	1,152	15	23	0	17	0	9	0	30	1
Madagascar	Analamanga	41752	2	3,038,530	0.0346	7,368	61	7,080	47	4,889	73	9,424	28	244	1	197	1	109	0	325	2
Madagascar	Analanjirofo	41753	2	1,188,460	0.0346	3,806	2	3,709	22	2,747	25	4,717	38	167	1	145	2	89	0	224	0
Madagascar	Anosy	41755	4	639,336	0.0346	2,072	3	2,034	13	1,718	4	2,413	8	89	0	83	0	63	0	110	1
Madagascar	Atsimo Andrefana	41756	5	1,222,760	0.0346	2,789	13	2,670	35	2,007	1	3,420	7	98	1	84	2	55	1	125	1
Madagascar	Atsimo Atsinanana	41757	3	685,524	0.0346	4,119	9	4,118	15	3,695	12	4,530	16	265	0	258	1	209	1	313	1
Madagascar	Haute Matsiatra	41763	2	1,242,210	0.0346	6,579	19	6,573	4	5,392	5	7,753	48	399	0	367	2	255	1	510	1
Madagascar	Menabe	41767	4	452,022	0.0346	1,265	4	1,233	6	970	26	1,543	6	48	0	43	1	29	1	63	1
Madagascar	Vakinankaratra	41770	2	1,812,550	0.0346	4,265	52	4,074	12	2,937	23	5,370	20	148	3	122	1	68	1	197	1
Madagascar	Vatovavy Fitovinany	41771	6	1,258,170	0.0346	8,084	11	8,094	15	7,380	20	8,794	16	555	2	546	1	453	3	639	0
Malawi	Southern Region	1890	14	7,304,820	0.0445	15,087	64	14,649	34	11,882	133	17,829	9	383	2	345	4	239	3	484	2

Country	Admin1 unit	GAUL	Surveys	Population	CBR	Mean	SE	Median	SE	Q25	SE	Q75	SE	Mean	SE	Median	SE	Q25	SE	Q75	SE
Mali	Koulikoro	1930	4	2,972,940	0.0450	14,006	65	13,707	68	11,350	44	16,591	55	653	11	595	2	433	5	822	11
Mali	Sikasso	1933	2	2,748,970	0.0450	13,633	34	13,503	37	11,197	54	15,825	38	707	5	656	3	471	1	875	8
Mozambique	Cabo Delgado	2112	5	1,915,120	0.0363	4,567	44	4,326	55	3,204	37	5,668	76	162	2	128	1	81	1	204	2
Mozambique	Gaza	2113	2	1,627,090	0.0363	651	15	398	12	171	4	838	16	11	1	4	0	1	0	11	0
Mozambique	Maputo (city)	2117	2	1,275,780	0.0363	954	10	828	22	540	11	1,248	9	12	0	8	0	4	0	16	0
Mozambique	Nampula	2118	2	4,290,360	0.0363	15,143	79	14,443	86	10,873	79	18,853	189	817	12	699	26	442	11	1,080	11
Namibia	Caprivi	2137	2	100,425	0.0252	45	0	27	1	9	0	61	1	1	0	0	0	0	0	1	0
Namibia	Kavango	2141	6	239,368	0.0252	374	0	360	3	276	2	466	1	13	0	11	0	7	0	18	0
Niger	Diffa	2203	3	411,442	0.0477	1,648	34	1,545	41	1,056	29	2,128	83	73	1	56	2	31	1	97	5
Niger	Tillaberi	2208	2	3,251,270	0.0477	22,880	123	23,048	68	19,469	41	26,191	110	1,387	8	1,321	10	998	6	1,702	7
Nigeria	Jigawa	2223	2	5,125,070	0.0393	20,174	61	19,359	103	14,431	98	25,126	98	973	3	809	12	518	6	1,264	8
Nigeria	Kaduna	2224	2	7,174,530	0.0393	53,425	146	53,496	278	47,227	275	59,490	135	3,893	7	3,722	31	2,956	12	4,624	22
Nigeria	Katsina	2226	4	6,545,700	0.0393	41,483	9	41,625	71	33,571	444	49,337	188	2,763	11	2,541	10	1,801	13	3,464	19
Nigeria	Lagos	2230	2	12,494,500	0.0393	108,491	21	108,425	73	99,496	131	117,602	464	8,699	2	8,457	10	7,047	6	10,143	102
Nigeria	Ogun	2232	3	4,460,800	0.0393	40,858	39	40,870	38	38,706	122	42,955	88	3,539	10	3,484	10	3,105	6	3,929	5
Nigeria	Osun	2234	3	4,466,810	0.0393	38,165	9	38,353	24	35,132	84	41,354	2	3,059	1	3,005	12	2,507	11	3,559	9
Nigeria	Oyo	2235	3	7,186,760	0.0393	63,733	233	63,863	158	58,902	611	68,586	14	5,443	32	5,315	23	4,520	81	6,272	12
Senegal	Fatick	47586	4	785,769	0.0359	3,554	12	3,558	24	3,051	11	4,039	0	170	1	163	2	124	1	207	3
Senegal	Tambacounda	2643	15	668,232	0.0359	3,798	48	3,788	58	3,038	47	4,486	68	257	5	234	7	164	3	317	9
Sudan	Central Equatoria	2748	5	779,795	0.0319	2,026	8	2,002	14	1,651	16	2,378	4	72	0	66	0	48	1	91	1
Sudan	Eastern Equatoria	2750	4	549,064	0.0319	1,020	8	956	7	723	3	1,249	13	35	0	29	0	20	0	44	0
Sudan	Khartoum	2753	6	7,313,860	0.0319	8,999	66	8,646	78	6,527	73	11,121	134	189	3	161	1	98	2	249	5
Sudan	Sennar	2762	2	1,932,200	0.0319	7,929	39	7,789	12	6,082	34	9,695	6	445	3	389	0	251	0	585	1
Sudan	Southern Kordofan	68785	3	2,294,240	0.0319	8,516	77	8,455	121	7,065	69	9,862	22	458	6	428	8	316	9	568	8
Sudan	Unity	2747	2	684,019	0.0319	938	24	846	33	559	14	1,216	31	29	1	20	1	10	1	39	2
Sudan	Upper Nile	37021	5	1,094,950	0.0319	421	16	360	15	212	12	570	26	9	0	5	0	2	0	12	1
Togo	Maritime	2972	3	2,878,020	0.0310	17,738	75	17,811	81	16,135	73	19,428	58	1,273	9	1,251	13	1,024	9	1,501	12
Togo	Plateaux	2973	2	1,510,980	0.0310	8,088	0	8,145	52	7,027	35	9,102	10	535	2	516	3	390	2	649	3
Tunisia	Tunis	3015	2	813,223	0.0165	322	3	291	5	196	1	413	1	5	0	3	0	2	0	6	0
Uganda	Kampala	42182	3	1,515,680	0.0439	10,104	9	10,128	34	9,095	47	11,189	27	535	2	523	3	421	0	630	2
Tanzania	Kagera	48361	4	2,567,560	0.0410	13,507	5	13,477	24	11,420	59	15,593	38	709	2	670	0	497	1	891	2
Tanzania	Kilimanjaro	48363	10	1,892,730	0.0410	3,100	5	2,965	9	2,329	3	3,778	9	72	0	62	0	42	0	93	0
Tanzania	Morogoro	48368	3	2,314,940	0.0410	12,546	10	12,456	57	9,853	22	15,118	9	714	3	641	0	420	2	915	7
Tanzania	Mwanza	48370	2	3,811,750	0.0410	25,644	176	25,676	147	20,971	156	30,296	299	1,703	26	1,592	13	1,090	13	2,166	49
Tanzania	Pwani	48373	3	1,132,920	0.0410	6,835	48	6,788	58	5,905	112	7,806	28	400	5	377	7	289	9	488	5

Country	Admin1 unit	GAUL	Surveys	Population	CBR	Mean	SE	Median	SE	Q25	SE	Q75	SE	Mean	SE	Median	SE	Q25	SE	Q75	SE
Tanzania	Tanga	48381	15	2,148,450	0.0410	9,090	68	9,046	43	7,975	4	10,165	80	393	5	380	4	302	2	468	8
Tanzania	Unguja North	48372	2	170,008	0.0410	739	3	730	1	620	5	854	2	29	0	28	0	20	0	37	0
Tanzania	Unguja South	48379	9	156,851	0.0410	525	1	522	1	460	0	586	2	16	0	16	0	13	0	20	0
Tanzania	Unguja Urban West	48382	2	522,047	0.0410	1,915	1	1,884	13	1,565	7	2,241	9	65	0	60	0	42	0	83	0
Zambia	Luapula	3429	2	996,460	0.0465	8,839	35	8,878	9	7,723	39	10,004	39	673	5	646	2	494	2	821	6
Zambia	Northern	3432	2	1,707,160	0.0465	12,757	136	12,637	60	10,301	40	15,020	343	900	25	815	11	566	8	1,119	42
Zambia	North-Western	3431	2	769,142	0.0465	6,241	27	6,277	62	5,209	46	7,273	30	480	2	438	8	313	7	593	5
Zambia	Western	3434	2	1,021,440	0.0465	3,538	7	3,468	31	2,625	15	4,340	6	161	1	140	1	87	0	212	1
Zimbabwe	Mashonaland East	69550	2	1,261,370	0.0287	2,011	25	1,918	8	1,441	6	2,471	62	62	2	53	1	33	1	80	4

ASIA						HbAS								HbSS							
Country	Admin1 unit	GAUL	Surveys	Population	CBR	Mean	SE	Median	SE	Q25	SE	Q75	SE	Mean	SE	Median	SE	Q25	SE	Q75	SE
China	Taiwan Sheng	925	7	27,603,700	0.0119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
India	Andaman and Nicobar	1484	8	404,656	0.0213	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
India	Andhra Pradesh	1485	21	90,604,700	0.0213	107,874	484	104,699	594	85,674	170	127,179	1,030	4,237	5	3,783	8	2,767	20	5,263	13
India	Chhattisgarh	70075	8	24,165,500	0.0213	39,033	974	38,019	858	31,681	1,041	45,487	1,292	1,667	68	1,538	60	1,208	59	1,994	93
India	Gujarat	1491	9	60,421,700	0.0213	88,628	1,232	84,780	1,478	69,441	1,339	104,503	1,357	3,530	79	3,234	125	2,451	85	4,319	73
India	Jharkhand	70078	3	32,676,100	0.0213	8,250	104	5,867	78	3,463	251	10,581	23	146	7	68	0	30	3	170	7
India	Karnataka	1494	6	62,125,300	0.0213	155,842	3,975	150,473	2,359	120,782	2,940	184,620	5,729	10,388	374	9,394	277	6,936	160	12,890	551
India	Kerala	1495	8	37,121,100	0.0213	28,072	1,380	26,739	1,168	21,265	976	33,472	1,796	1,065	72	964	60	695	37	1,335	112
India	Madhya Pradesh	70079	5	70,788,900	0.0213	91,872	868	86,888	355	66,685	195	111,513	1,021	3,871	90	3,346	55	2,273	19	4,854	99
India	Maharashtra	1498	14	115,681,000	0.0213	132,957	1,982	127,739	932	103,303	1,164	157,602	3,352	5,387	96	4,678	52	3,511	31	6,644	182
India	Orissa	1504	10	43,291,600	0.0213	55,843	470	54,318	958	46,360	1,248	62,997	256	2,323	24	2,205	43	1,794	22	2,736	36
India	Rajasthan	1506	2	66,017,300	0.0213	37,251	1,550	29,852	689	17,925	1,129	49,064	2,014	1,114	83	689	38	356	31	1,362	87
India	Tamil Nadu	1508	5	75,463,700	0.0213	120,340	739	113,504	1,512	81,234	1,251	152,672	838	6,326	86	5,221	24	3,271	123	8,169	200
India	West Bengal	1511	4	94,360,600	0.0213	9,178	70	6,069	244	3,097	87	12,053	270	105	1	44	2	15	1	118	0
Indonesia	NUSA TENGGARA TIMUR	1013683	7	3,897,850	0.0174	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indonesia	SUMATERA UTARA	1013681	2	13,056,600	0.0174	26	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Malaysia	Perak	1898	4	2,413,540	0.0198	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myanmar	Yangon Division	1012330	2	6,925,730	0.0167	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saudi Arabia	Asir	2622	3	1,965,050	0.0214	1,721	70	1,606	75	1,198	53	2,131	89	53	3	44	4	27	2	69	5
Saudi Arabia	Eastern Province	2624	12	3,702,700	0.0214	8,546	16	8,514	15	7,594	41	9,451	12	417	5	405	5	335	5	481	5
Saudi Arabia	Madinah	2628	2	1,746,360	0.0214	1,075	7	737	12	386	11	1,437	56	31	1	13	0	6	0	34	2
Saudi Arabia	Makkah	2629	5	7,054,850	0.0214	1,559	25	1,275	39	761	13	2,000	61	31	1	20	1	10	0	42	3
Saudi Arabia	Riyad	2633	2	6,111,720	0.0214	4,032	6	3,672	11	2,526	43	5,166	24	103	1	82	1	46	1	136	1

Country	Admin1 unit	GAUL	Surveys	Population	CBR	HbAS Mean	SE	Median	SE	Q25	SE	Q75	SE	HbSS Mean	SE	Median	SE	Q25	SE	Q75	SE
Sri Lanka	Central	2736	3	2,618,530	0.0170	41	0	28	0	13	0	53	0	0	0	0	0	0	0	0	0
Sri Lanka	Eastern	2737	3	1,531,360	0.0170	81	0	61	1	34	0	106	1	1	0	0	0	0	0	1	0
Sri Lanka	North Central	2738	2	1,224,280	0.0170	40	1	29	0	16	0	51	0	0	0	0	0	0	0	0	0
Sri Lanka	North Western	2739	4	2,375,170	0.0170	37	0	23	0	10	0	47	1	0	0	0	0	0	0	0	0
Sri Lanka	Northern	2740	5	1,180,100	0.0170	97	0	74	1	43	0	124	0	1	0	0	0	0	0	1	0
Sri Lanka	Sabaragamuwa	2741	2	2,005,920	0.0170	36	1	26	0	13	1	49	1	0	0	0	0	0	0	0	0
Sri Lanka	Southern	2742	3	2,514,960	0.0170	53	1	33	1	14	0	73	2	0	0	0	0	0	0	0	0
Sri Lanka	Uva	2743	2	1,259,060	0.0170	30	1	21	0	10	0	40	1	0	0	0	0	0	0	0	0
Sri Lanka	Western	2744	4	5,700,630	0.0170	59	0	30	0	10	0	76	1	0	0	0	0	0	0	0	0
Syria	Damascus	2837	3	1,726,370	0.0219	5,394	36	5,348	68	4,693	47	6,105	8	284	3	269	5	212	4	347	3
Turkey	Adana	3017	4	1,943,940	0.0169	1,898	1	1,861	7	1,536	2	2,229	9	65	0	61	1	44	0	81	1
Turkey	Hatay	3052	14	1,350,070	0.0169	1,552	41	1,546	39	1,376	42	1,724	43	50	2	49	2	40	2	59	3
Turkey	Icel	3053	16	2,016,630	0.0169	2,104	55	2,081	70	1,873	55	2,317	64	78	3	76	3	62	3	92	3
Turkey	K.maras	3058	9	1,113,540	0.0169	16	0	9	0	3	0	21	0	0	0	0	0	0	0	0	0
UAE	Abu Dhabi	3173	2	1,737,000	0.0123	301	5	221	9	111	4	402	17	5	0	2	0	1	0	6	0

NORTH AMERICA

						HbAS								HbSS							
Country	Admin1 unit	GAUL	Surveys	Population	CBR	Mean	SE	Median	SE	Q25	SE	Q75	SE	Mean	SE	Median	SE	Q25	SE	Q75	SE
Canada	Saskatchewan	836	2	1,102,480	0.0113	17	0	4	0	1	0	14	0	0	0	0	0	0	0	0	0
USA	Alaska	3215	2	682,465	0.0137	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
USA	California	3218	5	39,245,000	0.0137	11,911	236	11,030	264	7,832	353	15,032	204	260	7	199	8	114	6	336	8
USA	Florida	3223	3	18,312,800	0.0137	9,196	183	7,639	255	5,045	114	11,799	281	290	4	181	8	95	3	346	12
USA	New York	3246	7	21,636,900	0.0137	11,519	95	11,029	115	8,774	12	13,627	236	259	3	224	1	153	2	323	10
USA	North Carolina	3247	3	8,821,450	0.0137	3,088	111	2,211	64	1,137	78	4,272	91	94	5	40	3	14	2	114	3

SOUTH AMERICA

						HbAS								HbSS							
Country	Admin1 unit	GAUL	Surveys	Population	CBR	Mean	SE	Median	SE	Q25	SE	Q75	SE	Mean	SE	Median	SE	Q25	SE	Q75	SE
Belize	Stann Creek	607	3	32,388	0.0240	139	0	140	0	122	1	157	0	9	0	9	0	7	0	11	0
Brazil	Amazonas	668	5	2,642,080	0.0150	264	1	143	6	61	6	326	13	5	0	2	0	0	0	5	0
Brazil	Bahia	669	9	13,676,400	0.0150	14,817	60	14,078	12	11,465	2	17,488	300	640	4	558	1	393	3	780	12
Brazil	Rio Grande Do Sul	685	8	12,029,500	0.0150	3,721	25	3,493	7	2,643	41	4,484	17	65	1	56	1	35	0	82	1
Brazil	Rondonia	686	2	1,540,980	0.0150	75	4	12	1	1	0	62	1	2	0	0	0	0	0	0	0
Brazil	Sao Paulo	689	15	45,722,000	0.0150	26,450	512	23,546	718	15,886	433	33,552	590	700	24	505	26	290	18	867	36
Chile	Antofagasta (ii)	883	3	601,091	0.0140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
French Guiana	Cayenne	1271	3	167,704	0.0240	77	2	57	0	28	1	104	2	2	0	1	0	0	0	2	0

Country	Admin1 unit	GAUL	Surveys	Population	CBR	Mean	SE	Median	SE	Q25	SE	Q75	SE	Mean	SE	Median	SE	Q25	SE	Q75	SE
French Guiana	Saint-laurent-du-maroni	1272	3	63,209	0.0240	122	0	115	1	84	1	156	1	5	0	4	0	2	0	6	0
Haiti	Grand'Anse	72911	5	390,714	0.0257	1,144	1	1,124	8	827	3	1,431	5	54	0	45	1	27	0	71	1
Haiti	Nord-Ouest	1414	2	491,890	0.0257	1,205	1	1,168	4	913	6	1,479	5	48	0	41	0	26	0	62	0
Jamaica	Saint Andrew & Kingston	1640	3	688,272	0.0179	1,241	7	1,227	8	1,025	15	1,442	9	47	0	44	0	32	1	59	1
Mexico	Chiapas	1006348	2	4,239,470	0.0185	1,165	18	501	7	184	1	1,335	20	29	1	5	1	1	0	22	1
Mexico	Tabasco	1006373	2	2,125,840	0.0185	1,060	17	567	3	173	4	1,443	41	28	2	5	0	1	0	24	0
Nths Antilles	Not available	2157	2	200,555	0.0131	159	0	152	1	103	0	204	1	5	0	4	0	2	0	6	0
Peru	LORETO	1012328	3	1,032,140	0.0196	10	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Peru	PASCO	1012373	2	280,795	0.0196	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peru	UCAYALI	1012374	2	461,896	0.0196	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Venezuela	Amazonas	3302	14	59,011	0.0198	19	0	15	0	8	0	25	0	0	0	0	0	0	0	0	0
Venezuela	Anzoategui	3303	2	1,432,080	0.0198	888	1	718	3	388	8	1,196	9	22	0	12	0	5	0	27	0
Venezuela	Aragua	3305	3	1,716,840	0.0198	1,634	2	1,551	6	1,160	12	2,036	12	39	0	32	0	20	1	51	0
Venezuela	Bolivar	3307	3	1,543,730	0.0198	719	6	624	9	397	9	927	11	14	0	9	0	5	0	17	0
Venezuela	Falcon	3313	2	755,559	0.0198	911	0	865	8	611	9	1,160	7	30	0	24	0	14	0	39	0
Venezuela	Miranda	3317	2	3,079,300	0.0198	2,342	3	2,204	2	1,641	28	2,907	29	49	0	40	0	25	1	64	1
Venezuela	Sucre	3321	3	902,407	0.0198	787	3	729	4	531	7	981	9	21	0	17	0	11	0	27	0
Venezuela	Zulia	3325	4	4,230,060	0.0198	1,884	13	1,702	12	1,180	29	2,381	0	30	0	22	0	12	0	38	0

EUROPE						HbAS								HbSS							
Country	Admin1 unit	GAUL	Surveys	Population	CBR	Mean	SE	Median	SE	Q25	SE	Q75	SE	Mean	SE	Median	SE	Q25	SE	Q75	SE
Belgium	Region wallonne	602	17	3,480,780	0.0114	668	2	641	2	516	3	784	3	8	0	7	0	5	0	10	0
France	Ile-de-France	1259	3	12,074,800	0.0124	5,827	15	5,574	21	4,318	20	7,110	26	116	1	99	1	64	1	151	1
France	Prov-Alpes-Cote-d'Azur	1269	2	4,902,190	0.0124	1,110	6	951	8	587	5	1,464	12	19	0	12	0	5	0	24	0
Greece	Ipeiros	1341	3	342,146	0.0101	292	1	280	2	207	1	363	2	11	0	9	0	6	0	14	0
Greece	Kentriki Makedonia	1342	19	1,923,720	0.0101	1,064	5	1,018	6	776	6	1,301	7	31	0	27	0	18	0	39	0
Greece	Kriti	1343	2	604,300	0.0101	35	1	16	0	4	0	46	1	1	0	0	0	0	0	0	0
Greece	Notio Aigaio	40766	3	305,049	0.0101	41	0	28	0	11	0	58	1	1	0	0	0	0	0	1	0
Greece	Sterea Ellada	1346	2	562,603	0.0101	502	1	490	2	381	1	609	2	20	0	18	0	11	0	26	0
Italy	Sardegna	1629	13	1,707,900	0.0091	30	0	26	0	18	0	37	0	0	0	0	0	0	0	0	0
Italy	Sicilia	1630	41	5,269,760	0.0091	792	10	765	10	644	10	910	12	11	0	10	0	8	0	14	0
Spain	Madrid, Comunidad De	2729	2	6,090,270	0.0106	705	3	576	5	336	3	934	6	7	0	4	0	2	0	9	0
U.K.	England	3182	5	51,767,000	0.0121	15,809	135	14,509	116	10,263	75	20,013	214	357	4	269	3	150	2	466	7

Web Table 4: Global, regional and national rates of neonates affected (HbAS and HbSS) based on median estimates presented in this report (termed MAP) and on data calculated by Modell and Darlison (termed M&D). Births for 2003 and 2010 are shown in thousands and are based on the 2003 UN Demographic Yearbook and the 2010 UN World Population Prospects, respectively.

Country	Births 2003	Births 2010	MAP				M&D		
			AS		SS		SS		
			n	‰	n	‰	n (2003)	n (2010)	‰
Afghanistan	1,176	1,232	144	0.12	0	0.00	0	0	0.00
Albania	47	40	1,391	34.41	30	0.74	11	10	0.24
Algeria	627	680	10,486	15.42	191	0.28	50	54	0.08
Angola	604	758	112,443	148.37	8,364	11.04	9,560	11,996	15.83
Argentina	697	683	444	0.65	4	0.01	0	0	0.00
Armenia	36	46	0	0.00	0	0.00	0	0	0.00
Aruba	2	1	48	40.41	1	0.84	0	0	0.00
Australia	250	290	663	2.28	5	0.02	0	0	0.00
Austria	77	72	143	1.98	1	0.01	0	0	0.00
Azerbaijan	114	174	4	0.02	0	0.00	4	7	0.04
Bahamas	7	5	287	54.57	8	1.52	34	26	4.90
Bahrain	14	14	1,548	107.15	59	4.08	81	83	5.72
Bangladesh	3,536	3,206	3,459	1.08	16	0.00	0	0	0.00
Barbados	3	3	179	63.90	4	1.43	4	3	1.23
Belarus	89	107	0	0.00	0	0.00	0	0	0.00
Belgium	115	122	2,302	18.85	29	0.24	5	6	0.05
Belize	9	8	937	124.57	47	6.25	5	5	0.63
Benin	264	353	64,207	181.84	4,543	12.87	3,561	4,768	13.50
Bhutan	27	14	4	0.28	0	0.00	0	0	0.00
Bolivia (Plurinational State of)	300	258	6	0.02	0	0.00	0	0	0.00
Bosnia and Herzegovina	36	31	120	3.91	1	0.03	0	0	0.00
Botswana	53	45	300	6.63	4	0.09	0	0	0.00
Brazil	3,633	2,932	101,138	34.50	3,244	1.11	764	617	0.21
Brunei Darussalam	7	7	0	0.00	0	0.00	0	0	0.00
Bulgaria	67	75	1,076	14.36	17	0.23	0	0	0.00
Burkina Faso	491	689	71,083	103.17	3,124	4.53	1,065	1,493	2.17
Burundi	274	284	24,365	85.88	889	3.13	2,449	2,533	8.93
Cambodia	460	325	0	0.00	0	0.00	0	0	0.00
Cameroon	569	697	109,857	157.72	6,915	9.93	5,906	7,231	10.38
Canada	364	383	3,004	7.85	45	0.12	43	45	0.12
Cape Verde	13	10	625	61.22	18	1.76	6	5	0.44
Central African Republic	119	155	18,315	117.80	976	6.28	677	886	5.70
Chad	366	499	43,553	87.20	2,045	4.09	908	1,239	2.48
Chile	234	240	0	0.00	0	0.00	0	0	0.00
China	15,976	16,442	43	0.00	0	0.00	0	0	0.00
Colombia	1,060	875	14,464	16.53	321	0.37	537	444	0.51
Comoros	25	25	1,105	44.79	25	1.01	0	0	0.02
Congo	130	130	22,773	175.05	1,560	11.99	2,042	2,049	15.75
Congo, the Democratic Republic of the	2,325	2,856	489,745	171.50	38,217	13.38	20,113	24,698	8.65
Costa Rica	73	71	2,731	38.47	60	0.85	8	8	0.11
Côte d'Ivoire	720	712	74,168	104.19	3,567	5.01	1,564	1,546	2.17
Croatia	40	43	137	3.17	1	0.02	0	0	0.00
Cuba	151	108	6,578	61.16	240	2.23	259	185	1.72
Cyprus	8	10	147	15.11	2	0.21	0	0	0.03
Czech Republic	94	113	59	0.52	0	0.00	0	0	0.00
Denmark	65	62	11	0.18	0	0.00	2	2	0.03
Djibouti	31	25	3	0.12	0	0.00	0	0	0.00
Dominican Republic	201	214	9,461	44.27	247	1.16	722	769	3.60
Ecuador	329	273	45	0.16	0	0.00	12	10	0.04

Country	Births 2003	Births 2010	MAP				M&D		
			AS		SS		SS		
			n	‰	n	‰	n (2003)	n (2010)	‰
Egypt	1,774	1,884	47,754	25.35	1,196	0.63	19	21	0.01
El Salvador	125	124	4,039	32.57	80	0.65	8	8	0.07
Equatorial Guinea	18	25	5,059	203.35	385	15.48	182	249	10.00
Eritrea	151	179	767	4.28	9	0.05	0	0	0.00
Estonia	13	16	0	0.00	0	0.00	0	0	0.00
Ethiopia	2,380	2,550	11,197	4.39	137	0.05	1	2	0.00
Fiji	17	18	0	0.00	0	0.00	0	0	0.00
Finland	57	61	0	0.00	0	0.00	0	0	0.00
France	759	776	22,040	28.39	520	0.67	79	81	0.10
French Guiana	6	6	186	33.56	5	0.90	4	4	0.68
French Polynesia	4	4	0	0.00	0	0.00	0	0	0.00
Gabon	46	41	9,342	230.51	864	21.32	736	643	15.88
Gambia	58	65	8,657	133.98	418	6.47	305	342	5.30
Georgia	46	49	0	0.00	0	0.00	0	0	0.00
Germany	710	714	5,940	8.32	85	0.12	23	23	0.03
Ghana	726	737	102,229	138.62	5,474	7.42	4,847	4,924	6.68
Greece	105	113	6,667	58.97	206	1.82	1	1	0.01
Grenada	2	2	174	86.69	6	2.99	5	5	2.50
Guadeloupe	8	6	459	74.39	14	2.27	16	13	2.16
Guam	3	3	0	0.00	0	0.00	0	0	0.00
Guatemala	375	453	10,285	22.71	252	0.56	0	0	0.00
Guinea	310	388	70,965	182.82	5,232	13.48	4,325	5,418	13.96
Guinea-Bissau	53	62	5,011	81.35	192	3.12	0	0	1.83
Guyana	16	13	622	46.95	17	1.28	11	9	0.68
Haiti	249	262	26,801	102.35	1,088	4.16	622	655	2.50
Honduras	230	196	17,783	90.58	772	3.93	0	0	0.00
Hong Kong	47	64	0	0.00	0	0.00	0	0	0.00
Hungary	94	101	59	0.59	0	0.00	0	0	0.00
Iceland	4	5	0	0.00	0	0.00	0	0	0.00
India	26,492	25,495	996,563	39.09	42,016	1.65	25,768	24,798	0.97
Indonesia	4,863	4,046	328	0.08	1	0.00	0	0	0.00
Iran, Islamic Republic of	1,170	1,216	25,768	21.18	862	0.71	96	100	0.08
Iraq	903	1,072	23,488	21.91	629	0.59	499	592	0.55
Ireland	62	72	60	0.84	0	0.00	0	0	0.00
Italy	541	547	5,635	10.30	91	0.17	3	3	0.01
Jamaica	57	49	3,998	81.81	137	2.80	172	148	3.03
Japan	1,123	1,079	0	0.00	0	0.00	0	0	0.00
Jordan	148	153	6,365	41.57	145	0.95	4	4	0.03
Kazakhstan	247	325	1	0.00	0	0.00	0	0	0.00
Kenya	1,121	1,507	98,471	65.35	4,475	2.97	7,872	10,578	7.02
Korea, Democratic People's Republic of	495	340	0	0.00	0	0.00	0	0	0.00
Korea, Republic of	494	480	0	0.00	0	0.00	0	0	0.00
Kuwait	45	53	3,824	72.04	116	2.19	37	44	0.83
Kyrgyzstan	105	133	0	0.00	0	0.00	0	0	0.00
Lao People's Democratic Republic	218	140	0	0.00	0	0.00	0	0	0.00
Latvia	21	25	0	0.00	0	0.00	0	0	0.00
Lebanon	77	63	6,382	101.09	251	3.98	6	5	0.08
Lesotho	75	56	40	0.72	0	0.00	0	0	0.00
Liberia	127	154	13,217	85.69	562	3.64	105	127	0.82
Libyan Arab Jamahiriya	111	142	6,020	42.38	188	1.32	34	44	0.31
Lithuania	31	35	0	0.00	0	0.00	0	0	0.00
Luxembourg	5	6	48	8.26	0	0.00	0	0	0.06
Madagascar	609	697	69,295	99.41	3,379	4.85	2,084	2,383	3.42
Malawi	579	698	47,370	67.85	1,688	2.42	917	1,106	1.58

Country	Births 2003	Births 2010	MAP AS n	MAP AS ‰	MAP SS n	MAP SS ‰	M&D SS n (2003)	M&D SS n (2010)	M&D SS ‰
Malaysia	534	553	1	0.00	0	0.00	0	0	0.00
Maldives	5	5	0	0.00	0	0.00	0	0	0.01
Mali	494	601	56,236	93.53	2,701	4.49	4,421	5,385	8.96
Malta	4	4	143	38.33	2	0.54	0	0	0.00
Martinique	6	5	391	83.02	12	2.55	9	7	1.52
Mauritania	110	110	9,505	86.54	433	3.94	159	158	1.44
Mauritius	19	16	0	0.00	0	0.00	1	1	0.05
Mayotte	2	6	447	68.90	12	1.85	0	1	0.23
Mexico	2,564	2,045	31,120	15.21	641	0.31	105	84	0.04
Micronesia, Federated States of	3	3	0	0.00	0	0.00	0	0	0.00
Moldova, Republic of	36	43	1	0.02	0	0.00	0	0	0.00
Mongolia	46	61	0	0.00	0	0.00	0	0	0.00
Montenegro	87	8	72	9.18	1	0.13	0	0	0.00
Morocco	560	597	3,202	5.36	40	0.07	118	126	0.21
Mozambique	754	850	42,588	50.10	1,645	1.94	170	191	0.23
Myanmar	984	843	40	0.05	0	0.00	0	0	0.00
Namibia	65	56	1,138	20.42	30	0.54	10	9	0.15
Nepal	788	695	1,558	2.24	11	0.02	0	0	0.00
Netherlands	200	180	4,759	26.47	82	0.46	10	9	0.05
Netherlands Antilles	4	3	150	57.09	4	1.52	9	7	2.50
New Caledonia	4	4	0	0.00	0	0.00	0	0	0.00
New Zealand	56	62	0	0.00	0	0.00	9	10	0.16
Nicaragua	190	133	6,514	49.08	204	1.54	4	3	0.02
Niger	506	758	90,671	119.66	4,965	6.55	6,046	9,045	11.94
Nigeria	4,895	6,219	1,136,909	182.80	85,186	13.70	77,192	98,083	15.77
Norway	57	60	0	0.00	0	0.00	2	2	0.04
Oman	90	50	32	0.64	0	0.00	222	124	2.47
Pakistan	3,913	4,859	18,962	3.90	228	0.05	101	126	0.03
Panama	63	67	4,457	66.53	140	2.09	8	9	0.13
Papua New Guinea	175	200	0	0.00	0	0.00	0	0	0.00
Paraguay	168	153	664	4.34	7	0.05	0	0	0.00
Peru	649	578	2	0.00	0	0.00	25	22	0.04
Philippines	1,703	2,294	0	0.00	0	0.00	0	0	0.00
Poland	351	415	59	0.14	0	0.00	0	0	0.00
Portugal	113	90	2,170	24.11	41	0.46	3	2	0.03
Puerto Rico	59	52	326	6.32	2	0.04	23	21	0.40
Qatar	13	17	1,365	78.02	41	2.34	7	10	0.55
Réunion	14	14	6	0.42	0	0.00	1	1	0.10
Romania	213	218	320	1.46	2	0.01	0	0	0.00
Russian Federation	1,475	1,656	14	0.01	0	0.00	0	0	0.00
Rwanda	313	417	22,857	54.78	601	1.44	125	167	0.40
Saint Lucia	3	3	311	105.76	12	4.08	7	7	2.50
Saint Vincent and the Grenadines	2	2	176	98.46	6	3.36	2	2	1.16
Samoa	5	13	0	0.00	0	0.00	0	0	0.00
Saudi Arabia	766	561	19,447	34.68	691	1.23	5,397	3,950	7.04
Sao Tome and Principe	6	5	763	154.66	41	8.31	49	40	8.10
Senegal	407	462	53,002	114.75	2,535	5.49	1,895	2,153	4.66
Serbia	87	108	830	7.67	10	0.09	0	0	0.00
Sierra Leone	246	213	39,530	185.56	2,838	13.32	3,243	2,808	13.18
Singapore	46	45	0	0.00	0	0.00	0	0	0.00
Slovakia	52	58	12	0.21	0	0.00	0	0	0.00
Slovenia	17	20	22	1.10	0	0.00	0	0	0.00
Solomon Islands	15	16	0	0.00	0	0.00	0	0	0.00
Somalia	505	402	1,192	2.96	13	0.03	0	0	0.00

Country	Births 2003	Births 2010	MAP AS n	MAP AS ‰	MAP SS n	MAP SS ‰	M&D SS n (2003)	M&D SS n (2010)	M&D SS ‰
South Africa	1,258	1,036	4,946	4.78	73	0.07	0	0	0.00
Spain	440	480	7,324	15.25	149	0.31	0	1	0.00
Sri Lanka	363	347	425	1.22	2	0.01	0	0	0.00
Sudan	1,157	1,378	98,244	71.32	4,567	3.32	483	575	0.42
Suriname	10	9	653	69.97	19	2.04	13	12	1.30
Swaziland	36	34	398	11.61	4	0.12	1	1	0.03
Sweden	99	112	2	0.02	0	0.00	4	5	0.04
Switzerland	81	76	622	8.19	6	0.08	0	0	0.00
Syrian Arab Republic	493	496	24,448	49.34	901	1.82	66	66	0.13
Tajikistan	178	196	0	0.00	0	0.00	0	0	0.00
Tanzania, United Republic of	1,232	1,846	203,747	110.36	11,022	5.97	8,655	12,965	7.02
Thailand	1,054	784	0	0.00	0	0.00	0	0	0.00
Timor-Leste	28	44	0	0.00	0	0.00	0	0	0.00
Togo	202	210	34,057	162.19	2,175	10.36	1,746	1,816	8.65
Trinidad and Tobago	19	19	1,648	85.75	56	2.91	30	31	1.60
Tonga	2	3	0	0.00	0	0.00	0	0	0.00
Tunisia	166	171	4,420	25.82	81	0.47	63	64	0.38
Turkey	1,478	1,279	12,852	10.05	330	0.26	116	100	0.08
Turkmenistan	139	110	4	0.04	0	0.00	0	0	0.00
Uganda	1,164	1,484	189,801	127.92	10,143	6.84	8,216	10,469	7.06
Ukraine	410	495	33	0.07	0	0.00	0	0	0.00
United Arab Emirates	75	57	402	7.03	4	0.07	24	18	0.32
United Kingdom	697	749	15,746	21.02	296	0.40	108	116	0.16
United States of America	4,194	4,353	100,150	23.01	2,843	0.65	838	869	0.20
Uruguay	51	49	82	1.68	1	0.02	0	0	0.00
Uzbekistan	520	578	1	0.00	0	0.00	0	0	0.00
Vanuatu	6	7	0	0.00	0	0.00	0	0	0.00
Venezuela, Bolivarian Republic of	492	575	19,272	33.51	435	0.76	108	126	0.22
Viet Nam	1,807	1,415	0	0.00	0	0.00	0	0	0.00
Virgin Islands, U.S.	2	1	25	18.96	0	0.00	4	2	1.60
Western Sahara	9	9	144	15.32	3	0.32	2	2	0.21
Yemen	930	905	6,411	7.08	80	0.09	119	116	0.13
Zambia	457	616	88,801	144.09	5,652	9.17	3,346	4,517	7.33
Zimbabwe	408	363	16,345	45.04	483	1.33	162	144	0.40

WHO regions	Births 2003	Births 2010	MAP AS n	MAP AS ‰	MAP SS n	MAP SS ‰	M&D SS n (2003)	M&D SS n (2010)	M&D SS ‰ (2003/2010)
AFRO	**22,895**	**31,755**	**3,610,851**	**113.71**	**238,083**	**7.50**	**184,812**	**232,336**	**8.07/7.32**
AMRO	**16,609**	**15,210**	**391,257**	**25.72**	**13,104**	**0.86**	**4,432**	**4,156**	**0.27/0.27**
EMRO	**16,798**	**13,971**	**256,643**	**18.37**	**8,239**	**0.59**	**7,389**	**6,072**	**0.44/0.43**
EURO	**10,459**	**10,976**	**121,601**	**11.08**	**3,271**	**0.30**	**376**	**368**	**0.04/0.03**
SEARO	**38,139**	**35,820**	**1,020,489**	**28.49**	**42,597**	**1.19**	**25,768**	**24,798**	**0.68/0.69**
WPRO	**23,914**	**23,535**	**1,150**	**0.05**	**9**	**0.00**	**9**	**10**	**0.00/0.00**

World	Births 2003	Births 2010	MAP AS n	MAP AS ‰	MAP SS n	MAP SS ‰	M&D SS n (2003)	M&D SS n (2010)	M&D SS ‰ (2003/2010)
WORLD	**128,814**	**131,266**	**5,476,407**	**41.72**	**312,302**	**2.38**	**222,785**	**267,740**	**1.73/2.04**

Web Table 5. MCMC output parameter values. Summary statistics presented are the mean and median values, standard deviation (std), interquartile range (IQR) and 95% Bayesian credible interval (95 BCI). The scale parameter is measured in units of earth radii. Values are presented to two significant figures.

Parameter	Symbol	Mean	Median	Std	IQR	95 BCI
Nugget variance	V	0.450	0.443	0.079	0.062	0.204
Amplitude (or partial sill)	φ	2.715	2.665	0.348	0.174	0.836
Scale (or range)	θ	0.199	0.199	0.001	0.001	0.003

Web Table 6. Summary of data selection, mapping and modelling assumptions and suggestions for future improvements.

Data

1. *We assumed that surveys not reporting any selection bias in the sampling methodology were representative of the local population.*
   A complete and consistent description of the sampling method used would remove any ambiguity about the representativeness of the sample.
2. *We assumed that surveys targeting specific ethnic groups could not be included.*
   Studies targeting a specific ethnic group cannot be considered representative of the overall local population. Provided that the sample size is not too small, random or universal surveys testing all ethnic groups without selection bias can be considered as representative.
3. *We assumed that surveys georeferenced at the province or country level were too imprecise to be included.*
   Micromapping studies have shown that HbS allele frequency can highly vary over short distances. Surveys testing individuals from all over a region or country without giving the individuals' origin could not be used. Similarly, surveys not reporting the location of the survey also had to be excluded. Systematic reporting of basic geographical information would increase the number of included studies.
4. *We assumed that the diagnostic method had a minimum effect on the testing results.*
   The diagnostic method is not consistently reported. Most diagnostic methods for sickle haemoglobin can be considered as reliable.
5. *We assumed that interactions between HbS, HbC and β-thalassaemias were complex.*
   The number of individuals with compound status is relatively small and data available is very limited. Calculating newborn estimates for these compound individuals would require both the availability of a similar database on HbC and β-thalassaemia, and a good understanding of their interactions.

Mapping and modelling process

1. *We assumed that the crude birth rate was homogeneous within a country.*
   No data on crude birth rate are consistently available at sub-national levels. Local or national studies could allow us to incorporate more precise information.
2. *We assumed that populations were in Hardy-Weinberg equilibrium (HWE), and derived HbS allele frequency based on this assumption*.
   In some cases, we have observed differences between observed and HWE predicted genotype counts but there is currently not enough information on this relationship to use it within a global model.
3. *We assumed that information on consanguinity was too crude to be incorporated.*
   Information on consanguinity is not consistently reported in surveys. Moreover, although there is some global information (e.g. www.consang.net), only crude national information is available. Including such data in the model would likely have resulted in adding more uncertainty in the predictions.
4. *We assumed that the amount of data available was not sufficient to develop a spatio-temporal model.*
   Large amounts of data are required in order to analyse temporal changes at the global scale. Such a study might be possible in data-rich areas.

Web Dataset. List of published and unpublished sources from which data have been used as input into our model. Other references are ordered alphabetically by surname.

1. Abdulsalam AA, Bashour HN, Monem FS, Hamadeh FM. Pregnancy outcomes among Palestinian refugee women with sickle cell trait in Damascus, Syria. Saudi Med J. 2003; **24**(9): 986-90.
2. Acemoglu H, Beyhun NE, Vancelik S, Polat H, Guraksin A. Thalassaemia screening in a non-prevalent region of a prevalent country (Turkey): is it necessary? Public Health. 2008; **122**(6): 620-4.
3. Achidi EA, Salimonu LS, Asuzu MC, Berzins K, Walker O. Studies on *Plasmodium falciparum* parasitemia and development of anemia in Nigerian infants during their first year of life. Am J Trop Med Hyg. 1996; **55**(2): 138-43.
4. Acquaye CTA, Oldham JH. Variants of haemoglobin and glucose-6-phosphate dehydrogenase - I. Distribution in Southern Ghana. Ghana Med J. 1973; **12**: 412-8.
5. Adewuyi JO, Gwanzura C. Frequency of the sickle haemoglobin gene in Zimbabwe. East Afr Med J. 1994; **71**(3): 204-6.
6. Adeyemo OA, Soboyejo OB. Frequency distribution of ABO, RH blood groups and blood genotypes among the cell biology and genetics students of University of Lagos, Nigeria. Afr J Biotechnol. 2006; **5**(22): 2062-5.
7. Agrawal HN. A genetic survey among the Bhantus of Andaman. Bulletin of the Anthropological Survey India. 1963; **12**: 143-7.
8. Agrawal HN. A study of the ABO blood groups. P.T.C. taste sensitivity, middle phalangeal hair and sickle cell trait amonth three Nicobarese groups of Nicobar Archipelago. Bulletin of the Anthropological Survey India. 1964; **13**: 63-8.
9. Agrawal HN. A short note on a study of A.B.O. blood groups, P.T.C. taste sensitivity, middle phalangeal hairs and sickle cell trait among the Wad Balgel of Andhra Pradesh. Bulletin of the Anthropological Survey India. 1964; **13**: 111-3.
10. Agrawal HN. A study of ABO blood groups. P.T.C. taste sensitivity, sickle cell trait and middle phalangeal hairs among the Burmese immigrants of Andaman Islands. Eastern Anthropologist. 1966; **19**: 107-16.
11. Agrawal HN. ABO blood group and the sickle cell investigations among the Shompen of Great Nicobar. Journal of the Indian Anthropological Society. 1966; **1**: 149-50.
12. Agrawal HN. ABO blood groups, P.T.C. taste sensitivity, sickle cell trait, middle phalangeal hairs, and colour blindness in the coastal Nicobarese of Great Nicobar. Acta Genet Stat Med. 1968; **18**(2): 147-54.
13. Ágreda F, Arcia E, Jované S, Pino E, Tufiño E, Lagrutta F. Frecuencia de Portadores del Alelo S en la Población de 15 - 49 Años de Portobelo. Panamá. Junio 2004. Revista Médico Científica. 2004; **17**(2): 66-70.
14. Ahern EJ, Swan AV, Ahern VN. The prevalence of the rarer inherited haemoglobin defects in adult Jamaicans. Br J Haematol. 1973; **25**(4): 437-44.
15. Aidoo M, Terlouw DJ, Kolczak MS, McElroy PD, ter Kuile FO, Kariuki S, et al. Protective effects of the sickle cell gene against malaria morbidity and mortality. Lancet. 2002; **359**(9314): 1311-2.
16. Akinkugbe FM. Anaemia in a rural population in Nigeria (Ilora). Ann Trop Med Parasitol. 1980; **74**(6): 625-33.
17. Akoglu T, Ozer FL, Akoglu E. The coincidence of glucose-6-phosphate dehydrogenase deficiency and hemoglobin S gene in Cukurova Province, Turkey. Am J Epidemiol. 1986; **123**(4): 677-80.
18. Aksoy M. Sickle-cell trait in South Turkey. Lancet. 1955; **1**: 589.
19. Aksoy M. Hemoglobin S in Eti-Turks and the Allewits in Lebanon. Blood. 1961; **17**: 657-9.
20. Al-Awamy BH, Al-Musan M, Al-Turki M, Serjeant GR. Neonatal screening for sickle cell disease in the Eastern Province of Saudi Arabia. Trans R Soc Trop Med Hyg. 1984; **78**: 792-4.
21. Alexanderides C. Sur la frequence des hemoglobinopathies mediterraneenes en Grece. Proceedings of the 9th Congress of the European Society for Haematology (Lisbon, 1963) S, Karger; 1963; New York; 1963. p. 477-95.

22. Alkindi S, Al Zadjali S, Al Madhani A, Daar S, Al Haddabi H, Al Abri Q, et al. Forecasting hemoglobinopathy burden through neonatal screening in Omani neonates. Hemoglobin. 2010; **34**(2): 135-44.
23. Allard R. A propos de la conservation génétique du sickle cell trait. Ann Soc Belg Med Trop. 1955; **35**(6): 649-60.
24. Allbrook D, Barnicot NA, Dance N, Lawler SD, Marshall R, Mungai J. Blood groups, haemoglobin and serum factors of the Karamojo. Hum Biol. 1965; **37**(3): 217-37.
25. Allen SJ, Bennett S, Riley EM, Rowe PA, Jakobsen PH, O'Donnell A, et al. Morbidity from malaria and immune responses to defined *Plasmodium falciparum* antigens in children with sickle cell trait in The Gambia. Trans R Soc Trop Med Hyg. 1992; **86**(5): 494-8.
26. Allen SJ, Rowe P, Allsopp CE, Riley EM, Jakobsen PH, Hill AV, et al. A prospective study of the influence of alpha thalassaemia on morbidity from malaria and immune responses to defined *Plasmodium falciparum* antigens in Gambian children. Trans R Soc Trop Med Hyg. 1993; **87**(3): 282-5.
27. Allison AC. The sickle-cell trait in the mediterranean area. Man. 1953; **53**: 31.
28. Allison AC. The distribution of the sickle-cell trait in East Africa and elsewhere, and its apparent relationship to the incidence of subtertian malaria. Protection afforded by sickle-cell trait against subtertian malareal infection. Trans R Soc Trop Med Hyg. 1954; **48**(4): 312-8.
29. Allison AC. The sickle-cell and haemoglobin C genes in some African populations. Ann Hum Genet. 1956; **21**(1): 67-89.
30. Allison AC, Ikin EW, Mourant AE, Raper AB. Blood groups and other genetic traits in East African tribes. Journal of The Royal Anthropological Institute of Great Britain and Ireland. 1952; **82**: 55-60.
31. Almeida AM, Henthorn JS, Davies SC. Neonatal screening for haemoglobinopathies: the results of a 10-year programme in an English Health Region. Br J Haematol. 2001; **112**(1): 32-5.
32. Al-Nood H, Al-Ismail S, King L, May A. Prevalence of the sickle cell gene in Yemen: a pilot study. Hemoglobin. 2004; **28**(4): 305-15.
33. al-Nuaim L, Talib ZA, el-Hazmi MA, Warsy AS. Sickle cell and G-6-PD deficiency gene in cord blood samples: experience at King Khalid University Hospital, Riyadh. J Trop Pediatr. 1997; **43**(2): 71-4.
34. Aluoch JR. Higher resistance to *Plasmodium falciparum* infection in patients with homozygous sickle cell disease in western Kenya. Trop Med Int Health. 1997; **2**(6): 568-71.
35. Alusala DN, Estambale BB, Magnussen P, Friis H, Luoba AI, Mwaniki D. Predictors of serum ferritin and haemoglobin during pregnancy, in a malaria-endemic area of western Kenya. Ann Trop Med Parasitol. 2008; **102**(4): 297-308.
36. Amano H, Yamamoto T, Kurata S, Sano A, Takahashi Y. The correlation between Hb-S and malaria in Brazzaville, Congo (author's transl). Jpn J Hum Genet. 1974; **19**: 65-6.
37. Arends. Data for Venezuela. 2009.
38. Arends A. Data for Venezuela. 2010.
39. Arends T. Absence of abnormal haemoglobins in Colombian Tunebo Indians. Nature. 1961; **190**: 93-4.
40. Arends T. [Current status of the study of abnormal hemoglobins in Venezuela]. Sangre (Barc). 1963; **8**: 1-14.
41. Arends T. Frecuencia de hemoglobinas anormales en poblacionas humanas sudamericanas. Acta Cient Venez. 1963; **14**(Suppl I): 46-57.
42. Arends T, Brewer G, Chagnon N, Gallango ML, Gershowitz H, Layrisse M, et al. Intratribal genetic differentiation among the Yanomama Indians of southern Venezuela. Proc Natl Acad Sci U S A. 1967; **57**(5): 1252-9.
43. Arends T, Gallango ML, Muller A, Gonzalez-Marroro M, Perez Bandez O. Tapipa: a negroid Venezuelan isolate. Papers IX. International Congress on Anthropological and Ethnological Sciences; 1973; Chicago; 1973. p. 1.
44. Arends T, Garlin G, Anchustogut M, Arends T. Variants hemoglobinicas *Gamma* type de talasemia de origen espanol en la poblacion venecolana. Sangre (Barc). 1983; **28**: 542-50.

45. Asghar M, Sachdeva MP. Glucose-6-phosphate dehydrogenase deficiency and sickle cell hemoglobin among the Dhodias of Dadra Nagar Haveli. Anthropologist. 2009; **11**(1): 61-2.
46. Atkinson SH, Rockett K, Sirugo G, Bejon PA, Fulford A, O'Connell MA, et al. Seasonal childhood anaemia in West Africa is associated with the haptoglobin 2-2 genotype. PLoS Med. 2006; **3**(5): e172.
47. Aung Than B, Pe UH. Haemoglobinopathies in Burma. I. The incidence of haemoglobin E. Trop Geogr Med. 1971; **23**: 15-9.
48. Auricchio MTBDM, Vicente JP, Meyer D, Mingroni-Netto RC. Frequency and origins of hemoglobin S mutation in African-derived Brazilian populations. Hum Biol. 2007; **79**(6): 667-77.
49. Ayodo G, Price AL, Keinan A, Ajwang A, Otieno MF, Orago ASS, et al. Combining evidence of natural selection with association analysis increases power to detect malaria-resistance variants. Am J Hum Genet. 2007; **81**(2): 234-42.
50. Azevedo ES, Alves AFP, Da Silva MCBO, Souza M Das GF, Muniz Dias Lima AM, Azevedo WC. Distribution of abnormal hemoglobins and glucose-6-phosphate dehydrogenase variants in 1200 school children of Bahia, Brazil. Am J Phys Anthropol. 1980; **53**: 509-12.
51. Azevedo ES, Costa Silva KM, Da Silva MCBO, Dias Lima AM, Mascaronhas Fortuna CM, Santos MG. Genetic and anthropological studies in the island of Itaparica, Bahia, Brazil. Hum Hered. 1981; **31**(6): 353-7.
52. Baghernajad-Salehi L, D'Apice MR, Babameto-Laku A, Biancolella M, Mitre A, Russo S, et al. A pilot beta-thalassaemia screening program in the Albanian population for a health planning program. Acta Haematol. 2009; **121**(4): 234-8.
53. Balgir RS. Genetic heterogeneity of population structure in 15 major scheduled tribes in central-eastern India: A study of immuno-hematological disorders. Indian Journal of Human Genetics. 2006; **12**(2): 86-92.
54. Ballas SK, Park D, Wapner RJ. Neonatal screening for sickle cell disease in a metropolitan university hospital: efficacy and problems. J Med Screen. 1994; **1**(4): 229-32.
55. Barclay GP, Jones HI, Splaine M. A survey of the of sickle cell trait and glucose-6-phosphate dehydrogenase deficiency in Zambia. Trans R Soc Trop Med Hyg. 1970; **64**: 78-93.
56. Barclay GP, Splaine M. The distribution of the sickle cell trait in Zambia. Trop Geogr Med. 1972; **24**: 393-400.
57. Barnicot NA, Allison AC, Blumberg BS, Deliyannis G, Krimbas C, Ballas A. Haemoglobin types in Greek populations. Ann Hum Genet. 1963; **26**: 229-36.
58. Barnicot NA, Ikin EW, Mourant AE. Les groupes sangiuns ABB, MNS, et Rh des Touaregs de l'air. L'Anthropologie. 1954; **58**: 231-40.
59. Basu A, Namboodiri KK, Weitkamp LR, Brown WH, Pollitzer WS, Spivey MA. Morphology, serology, dermatoglyphics, and microevolution of some village populations in Haiti, West Indies. Hum Biol. 1976; **48**(2): 245-69.
60. Basu S, Kumar A, Sachdeva MP, Saraswathy KN. Incidence of NESTROFT-positives and haemoglobin S among the Jats and Brahmins of Sampla, Haryana. Anthropologist. 2008; **10**(3): 203-5.
61. Bayoumi RA, Omer A, Samuel AP, Saha N, Sebai ZA, Sabaa HM. Haemoglobin and erythrocytic glucose-6-phosphate dehydrogenase variants among selected tribes in Western Saudi Arabia. Trop Geogr Med. 1979; **31**(2): 245-52.
62. Beall CM, Decker MJ, Brittenham GM, Kushner I, Gebremedhin A, Strohl KP. An Ethiopian pattern of human adaptation to high-altitude hypoxia. Proc Natl Acad Sci U S A. 2002; **99**(26): 17215-8.
63. Becquet R, Gasteau T, Happi C. Drepanocytosis in Pays Bamileke (Cameroons). Statistical study. Bull Soc Pathol Exot Filiales. 1959; **52**: 836-43.
64. Ben Rachid MS, Farhat M, Brumpt LC. Hemoglobinopathie s en Tunise. Nouv Rev Fr Hematol. 1967; **7**: 393-400.
65. Benoist J. Anthropologie physique de la population de l'ilo de la tortue (Haiti). Contribution à l'étude de l'origine des noirs des antilles françaises. Bull Mem Soc Anthropol Paris. 1962; **3**(11): 315-35.
66. Bernstein SC, Bowman JE, Kaptue Noche L. Population studies in Cameroon: hbs, G-6pd deficiency and falciparum malaria. Hum Hered. 1980; **30**: 251-8.

67. Beuzard Y, Caburl-Martin J, Auffret C, Rouyer-Fessard P, Kleman K, Lubin B, et al. Depistage des hemoglobinopathies dang le sang de cordon par isoelectrofocalisation. Nouv Rev Fr Hematol. 1979; **21**(Suppl 1): 126.
68. Bianco I, Graziani B, Salvini P, Mastromonaco I, Silvestroni E. [Incidence and characters of alpha-microcythaemia in the populations of northern Sardinia. Early findings]. Nouv Rev Fr Hematol. 1972; **12**(2): 191-200.
69. Bienzle U, Komp H, Feldheim M, Reimer A, Steffen E, Guggenmoos-Holzmann I. The distribution and interaction of haemoglobin variants and the beta thalassaemia gene in Liberia. Hum Genet. 1983; **63**(4): 400-3.
70. Bienzle U, Okoye VC, Gogler H. Haemoglobin and glucose-6-phosphate dehydrogenase variants: distribution in relation to malaria endemicity in a Togolese population. Z Tropenmed Parasitol. 1972; **23**(1): 56-62.
71. Biondi G, Calandra PL, Coppa A, Falcone G, Rickards O, Vecchi F. Distribution of the S and C hemoglobins in Atakora District (Benin). Human biology; an international record of research. 1980; **52**(2): 205-13.
72. Blackwell RQ, Tung-Hsiang Huang J, Chien LC. Abnormal hemoglobin characteristics of Taiwan aborigines. Human biology; an international record of research. 1965; **37**(4): 343-56.
73. Blake NM, Ramesh A, Vijayakumar M, Murty JS, Bhatia KK. Genetic studies on some tribes of the Telangana region, Andhra, Pradesh, India. Acta Anthropogenet. 1981; **5**(1): 41-56.
74. Blakebrough IS, Greenwood BM, Whittle HC, Bradley AK, Akintunde A. Sickle cell trait and the immune response to meningococcal vaccines. Trans R Soc Trop Med Hyg. 1981; **75**(6): 905-6.
75. Bloch M, Rivera H. [Abnormal hemoglobins and glucose-6-phosphate dehydrogenase deficiency in El Salvador]. Sangre (Barc). 1969; **14**(2): 121-4.
76. Blumberg BS, Allison AC, Garry B. The haptoglobins and haemoglobins of Alaskan Eskimos and Indians. Ann Hum Genet. 1959; **23**: 349-56.
77. Bobhate SK, Kabinwar N, Sonule SS. Incidence of sickle cell disease in Chandrapur area. Indian J Med Sci. 1983; **37**(11): 201-3.
78. Boemer F, Vanbellinghen JF, Bours V, Schoos R. Screening for sickle cell disease on dried blood: a new approach evaluated on 27,000 Belgian newborns. J Med Screen. 2006; **13**(3): 132-6.
79. Bouloux C, Gomila J, Langaney A. Hemotypology of the Bedik. Human biology; an international record of research. 1972; **44**(2): 289-302.
80. Boyer SH, Crosby EF, Fuller GF, Ulenurm L, Buck AA. A survey of hemoglobins in the Republic of Chad and characterization of hemoglobin Chad:alpha-2-23Glu--Lys-beta-2. Am J Hum Genet. 1968; **20**(6): 570-8.
81. Boyo AE. Starch gel electrophoresis of the haemoglobin of Nigerian children. A preliminary investigation of the incidence of thalassaemia. The West African medical journal. 1963; **12**: 75-81.
82. Breguet G, Ney R, Kirk RL, Blake NM. Genetic survey of an isolated community in Bali, Indonesia. II. Haemoglobin types and red cell isozymes. Hum Hered. 1982; **32**(5): 308-17.
83. Brittenham G, Lozoff B, Harris JW, Mayson SM, Miller A, Huisman TH. Sickle cell anemia and trait in southern India: further studies. Am J Hematol. 1979; **6**(2): 107-23.
84. Brittenham G, Lozoff B, Harris JW, Sharma VS, Narasimhan S. Sickle cell anemia and trait in a population of southern India. Am J Hematol. 1977; **2**(1): 25-32.
85. Bronte-Stewart B, Budtz-Olsen DE, Hickley JM, Brock JF. The health and nutritional status of the kung Bushmen of Southwest Africa. South African Journal of Laboratory and Clinical Medicine. 1960; **6**: 187-216.
86. Bruce-Tagoe AA, Belcher DW, Wurapa FK, Turkson P, Nicholas DD, Ofosu-Amaah S. Haematological values in a rural Ghanaian population. Trop Geogr Med. 1977; **29**(3): 237-44.
87. Buchi EC. [Blut, Geshmack, and Farbensinn bel den Kurumba (Nilgiri, Sudindied)]. Arch Julius Klaus Stift Vererbungsforsch Sozialanthropol Rassenhyg. 1959; **34**: 310-6.
88. Buettner Janusch J, Bove JR, Young N. Genetic Traits and Problems of Biological Parenthood in Two Peruvian Indian Tribes. Am J Phys Anthropol. 1964; **22**: 149-54.
89. Buettner Janusch J, Buettner Janusch V. Haemoglobin S in the Malagasy. Arch Inst Pasteur Madag. 1970; **39**: 211-4.

90. Buettner-Janusch J, Buettner-Janusch V. Hemoglobins, haptoglobins, and transferrins in indigenous populations of Kenya. Am J Phys Anthropol. 1970; **32**(1): 27-32.
91. Cabannes R. Repartition des haemoglobines anormales dans la partie ouest du continent Africain. In: Jonxis JHP, editor. Abnormal Haemoglobins in Africa. Philadephia: Davis, F. A.; 1965. p. 291-317.
92. Cabannes R, Beurrier A, Larrouy G. [Thalassemia in the Indians of French Guiana]. Nouv Rev Fr Hematol. 1965; **5**(4): 617-29.
93. Cabannes R, Larrouy G, Fernet P, Sendrail A. Etude hemotypologique des populations sedentaires de la Saoura (Sahara occidental). II. Les hemoglobines. Bull Mem Soc Anthropol Paris. 1969; **12**(4): 139-42.
94. Cabannes R, Larrouy G, Sendrail A. Etude hemotypologique des populations du massif du Hoggar et du plateau de l'Air. III. Les hemoglobines. Bull Mem Soc Anthropol Paris. 1969; **12**(4): 143-6.
95. Cabannes R, Lefevre-Witier P, Sendrail A. III. Etude des hemoglobines dans les populations du Tassili N'Ajjer. Bull Mem Soc Anthropol Paris. 1967; **12**(1): 434-9.
96. Cabannes R, Nicolas C, Clerc M, Rives P, Seguin G, Cierea P, et al. Etude hemotypologique des Koulango-de Cote-d'Ivoire. Ann Univ Abidjan Fac Ned. 1975; **9**: 16-32.
97. Cabannes R, Nicolas C, Houvet D, Fellenz C, Sangare A. Etudehemotypologique et biologique des Abrons et des metis Koulango-abron. Ann Univ Abidjan Fac Ned. 1978; **12**: 119-41.
98. Cabannes R, Schmidt-Beurrier A. Recherches sur les haemoglobines des populations indiennes de l'Amerique de Sud. L'Anthropologie. 1966; **70**: 331-4.
99. Cabannes R, Schmidt-Beurrier A, Monnet B. Etude des protéines, des haptoglobines, des transférrines et des hémoglobines d'une population noire de Guyane française (Boni). Bull Soc Pathol Exot Filiales. 1966; **59**: 908-16.
100. Cabannes R, Sy B, Martineaud M, Boissezon J, Blanc M, Clerc M, et al. Etude hemotypologique et biologique des Attie du village d'Atiekwa. Medecine d'Afrique Noire. 1970; **17**: 835-41.
101. Cabannes R, Sy B, Schmidt-Beurrier A. [Study of hemoglobinoses in the Niamey region (Middle Niger)]. Nouv Rev Fr Hematol. 1967; **7**(2): 309-13.
102. Cabannes R, Sy B, Schmidt-Beurrier A. Etudes des haemolobines en Cote d'Ivoire. Medecine d'Afrique Noire. 1967; **14**: 367-74.
103. Calis JC, Phiri KS, Faragher EB, Brabin BJ, Bates I, Cuevas LE, et al. Severe anemia in Malawian children. The New England Journal of Medicine. 2008; **358**(9): 888-99.
104. Calvo-Villas JM, Zapata Ramos MF, Cuesta Tovar J, de la Iglesia Inigo S, Ropero Gradilla P, Carreter de Granda E, et al. [Prevalence of hemoglobinopathies in pregnant women in the Lanzarote health sanitary area]. An Med Interna. 2006; **23**(5): 206-12.
105. Campos LMFR, Dias FL, Mendes M. Abnormal hemoglobins in umbilical cord blood. Revista Brasileira de Hematologia e Hemoterapia. 2006; **28**(1): 67-9.
106. Cao A, Congiu R, Sollaino MC, Desogus MF, Demartis FR, Loi D, et al. Thalassaemia and glucose-6-phosphate dehydrogenase screening in 13- to 14-year-old students of the Sardinian population: preliminary findings. Community Genet. 2008; **11**(3): 121-8.
107. Cao A, Galanello R, Furbetta M, Muroni PP, Garbato L, Rosatelli C, et al. Thalassaemia types and their incidence in Sardinia. J Med Genet. 1978; **15**(6): 443-7.
108. Carnevale P, Bosseno MF, Lallemant M, Feingold J, Lissouba P, Molinier M, et al. [*Plasmodium falciparum* malaria and sickle cell gene in the popular Republic of Congo. I. Relationship between parasitemia and sicke cell trait in Djoumouna (region of Brazzaville) (author's transl)]. Ann Genet. 1981; **24**(2): 100-4.
109. Cezar PC, Mizusaki K, Pinto W, Jr., Opromolla DW, Beiguelman B. [S hemoglobin and leprosy (author's transl)]. Rev Bras Pesqui Med Biol. 1974; **7**(2): 151-67.
110. Chabeuf M, Zeldine G. Groupes sanguins et drepanocytose dans l'ile de Sainte Marie (Madagascar). Med Trop (Mars). 1962; **22**: 261-7.
111. Char KS, Rao PR. Occurrence of hemoglobin D Los Angeles in Brahmins of Andhra Pradesh, South India. Hemoglobin. 1981; **5**(6): 609-11.
112. Chasen ST, Loeb-Zeitlin S, Landsberger EJ. Hemoglobinopathy screening in pregnancy: comparison of two protocols. Am J Perinatol. 1999; **16**(4): 175-80.

113. Chaudhuri S, Chakravartti MR, Mukhrejee B, Sen SN, Ghosh J, Maitra A. Study of haemotological factors, blood groups, anthropometric measurments and genetics of some of the tribal and caste groups:1 South India - Keraia, Nilgiris, and Andhra Pradesh, 2. North Eastern India (Indo-Bhutan bordar). In: Totopara, editor. Proceedings of the 9th Congress of the International Society of Blood Transfusion; 1964; mexico, 1962: Karger, S.; 1964. p. 196-205.
114. Chopra JG, Byam NT. Anemia survey in Trinidad and Tobago. Am J Public Health Nations Health. 1968; **58**(10): 1922-36.
115. Chopra JG, Mbaye AH. Sickling in Zanzibar Island - Its Incidence, regional variation, and relationship with splenomegaly rates. Trans R Soc Trop Med Hyg. 1969; **63**: 270-4.
116. Choremis C, Fessas P, Kattamis C, Stamatoyannopoulos G, Zannos-Mariolea L, Karaklis A, et al. Three inherited red-cell abnormalities in a district of Greece. Thalassaemia, sickling, and glucose-6-phosphate-dehydrogenase deficiency. Lancet. 1963; **1**: 907-9.
117. Choremis C, Zannos-Mariolea L, Katamis MD. Frequency of glucose-6-phosphate-dehydrogenase deficiency in certain highly malarious areas of Greece. Lancet. 1962; **1**: 17-8.
118. Choubisa SL, Choubisa L, Pande S, Srivastava YK. Incidence of abnormal haemoglobins and G-6-PD deficiency in school children of Udaipur (Rajasthan), India. J Trop Med Hyg. 1987; **90**(4): 215-6.
119. Clark TD, Greenhouse B, Njama-Meya D, Nzarubara B, Maiteki-Sebuguzi C, Staedke SG, et al. Factors determining the heterogeneity of malaria incidence in children in Kampala, Uganda. J Infect Dis. 2008; **198**(3): 393-400.
120. Colauto EM, Barraviera B, Meira DA, Matsubara LS, Pellegrino JJ, Machado PE, et al. [Malaria in the municipality of Humaita, State of Amazonas. XII - Incidence of erythrocyte resistance factors in the general population and in patients: hemoglobin S and Duffy blood system]. Rev Inst Med Trop Sao Paulo. 1981; **23**(5 Suppl 5): 72-8.
121. Colbourne MJ, Edington GM. Sickling and malaria in the Gold Coast. Br Med J. 1956; (4970): 784-6.
122. Colbourne MJ, Edington GM, Hughes MH, Ward-Brew A. A medical survey in a Gold Coast village. Trans R Soc Trop Med Hyg. 1950; **44**(3): 271-90.
123. Colombo B, Felicetti L. Admission of Hb S heterozygotes to a general hospital is relatively reduced in malarial areas. J Med Genet. 1985; **22**(4): 291-2.
124. Compri MB, Polimeno NC, Stella MB, Ramalho AS. [Public health programs for hereditary hemoglobinopathies in high school students in Brazil]. Rev Saude Publica. 1996; **30**(2): 187-95.
125. Cook JA, Kellermeyer WF, Jr., Warren KS, Kellermeyer RW. Sickle cell haemoglobinopathy and Schistosoma mansoni infection. Ann Trop Med Parasitol. 1972; **66**(2): 197-202.
126. Cresta M. [Morphological and Serological Anthropometry of the N'zakaras of the Republic of Central Africa.]. La Ricerca Scientifica 2 ser, pt 2: Rendiconti Sezione B: Biologica. 1964; **14**: 131-42.
127. Cresta M, Avoundogba N. [Risultati delio studio longitdinale dalla nasciia a 5 anni in un gruppo di bambini di Porto Novo (Repubblica Popolare del Benin)]. Rivista di Antropologia. 1980; **61**: 43-132.
128. Cresta M, Spedini G, Dlivieri V. [Antropologia morfologica ed emalogica del basso Dahomey. Nota III-Emazie. emoglobine, caratteri chimici]. Rivista di Antropologia. 1968; **55**: 189-202.
129. Crompton PD, Traore B, Kayentao K, Doumbo S, Ongoiba A, Diakite SA, et al. Sickle cell trait is associated with a delayed onset of malaria: implications for time-to-event analysis in clinical studies of malaria. J Infect Dis. 2008; **198**(9): 1265-75.
130. Currat M, Trabuchet G, Rees D, Perrin P, Harding RM, Clegg JB, et al. Molecular analysis of the beta-globin gene cluster in the Niokholo Mandenka population reveals a recent origin of the beta(S) Senegal mutation. Am J Hum Genet. 2002; **70**(1): 207-23.
131. Das SR, Mukherjee CP, B. SD. Sickle-cell trait in Koraput District and other parts of India. Acta Genet Stat Med. 1967; **17**: 62-73.
132. Daudt LE, Zechmaister D, Portal L, Neto EC, Silla LM, Giugliani R. [Neonatal screening for hemoglobinopathies: a pilot study in Porto Alegre, Rio Grande do Sul, Brazil]. Cad Saude Publica. 2002; **18**(3): 833-41.
133. David S, Trincao C. [Drepanocytemia, Erythrocytic Glucose-6-Phosphate Dehydrogenase Deficiency (G-6-Pd) and Malaria in the Cuango Post (Lunda-Angola)]. An Inst Med Trop (Lisb). 1963; **20**: 5-15.

134. de Araujo MC, Serafim ES, de Castro Jr WA, de Medeiros TM. [Prevalence of abnormal hemoglobins in newborns in Natal, Rio Grande do Norte, Brazil]. Cad Saude Publica. 2004; **20**(1): 123-8.
135. De Bernal M, Collazos A, Bonilla RD, Tascon EP. Determination of the prevalence of hemoglobin S, C, D, and G in neonates from Buenaventura, Colombia. Colomb Medica. 2010; **41**(2): 141-7.
136. de Pinango CLA, Arends T. Abnormal haemoglobins in native blood donors of Bolivar State. Acta Cient Venez. 1965; **16**: 215-8.
137. de Souza RAV, Pratesi R, Fonseca SF. Neonatal screening program for hemoglobinopathies in dourados, MS-an analysis. Programa de triagem neonatal para hemoglobinopatias em dourados, MS-uma análise. 2010; **32**(2): 126-30.
138. Delbrouck J. [The genetics of sicklemia; maintenance of an elevated incidence of sicklemia in the Belgian Congo.]. Ann Soc Belg Med Trop. 1958; **38**(2): 103-34.
139. Deliyannis GA, Tavlarakis N. Sickling phenomenon in Northern Greece. Br Med J. 1955; **2**(4934): 299-301.
140. Deloron P, Ringwald P, Luty AJF, Renaut A, Minh TN, Mbessy JR, et al. Relationships between malaria prevalence and malaria-related morbidity in school children from two villages in central Africa. Am J Trop Med Hyg. 1999; **61**(1): 99-102.
141. Destro-Bisol G, Spedini G. Anthropological survey on red cell glutathione peroxidase (GPX1) polymorphism in central western Africa: a tentative hypothesis on the interaction between GPX1*2 and Hb beta *S allelic products. Am J Phys Anthropol. 1989; **79**(2): 217-24.
142. Devoucoux R, Hurpin C, Baudon D, Molez JF, Roux JF, Guilloud-Bataille M, et al. Population genetics of abnormal haemoglobins in Burkina Faso, west Africa. Ann Hum Biol. 1991; **18**(4): 295-302.
143. Dewi M. 2011.
144. Dey A, Sahu PN. Distribution of HbS gene and variability of the index of the opportunity for natural selection in a caste population of Western Orissa, India. Anthropological Science. 1996; **104**(2): 99-106.
145. Deyde VM, Lo BB, Khalifa IO, Ly B, Ball A, Fattoum S. Epidemiological profile of hemoglobinopathies in the Mauritanian population. Ann Hematol. 2002; **81**(6): 320-1.
146. Didier R, Diacono G. Enquête sur la siclémie en Tunisie. Arch Inst Pasteur Tunis. 1956; **33**: 61-4.
147. Dreyfus F, Benyesch M. Sickle-cell trait in Arabs. Lancet. 1952; **1**: 1213.
148. Dufrenot, Legait JP. [Distribution of hemoglobin S and C genes in Upper Volta, Mali and Niger]. Bull Soc Pathol Exot Filiales. 1970; **63**(5): 606-14.
149. Dulin-Iniguez E. [Newborn screening for sickle cell anemia]. Med Clin (Barc). 2006; **126**(8): 293-4.
150. Edington GM. Some observations on the abnormal haemoglobin disease in Ghana. In: Jonxis JHP, Delafresnaye JF, editors. CIOMS Symposium on Abnormal Haemogllobins: Blackwell Scientific Publications; 1959. p. 290-9.
151. Edington GM, Laing WN. Relationship between haemoglobins C and S and malaria in Ghana. Br Med J. 1957; **2**(5037): 143-5.
152. el-Hazmi MA, al-Swailem A, Warsy AS. Glucose-6-phosphate dehydrogenase deficiency and sickle cell genes in Bisha. J Trop Pediatr. 1995; **41**(4): 225-9.
153. el-Hazmi MA, Warsy AS. Interaction between glucose-6-phosphate dehydrogenase deficiency and sickle cell gene in Saudi Arabia. Trop Geogr Med. 1987; **39**(1): 32-5.
154. Elhazmi MAF, Warsy AS. The Frequency of Hbs and Glucose-6-Phosphate-Dehydrogenase Phenotypes in Relation to Malaria in Western Saudi-Arabia. Saudi Med J. 1993; **14**(2): 121-5.
155. Enevold A, Alifrangis M, Sanchez JJ, Carneiro I, Roper C, Borsting C, et al. Associations between alpha+-thalassemia and *Plasmodium falciparum* malarial infection in northeastern Tanzania. J Infect Dis. 2007; **196**(3): 451-9.
156. Etcheverry R, Guzman C, Hille A, Nagel R, Covarrubias E, Regonesi C, et al. [Investigation of blood groups and other genetic blood characteristics in Chilean natives. I. In Atacamenos and Mapuches]. Rev Med Chil. 1967; **95**(10): 599-604.
157. Evans DI, Blair VM. Neonatal screening for haemoglobinopathy. Results in 7691 Manchester newborns. Arch Dis Child. 1976; **51**(2): 127-30.

158. Ewing N, Powars D, Hilburn J, Schroeder WA. Newborn diagnosis of abnormal hemoglobins from a large municipal hospital in Los Angeles. Am J Public Health. 1981; **71**(6): 629-31.
159. Ezeilo GC. Sickle-cell trait frequency in Zambia. Trop Geogr Med. 1970; **22**(2): 189-97.
160. Farzana F, Zuberi SJ, Hashmi JA. Prevalence of abnormal hemoglobin and thalassemia trait in a group of professional blood donors and hospital staff in Karachi. J Pak Med Assoc. 1975; **25**(9): 237-9.
161. Fattoum S. [Hemoglobinopathies in Tunisia. An updated review of the epidemiologic and molecular data]. Tunis Med. 2006; **84**(11): 687-96.
162. Firschein IL. Population dynamics of the sickle-cell trait in the Black Caribs of British Honduras, Central America. Am J Hum Genet. 1961; **13**: 233-54.
163. Fleming AF, Storey J, Molineaux L, Iroko EA, Attai ED. Abnormal haemoglobins in the Sudan savanna of Nigeria. I. Prevalence of haemoglobins and relationships between sickle cell trait, malaria and survival. Ann Trop Med Parasitol. 1979; **73**(2): 161-72.
164. Foster K, Forbes M, Hayes R, Serjeant GR. Cord blood screening for sickle hemoglobin: evidence against a female preponderance of hemoglobin S. J Pediatr. 1981; **98**(1): 79-81.
165. Fourquet R. [Hemotypological study of the Issa and Gadaboursi Somalis]. Médecine Tropicale : Revue du Corps de Santé Colonial. 1970; **30**(3): 353-62.
166. Fowkes FJ, Imrie H, Migot-Nabias F, Michon P, Justice A, Deloron P, et al. Association of haptoglobin levels with age, parasite density, and haptoglobin genotype in a malaria-endemic area of Gabon. Am J Trop Med Hyg. 2006; **74**(1): 26-30.
167. Foy H, Kondi A, Rebello A, Martins F. The distribution of sickle cell trait and the incidence of sickle cell anaemia in the Negro tribes of Portuguese East Africa. East Afr Med J. 1952; **29**(7): 247-51.
168. Foy H, Kondi A, Timms GL, Brass W, Bushra F. The variability of sickle-cell rates in tribes of Kenya and the Southern Sudan. Br Med J. 1964; **1**: 294-7.
169. Fraser GR, Stamatoyannopoulos G, Kattamis C, Loukopoulos D, Defaranas B, Kitsos C, et al. Thalassemias, Abnormal Hemoglobins and Glucose-6-Phosphate Dehydrogenase Deficiency in the Arta Area of Greece: Diagnostic and Genetic Aspects of Complete Village Studies. Ann N Y Acad Sci. 1964; **119**: 415-35.
170. Fujiki N, Ohkawara Y, Yamamoto M, Fukuda K, Nishimura J, Takenaka S, et al. Hematological survey in the isolated villages in Japan. Isr J Med Sci. 1965; **1**(4): 712-3.
171. Galacteros F. [Neonatal detection of sickle cell disease in metropolitan France. Association francaise pour le depistage et la prevention des handicaps de l'enfant (AFDPHE)]. Arch Pediatr. 1996; **3**(10): 1026-31.
172. Gali AE, Polat G, Dogdu O, Akgol M, Parlar HR, Arpaci A, et al. A premarital screening programme of hemoglobinopathies in Hatay. Annals of Medical Sciences. 1999; **8**(2): 88-92.
173. Gamet A. Premiere etude sur les hemoglobinoses au centre-Cameroun. Bull Soc Pathol Exot Filiales. 1964; **57**: 1125-33.
174. Gelpi AP. Glucose-6-phosphate dehydrogenase deficiency, the sickling trait, and malaria in Saudi Arab children. J Pediatr. 1967; **71**(1): 138-46.
175. Gentilini M, Laroche V, Degremont A. [Aspects of Parasitic and Infectious Tropical Pathology in the Republic of Haiti.]. Bull Soc Pathol Exot Filiales. 1964; **57**: 565-70.
176. Gentilini M, M'Bengue JL, Danis M, Richard-Lenoble D. [Results of the electrophoretic study of hemoglobin in 500 Cameroonds of the Foumbot region (East Cameroon)]. Médecine Tropicale : Revue du Corps de Santé Colonial. 1972; **32**(5): 579-85.
177. George E, Khuziah R. Malays with thalassaemia in West Malaysia. Trop Geogr Med. 1984; **36**(2): 123-5.
178. Ghatge SG, Pradhan PK, Agarwal S. Haemoglobin-S in Kurmi community of Madhya Pradesh--a preliminary report. Indian J Med Res. 1977; **66**(2): 260-4.
179. Ghosh K, Mukherjee MB, Surve RR, Shankarkumar U, Kate SL, Nagtilak SB, et al. Splenomegaly in school children in a remote tribal area of Dhole district, Maharashtra. Indian J Malariol. 2000; **37**(3-4): 68-73.
180. Giordano PC, Plancke A, Van Meir CA, Janssen CA, Kok PJ, Van Rooijen-Nijdam IH, et al. Carrier diagnostics and prevention of hemoglobinopathies in early pregnancy in The Netherlands: a pilot study. Prenat Diagn. 2006; **26**(8): 719-24.

181. Giri AK, Datta S, Gajra B, Roychaudhury A, Datta S, Talukder G, et al. Some genetic markers in tribals of Eastern India. Acta Anthropogenet. 1982; **6**(2): 99-106.
182. Godber M, Kopec AC, Mourant AE, Teesdale P, Tills D, Weiner JS, et al. The blood groups, serum groups, red-cell isoenzymes and haemoglobins of the Sandawe and Nyaturu of Tanzania. Ann Hum Biol. 1976; **3**(5): 463-73.
183. Goedde HW, Benkmann HG, Agarwal DP, Hirth L, Bienzle U, Dietrich M, et al. Genetic studies in Saudi Arabia: red cell enzyme, haemoglobin and serum protein polymorphisms. Am J Phys Anthropol. 1979; **50**(2): 271-7.
184. Gouagna LC, Bancone G, Yao F, Yameogo B, Dabire KR, Costantini C, et al. Genetic variation in human HBB is associated with *Plasmodium falciparum* transmission. Nat Genet. 2010; **42**(4): 328-31.
185. Goud JD, Rao PR. Genetic distances among the five tribal populations of Andhra, Pradesh, South India. Anthropologischer Anzeiger; Bericht uber die biologisch-anthropologische Literatur. 1979; **37**(1): 1-9.
186. Gozal D, Lorey FW, Chandler D, Derry MK, Lisbin A, Keens TG, et al. Incidence of sudden infant death syndrome in infants with sickle cell trait. J Pediatr. 1994; **124**(2): 211-4.
187. Greengross P, Hickman M, Gill M, Dugan B, Davies SC. Outcomes of universal antenatal screening for haemoglobinopathies. J Med Screen. 1999; **6**(1): 3-10.
188. Greenwood BM, Bradley AK, Blakebrough IS, Whittle HC, Marshall TF, Gilles HM. The immune response to a meningococcal polysaccharide vaccine in an African village. Trans R Soc Trop Med Hyg. 1980; **74**(3): 340-6.
189. Griffiths SB. Absence of the sickle cell trait in the Bushmen of South-West Africa. Nature. 1953; **171**(4352): 577-8.
190. Griffiths SB. The distribution of the sickle-cell trait in Africa. S Afr J Med Sci. 1954; **19**: 56-7.
191. Gulbis B, Cotton F, Ferster A, Ketelslegers O, Dresse MF, Ronge-Collard E, et al. Neonatal haemoglobinopathy screening in Belgium. J Clin Pathol. 2009; **62**(1): 49-52.
192. Guler E, Karacan M. Prevalence of beta-thalassemia and sickle cell anemia trait in premarital screening in Konya urban area, Turkey. J Pediatr Hematol Oncol. 2007; **29**(11): 783-5.
193. Haj Khelil A, Laradi S, Miled A, Omar Tadmouri G, Ben Chibani J, Perrin P. Clinical and molecular aspects of haemoglobinopathies in Tunisia. Clin Chim Acta. 2004; **340**(1-2): 127-37.
194. Halberstein RA, Davies JE, Mack AK. Hemoglobin variations on a small Bahamian island. Am J Phys Anthropol. 1981; **55**(2): 217-21.
195. Hamza S, Kamel K, Moafy N, Ibrahim WN, Selim O, Azim A, et al. Hereditary blood factors of North Sinai inhabitants. Human biology; an international record of research. 1976; **48**(1): 193-202.
196. Harley JD, Agar NS, Turner TB. Letter: sickle-cell anaemia and trait in Sydney. The Medical journal of Australia. 1976; **1**(23): 894.
197. Hassan MK, Taha JY, Al-Naama LM, Widad NM, Jasim SN. Frequency of haemoglobinopathies and glucose-6-phosphate dehydrogenase deficiency in Basra. East Mediterr Health J. 2003; **9**(1-2): 45-54.
198. Heijboer H, Van Den Tweel XW, Peters M, Knuist M, Prins J, Heymans BSA. [One year of neonatal screening for sickle cell disease in the emma kinderziekenhuis/academisch medisch centrum, Amsterdam]. Ned Tijdschr Geneeskd. 2001; **145**(37): 1795-9.
199. Henthorn J, Anionwu E, Brozovic M. Screening cord blood for sickle haemoglobinopathies in Brent. British Medical Journal (Clinical research ed). 1984; **289**(6443): 479-80.
200. Herzog P, Bohatova J, Drdova A. Genetic polymorphisms in Kenya. Am J Hum Genet. 1970; **22**(3): 287-91.
201. Hewitt R, Krause A, Goldman A, Campbell G, Jenkins T. Beta-globin haplotype analysis suggests that a major source of Malagasy ancestry is derived from Bantu-speaking Negroids. Am J Hum Genet. 1996; **58**(6): 1303-8.
202. Hiernaux J. Blood polymorphism frequencies in the Sara Majingay of Chad. Ann Hum Biol. 1976; **3**(2): 127-40.
203. Horsfall WR, Lehman H. Absence of the sickle cell trait in seventy-two Australian aboriginals. Nature. 1953; **172**(4379): 638.

204. Horsfall WR, Lehmann H. Absence of abnormal haemoglobins in some Australian aboriginals. Nature. 1956; **177**(4497): 41-2.
205. Ibarra B, Vaca G, Franco-Gamboa E, Garcia-Cruz D, de la Mora E, Castro-Felix LP, et al. Abnormal hemoglobins in Northwestern Mexico. Acta Anthropogenet. 1982; **6**(4): 217-23.
206. Ibrahim WN, Kamel K, Selim O, Azim A, Gaballah MF, Sabry F, et al. Hereditary blood factors and anthropometry of the inhabitants of the Egyptian Siwa Oasis. Human biology; an international record of research. 1974; **46**(1): 57-68.
207. Idowu OA, Mafiana CF, Dapo S. Anaemia in pregnancy: a survey of pregnant women in Abeokuta, Nigeria. Afr Health Sci. 2005; **5**(4): 295-9.
208. Iyer SR, Iyer RR, Oza GD, Rane RM, Khandwala RM, Desai PK, et al. Sickle cell syndromes in and around Bardoli. J Assoc Physicians India. 1994; **42**(11): 885-7.
209. Jacob GF. A study of the survival rate of cases of sickle-cell anaemia. Br Med J. 1957; **1**(5021): 738-9.
210. Jain AP, Khan N, Gupta OP. A survey of glucose-6-phosphate dehydrogenase deficiency and some of its correlates in a Maharashtra village. J Indian Med Assoc. 1981; **76**(1-2): 1-3.
211. Jain RC. Sickle cell and thalassaemic genes in Libya. Trans R Soc Trop Med Hyg. 1985; **79**(1): 132-3.
212. Jain RC, Mehta J, Mehta NL, Joshi KC, Gupta OP, Andrew AM. Sickle cell trait, thalassaemia and glucose-6-phosphate dehydrogenase deficiency in the Bhil tribe of southern Rajasthan. Indian J Med Res. 1981; **73**: 548-53.
213. Jelliffe DB, Bennett FJ, Stroud CE, Novotny ME, Karrach HA, Musoke LK, et al. Field survey of the health of Bachiga children in the Kayonza district of Kigezi. Uganda. Am J Trop Med Hyg. 1961; **10**: 435-45.
214. Jelliffe DB, Bennett FJ, Stroud CE, Welbourn HF, Williams MC, Jelliffe EF. The Health of Acholi Children. (with Special Reference to Congenital Abnormalities Following an Epidemic of "O'nyong-Nyong"). Trop Geogr Med. 1963; **15**: 411-21.
215. Jelliffe DB, Bennett FJ, White RH, Cullinan TR, Jelliffe EF. The children of the Lugbara. A study in the techniques of paediatric field survey in tropical Africa. Trop Geogr Med. 1962; **14**: 33-50.
216. Jelliffe DB, Stuart KL, Wills VG. The sickle cell trait in Jamaica. Blood. 1954; **9**(2): 144-52.
217. Jenkins T. Sickle Cell Anaemia in Wankie, Southern Rhodesia. Cent Afr J Med. 1963; **40**: 307-19.
218. Jenkins T, Blecher SR, Smith AN, Anderson CG. Some hereditary red-cell traits in Kalahari Bushmen and Bantu: hemoglobins, glucose-6-phosphate dehydrogenase deficiency, and blood groups. Am J Hum Genet. 1968; **20**(4): 299-309.
219. Jeremiah ZA. Abnormal haemoglobin variants, ABO and Rh blood groups among student of African descent in Port Harcourt, Nigeria. Afr Health Sci. 2006; **6**(3): 177-81.
220. Joyanes B, Moro M, Ropero P, Briceno O, Dulin E, Villegas A. [Screening of hemoglobinopathies in a cohort of newborns in Madrid]. Med Clin (Barc). 2006; **126**(8): 290-2.
221. Junien C, Chaventre A, Fofana Y, Lapoumeroulie C, Floury B, Duflo B, et al. Glucose-6-phosphate dehydrogenase and hemoglobin variants in Kel Kummer Tuareg and related groups. Indirect evidence for alpha-thalassemia trait. Hum Hered. 1982; **32**(5): 318-28.
222. Kadkhodaei Elyaderani M, Cinkotai KI, Hyde K, Waters HM, Howarth J, Goldstone S, et al. Ethnicity study and non-selective screening for haemoglobinopathies in the antenatal population of central Manchester. Clin Lab Haematol. 1998; **20**(4): 207-11.
223. Kaine WN, Udeozo I. Incidence of sickle cell trait and anemia in Ibo, preschool children Nigerian Journal of Peadiatrics. 1981; **8**: 87-9.
224. Kalmus H. Defective colour vision, P.T.C. tasting and drepanocytosis in samples from fifteen Brazilian populations. Ann Hum Genet. 1957; **21**(4): 313-7.
225. Kamel K, Chandy R, Mousa H, Yunis D. Blood groups and types, hemoglobin variants, and G-6-PD deficiency among Abu Dhabians in the United Arab Emirates. Am J Phys Anthropol. 1980; **52**(4): 481-4.
226. Kamel K, Umar M, Ibrahim W, Mansour A, Gaballah F, Selim O, et al. Anthropological studies among Libyans. Erythrocyte genetic factors, serum haptoglobin phenotypes and anthropometry. Am J Phys Anthropol. 1975; **43**(1): 103-11.

227. Kaptue-Noche L, Mbantenkhu JF, Nsangow JFI. Geographic distribution of human hemoglobins and thalassemia in Cameroon, Middle and East Africa. In: Bowman JE, editor. Distribution and Evolution of the Haemoglobin and Globin Loci. New York: Elsevier; 1983. p. 159-66.
228. Kar BC. Sickle cell disease in India. J Assoc Physicians India. 1991; **39**(12): 954-60.
229. Kate SL, Mukherjee BN, Malhotra KC, Phadke MA, Mutalik GS, Sainani GS. Red cell glucose-6-phosphate dehydrogenase deficiency and haemoglobin variants among ten endogamous groups of Maharshtra and West Bengal. Hum Genet. 1978; **44**(3): 339-43.
230. Kaufman M, Steier W, Applewhaite F, Ruggiero S, Ginsberg V. Sickle-Cell Trait in Blood Donors. Am J Med Sci. 1965; **249**: 56-61.
231. Keskin A, Turk T, Polat A, Koyuncu H, Saracoglu B. Premarital screening of beta-thalassemia trait in the province of Denizli, Turkey. Acta Haematol. 2000; **104**(1): 31-3.
232. Kifude C, Waitumbi J. Sickle cell and alpha thalassemia in children participating in a malaria vaccine clinical trial in Kisumu, Kenya. International Journal of Laboratory Hematology. 2007; **29**: 107-.
233. Kirk RL, Lai LY, Vos GH, Vidyarthi LP. A genetical study of the Oraons of the Chota Nagpur Plateau (Bihar, India). Am J Phys Anthropol. 1962; **20**: 375-85.
234. Kirk RL, Lai LY, Vos GH, Wickremasinghe RL, Perera DJ. The blood and serum groups of selected populations in South India and Ceylon. Am J Phys Anthropol. 1962; **20**: 485-79.
235. Kobbe R, Kreuzberg C, Adjei S, Thompson B, Langefeld I, Thompson PA, et al. A randomized controlled trial of extended intermittent preventive antimalarial treatment in infants. Clinical infectious diseases : an official publication of the Infectious Diseases Society of America. 2007; **45**(1): 16-25.
236. Kofi Ekue JM, Wurapa FK, Rwabwogo-Atenyi J. Haemoglobin genotypes, glucose - 6 - phosphate dehydrogenase deficiency and bronchial asthma. East Afr Med J. 1983; **60**(10): 676-8.
237. Konate L, Zwetyenga J, Rogier C, Bischoff E, Fontenille D, Tall A, et al. The epidemiology of multiple *Plasmodium falciparum* infections - 5. Variation of *Plasmodium falciparum* msp1 block 2 and msp2 allele prevalence and of infection complexity in two neighbouring Senegalese villages with different transmission conditions. Trans R Soc Trop Med Hyg. 1999; **93**: S21-S8.
238. Kreuels B, Kobbe R, Adjei S, Kreuzberg C, von Reden C, Bater K, et al. Spatial variation of malaria incidence in young children from a geographically homogeneous area with high endemicity. J Infect Dis. 2008; **197**(1): 85-93.
239. Kulkarni AG, Jekeme SD. Cord blood screening for haemoglobinopathies in northern Nigeria. Ann Trop Med Parasitol. 1986; **80**(5): 549-51.
240. Kumar N, Ghosh AK. ABO blood groups and sickle-cell trait investigations in Madhya Pradesh, Ujjain and Dewas Districts. Acta Genet Stat Med. 1967; **17**: 55-61.
241. Kumar N, Mukherjee DP. Genetic distances among the Ho tribe and other groups of Central Indians. Am J Phys Anthropol. 1975; **42**: 489-94.
242. Labie D, Richin C, Pagnier J, Gentilini M, Nagel RL. Hemoglobins S and C in Upper Volta. Hum Genet. 1984; **65**(3): 300-2.
243. Lallemant M, Galacteros F, Lallemant-Lecoeur S, Feingold J, Carnevale P, Boukila V, et al. Hemoglobin abnormalities. An evaluation on new-born infants and their mothers in a maternity unit close to Brazzaville (P.R. Congo). Hum Genet. 1986; **74**(1): 54-8.
244. Languillon J, Delas A. Not Available. Médecine Tropicale : Revue du Corps de Santé Colonial. 1957; **17**(6): 830-5.
245. Languillon J, Linhard J, Diebolt G. [Blood groups: abnormal hemoglobins and leprosy]. Bull Soc Med Afr Noire Lang Fr. 1971; **16**(4): 581-4.
246. Lauder JR, Ibrahim SA. Sickling in south-west Kordofan. Sud Med J. 1970; **8**: 207-14.
247. Laurens A, Diakhate L, Blavy G, Diebolt G, Linhard J. [Drepanocytosis and genetics]. Bull Soc Med Afr Noire Lang Fr. 1978; **23**(4): 441-4.
248. Layrisse M, Layrisse Z, Wilbert J. Blood group antigens among the Paraujano. Am J Phys Anthropol. 1960; **18**: 131-9.

249. Le Gallais D, Lonsdorfer J, Fabritius H, Bogui P, Sangare A, Cabannes R. Prevalence of the sickle cell trait among students in a physical education college in Cote-d'Ivoire. Nouv Rev Fr Hematol. 1989; **31**(6): 409-12.
250. Le Hesran JY, Personne I, Personne P, Fievet N, Dubois B, Beyeme M, et al. Longitudinal study of *Plasmodium falciparum* infection and immune responses in infants with or without the sickle cell trait. International Journal of Epidemiology. 1999; **28**(4): 793-8.
251. Lefranc MP, Lefranc G, Farhat M, Jmour R, Boukef K, Beuzard Y, et al. Frequency of human A gamma 75Thr globin chain in a population from Tunisia. Hum Genet. 1981; **59**(1): 89-91.
252. Lehmann H. Distribution of the Sickle cell gene. Eugen Rev. 1954; **46**: 101-21.
253. Lehmann H, Maranjian G, Mourant AE. Distribution of sickle-cell hemoglobin in Saudi Arabia. Nature. 1963; **198**: 492-3.
254. Lehmann H, Raper AB. Maintenance of high sickling rate in an African community. Br Med J. 1956; **2**(4988): 333-6.
255. Lelong M, Kaddari F, Hanichi A, Porte P. Interet du depistage neonatal systmematique des hemoglobinopathies a l'Hopital des Saint-Denis (93). Revue Francaise des Laboratoires. 2001; **2001**(329): 19-21.
256. Liljestrand J, Bergstrom S, Birgegard G. Anaemia of pregnancy in Mozambique. Trans R Soc Trop Med Hyg. 1986; **80**(2): 249-55.
257. Lima AMMD, Azevedo E, Krieger H, Cabello PH, Pollitzer WS. Admixture and relationships of the population of Jacobina, Bahia, Brazil. Am J Hum Biol. 1996; **8**(4): 483-8.
258. Linhard J, Diebolt G, Baylet R, Diop S. [Diagnosis of hemoglobinopathies in 2 Serer populations]. Bull Soc Med Afr Noire Lang Fr. 1973; **18**(4): 587-9.
259. Lisker R, Cordova MS, Graciela Zarate QB. Studies on several genetic hematological traits of the Mexican population. XVI. Hemoglobin, S and glucose-6-phosphate dehydrogenase deficiency in the east coast. Am J Phys Anthropol. 1969; **30**(3): 349-54.
260. Lisker R, Loria A, Cordova MS. Studies on Several Genetic Hematological Traits of the Mexican Population. 8. Hemoglobin S, Glucose-6-Phosphate Dehydrogenase Deficiency, and Other Characteristics in a Malarial Region. Am J Hum Genet. 1965; **17**: 179-87.
261. Lisker R, Zarate G, Loria A. Studies on several genetic hematologic traits of Mexicans IX. Abnormal hemoglobins and erythrocytic glucose-6-phosphate dehydrogenase deficiency in several Indian tribes. Blood. 1966; **27**(6): 824-30.
262. Lorey FW, Arnopp J, Cunningham GC. Distribution of hemoglobinopathy variants by ethnicity in a multiethnic state. Genet Epidemiology. 1996; **13**(5): 501-12.
263. Magana MT, Ongay Z, Tagle J, Bentura G, Cobian JG, Perea FJ, et al. Analysis of betaS and betaA genes in a Mexican population with African roots. Blood cells, molecules & diseases. 2002; **28**(2): 121-6.
264. MalGEN. Data for Burkina Faso, Cameroon, Gambia, Ghana, Malawi and Tamzania. 2009.
265. Marsh K, Otoo L, Hayes RJ, Carson DC, Greenwood BM. Antibodies to blood stage antigens of *Plasmodium falciparum* in rural Gambians and their relation to protection against infection. Trans R Soc Trop Med Hyg. 1989; **83**(3): 293-303.
266. Marti HR, Schoepf K, Gsett OR. Frequency of hemoglobin S and glucose-6-phosphate dehydrogenase deficiency in Southern Tanzania. Br Med J. 1965; **1**: 1476-7.
267. Martinez G, Canizares ME. Genetic hemoglobin abnormalities in 2363 Cuban newborns. Hum Genet. 1982; **62**(3): 250-1.
268. Masmas TN, Garly ML, Lisse IM, Rodriques A, Petersen PT, Birgens H. Inherited hemoglobin disorders in Guinea-Bissau, West Africa: a population study. Hemoglobin. 2006; **30**(3): 355-64.
269. Matson GA, Sutton HE, Swanson J, Robinson A. Distribution of hereditary blood groups among Indians in South America. II. In Peru. Am J Phys Anthropol. 1966; **24**(3): 325-49.
270. Matson GA, Sutton HE, Swanson J, Robinson AR. Distribution of haptoglobin, transferrin, and hemoglobin types among Indians of Middle America: in British Honduras, Costa Rica and Panama. Am J Phys Anthropol. 1965; **23**(2): 123-9.

271. Mauran-Sendrail A, Bouloux C, Gomila J, Langaney A. Comparative study of haemoglobin types of two populations of eastern Senegal--Bedik and Niokholonko. Ann Hum Biol. 1975; **2**(2): 129-36.
272. Medina JW, de Escobar DM, de Vizcaino MA, Sanchez OG, Ballas SK. Characteristics of a donor population in western Venezuela. Transfusion (Paris). 1987; **27**(6): 488-90.
273. MendonçaI AC, GarciaI JL, AlmeidaI CM, MegidI TBC, Fabron Júnior A. Muito além do "Teste do Pezinho". Revista Brasileira de Hematologia e Hemoterapia. 2009; **31**(2): 88-93.
274. Menendez C, Todd J, Alonso PL, Francis N, Lulat S, Ceesay S, et al. The response to iron supplementation of pregnant women with the haemoglobin genotype AA or AS. Trans R Soc Trop Med Hyg. 1995; **89**(3): 289-92.
275. Mercier J, Romana G, Le Correller Y. Prevalence de la drepanocytose en Guadeloupe. Med Trop (Mars). 1982; **42**: 611-5.
276. Merghoub T, Sanchez-Mazas A, Tamouza R, Lu CY, Bouzid K, Ardjoun FZ, et al. Haemoglobin D-Ouled Rabah among the Mozabites: a relevant variant to trace the origin of Berber-speaking populations. Eur J Hum Genet. 1997; **5**(6): 390-6.
277. Millan J, Dodin A. Premiers resultats d'une enquete hematologique sur la population comorienne de Moroni. Ann Univ Madagascar Med. 1965; **7**: 95-7.
278. Miller JM, Davis DC. Experience of a sickle cell screening program in Baltimore. J Natl Med Assoc. 1979; **71**(9): 839-41.
279. Mitchell R, Fupi F. Sickling in Tanzania. East Afr Med J. 1973; **49**: 638-42.
280. Mockenhaupt FP, Rong B, Gunther M, Beck S, Till H, Kohne E, et al. Anaemia in pregnant Ghanaian women: importance of malaria, iron deficiency, and haemoglobinopathies. Trans R Soc Trop Med Hyg. 2000; **94**(5): 477-83.
281. Modica R, Livadiotti M, Macaluso AS. Incidenza della sicklemia pregressa malaria a distribuzione razziale nell gasi costiera di Tauorga. Arch Ital Sci Med Trop Parassitol. 1960; **41**: 595-604.
282. Modica RE, Flores JR. Sickle-cell haemoglobin in Equatorial Guinea. Trans R Soc Trop Med Hyg. 1970; **64**(5): 730-2.
283. Monekosso GL. Clinical Survey of a Yoruba Village. The West African medical journal. 1964; **13**: 47-59.
284. Monekosso GL, Ibiama AA. Splenogamy and sickle-cell trait in a malaria-endemic village. Lancet. 1966; **1**(1347-1348).
285. Monplaisir N, Casius de Linval JC, Sellaye M, Galacteros F, Braconnier F, Beuzard Y, et al. [Detection of haemoglobinopathies at birth, using isoelectric focalization (author's transl)]. La Nouvelle presse medicale. 1981; **10**(38): 3127-30.
286. Monteiro C, Rueff J, Falcao AB, Portugal S, Weatherall DJ, Kulozik AE. The frequency and origin of the sickle cell mutation in the district of Coruche/Portugal. Hum Genet. 1989; **82**(3): 255-8.
287. Moormann AM, Embury PE, Opondo J, Sumba OP, Ouma JH, Kazura JW, et al. Frequencies of sickle cell trait and glucose-6-phosphate dehydrogenase deficiency differ in highland and nearby lowland malaria-endemic areas of Kenya. Trans R Soc Trop Med Hyg. 2003; **97**(5): 513-4.
288. Moreno JL, Baribwira C. The Epidemiology of Neonatal Sickle-Cell-Anemia in Bujumbura (Burundi). Ann Pediatr (Paris). 1994; **41**(4): 215-8.
289. Motulsky AG, Vandepitte J, Fraser GR. Population genetic studies in the Congo. I. Glucose-6-phosphate dehydrogenase deficiency, hemoglobin S, and malaria. Am J Hum Genet. 1966; **18**(6): 514-37.
290. Mukherjee B, Kate SL, Bhanu BV, Kurian JC. Etude de douze marquers genetiques sanguins chez les Santals du Bengale occidental et les Madias de Maharashtra (Inde). L'Anthropologie (Paris). 1981; **85**: 119-24.
291. Mutesa L, Boemer F, Ngendahayo L, Rulisa S, Rusingiza EK, Cwinya-Ay N, et al. Neonatal screening for sickle cell disease in Central Africa: a study of 1825 newborns with a new enzyme-linked immunosorbent assay test. J Med Screen. 2007; **14**(3): 113-6.
292. Nasr A, Elghazali G, Giha H, Troye-Blomberg M, Berzins K. Interethnic differences in carriage of haemoglobin AS and Fcgamma receptor IIa (CD32) genotypes in children living in eastern Sudan. Acta Trop. 2008; **105**(2): 191-5.

293. Nasserullah Z, Al Jame A, Abu Srair H, Al Qatari G, Al Naim S, Al Aqib A, et al. Neonatal screening for sickle cell disease, glucose-6-phosphate dehydrogenase deficiency and a-thalassemia in Qatif and Al Hasa. Ann Saudi Med. 1998; **18**(4): 289-92.
294. Nasserullah Z, Alshammari A, Abbas MA, Abu-Khamseen Y, Qadri M, Jafer SA, et al. Regional experience with newborn screening for sickle cell disease, other hemoglobinopathies and G6PD deficiency. Ann Saudi Med. 2003; **23**(6): 354-7.
295. Nayudu NV. Field survey for sickle cell disease in the tribal population of East Godavari District, Andhra Pradesh. J Assoc Physicians India. 1990; **38**(7): 479-81.
296. Negi RS. The incidence of sickle-cell trait in two Bastar tribes. Man. 1962; **62**: 142.
297. Negi RS. The incidence of sickle-cell trait in Bastar. II. Man. 1963; **63**: 22.
298. Negi RS. The incidence of sickle-cell trait in Bastar. III. Man. 1964; **64**: 214.
299. Nguematcha R, Savina JF, Juhan I, Boche R, Ravisse P. Recherche de latare drepanocytaire dans un groupe Pygmee du Sud Cameroun. Medecine d'Afrique Noire. 1973; **20**: 605-6.
300. Nhonoli AM, Kujwalile JM, Kigoni EP, Masawe AE. Correlation of glucose-6-phosphate dehydrogenase (G-6-PD) deficiency and sickle cell trait (Hb-AS). Trop Geogr Med. 1978; **30**(1): 99-101.
301. Nieuwenhuis F, Wolf B, Bomba A, De Graaf P. Haematological study in Cabo Delgado province, Mozambique; sickle cell trait and G6PD deficiency. Trop Geogr Med. 1986; **38**(2): 183-7.
302. North ML, Piffaut MC, Duwig I, Locoh-Donou AG, Locoh-Donou AM. Detection of haemoglobinopathies at birth in Togo. Nouv Rev Fr Hematol. 1988; **30**(4): 237-41.
303. Ntoumi F, Mercereau-Puijalon O, Ossari S, Luty A, Reltien J, Georges A, et al. *Plasmodium falciparum*: sickle-cell trait is associated with higher prevalence of multiple infections in Gabonese children with asymptomatic infections. Exp Parasitol. 1997; **87**(1): 39-46.
304. Nurse GT, Jenkins T. Serogenetic studies on the Kavango peoples of South West Africa. Ann Hum Biol. 1977; **4**: 465-78.
305. Nurse GT, Jenkins T, David JH, Steinberg AG. The Njinga of Angola: a serogenetic study. Ann Hum Biol. 1979; **6**(4): 337-48.
306. Odunvbun ME, Okolo AA, Rahimy CM. Newborn screening for sickle cell disease in a Nigerian hospital. Public Health. 2008; **122**(10): 1111-6.
307. Ogala WN. Haematological values in healthy Nigerian infants. Ann Trop Paediatr. 1986; **6**(1): 63-6.
308. Ohene-Frempong K, Oduro J, Tetteh H, Nkrumah F. Screening newborns for sickle cell disease in Ghana. Pediatrics. 2008; **121**: S120-S1.
309. Omer A, Ali M, Omer AH, Mustafa MD, Satir AA, Samuel AP. Incidence of G-6-PD deficiency and abnormal haemoglobins in the indigenous and immigrant tribes of the Sudan. Trop Geogr Med. 1972; **24**(4): 401-5.
310. Omotade OO, Kayode CM, Falade SL, Ikpeme S, Adeyemo AA, Akinkugbe FM. Routine screening for sickle cell haemoglobinopathy by electrophoresis in an infant welfare clinic. West Afr J Med. 1998; **17**(2): 91-4.
311. Ondo A. [La drepanocytoso au Gabon. Aspects epidemiologiques et preventifs]. Clinical Respiratory Physiology. 1983; **19**: 383.
312. Oomen JM, Meuwissen JH, Gemert W. Differences in blood status of three ethnic groups inhabiting the same locality in Northern Nigeria. Anaemia, splenomegaly and associated causes. Trop Geogr Med. 1979; **31**(4): 587-606.
313. Orbell SF, Bell RM. Sickle cell trait and intellectual ability. Cent Afr J Med. 1977; **23**(8): 179-82.
314. Ozsoylu S, Sahinoglu M. Haemoglobinopathy survey in an Eti-Turk village. Hum Hered. 1975; **25**(1): 50-9.
315. Pales L, Gallais P, Bert J, Fourquet R. La sicklémie (sickle cell trait) chez certaines populations nigero-tchadiennes de l'Afrique Occidentale française. L'Anthropologie. 1954; **58**: 472-80.
316. Pandey PL, Gupta RB, Tiwary RS. A Study of Sickle-Cell Hemoglobin and Glucose-6-Phosphate-Dehydrogenase Deficiency among the Tribals of Madhya-Pradesh. Man in India. 1992; **72**(4): 485-90.
317. Papiha SS. Haptoglobin and abnormal haemoglobin types in Sinhalese and Punjabis. Hum Hered. 1973; **23**(2): 147-53.

318. Parent J. Sickle cell anemia. Ann Soc Belg Med Trop. 1950; **30**(1): 47-52.
319. Parikh S, Dorsey G, Rosenthal PJ. Host polymorphisms and the incidence of malaria in Ugandan children. Am J Trop Med Hyg. 2004; **71**(6): 750-3.
320. Pegelow CH, Mack AK. Incidence of hemoglobins S and C in infants born in Miami to recent Haitian immigrants. Trop Geogr Med. 1989; **41**(4): 316-9.
321. Penaloza-Espinosa RI, Buentello-Malo L, Hernandez-Maya MA, Nieva-Garcia B, Lisker-Yurkowitzki R, Salamanca-Gomez F. [Hemoglobin S frequency in five Mexican populations and its importance in public health]. Salud Publica Mex. 2008; **50**(4): 325-9.
322. Peres MJ, Carreiro MH, Machado MC, Seixas T, Picanco I, Batalha L, et al. [Neonatal screening of hemoglobinopathies in a population residing in Portugal]. Acta Med Port. 1996; **9**(4-6): 135-9.
323. Perine PL, Michael MT. A preliminary survey for glucose-6-phosphate dehydrogenase deficiency and haemoglobin S in Ethiopia. Ethiop Med J. 1974; **12**(4): 179-84.
324. Perrine RP, John P, Pembrey M, Perrine S. Sickle cell disease in Saudi Arabs in early childhood. Arch Dis Child. 1981; **56**(3): 187-92.
325. Perutelli P, Scuderi F, Ragazzini G, Arigliani R, Bottini W, Mori PG. [Epidemiologic research for thalassemia and hemoglobinopathy traits in the territory of a local health unit in Liguria]. La Pediatria Medica e Chirurgica. 1988; **10**(1): 77-9.
326. Piliszek TS. Hb Bart's and its significance in the South African Negro. Acta Haematol. 1979; **61**(1): 33-8.
327. Pinheiro LS, Gonçalves RP, Sousa Tome CA, Evangelista Alcântara AE, Cintra Marques AR, Da Silva MM. The prevalence of hemoglobin S in newborns from Fortaleza, Brazil: The importance of neonatal research. Revista Brasileira de Ginecologia e Obstetricia. 2006; **28**(2): 122-5.
328. Plato CC, Rucknagel DL, Gershowitz H. Studies on the Distribution of Glucose-6-Phosphate Dehydrogenase Deficiency, Thalassemia, and Other Genetic Traits in the Coastal and Mountain Villages of Cyprus. Am J Hum Genet. 1964; **16**: 267-83.
329. Platt OS, Brambilla DJ, Rosse WF, Milner PF, Castro O, Steinberg MH, et al. Mortality In Sickle Cell Disease -- Life Expectancy and Risk Factors for Early Death. New England Journal of Medicine. 1994; **330**(23): 1639-44.
330. Poindexter HA. Epidemiological survey among the Gola tribe in Liberia. Am J Trop Med Hyg. 1953; **2**(1): 30-8.
331. Pollitzer WS, Chernoff AI, Horton LL, Froehlich M. Hemoglobin patterns in American Indians. Science. 1959; **129**(3343): 216.
332. Pollitzer WS, Namboodiri KK, Elston RC, Brown WH, Leyshon WC. The Seminole Indians of Oklahoma: morphology and serology. Am J Phys Anthropol. 1970; **33**(1): 15-29.
333. Pollitzer WS, Rucknagel D, Tashian R, Shreffler DC, Leyshon WC, Namboodiri K, et al. The Seminole Indians of Florida: morphology and serology. Am J Phys Anthropol. 1970; **32**(1): 65-81.
334. Polunin I, Sneath PHA. Studies of blood groups in South-East Asia. Journal of the Royal Anthropological Institute of Britain and Ireland. 1953; **83**: 215-51.
335. Raccurt CP, Seytor S, Saint-Martin C, Kernizan MS, Duverseau YT, Helmcke MS, et al. [Prevalence of abnormal hemoglobins in Haiti. Survey among a rural population of Plaine du Cul-de-Sac]. Ann Soc Belg Med Trop. 1983; **63**(3): 241-6.
336. Rachmilewitz EA, Tamari H, Liff F, Ueda Y, Nagel RL. The interaction of hemoglobin O Arab with Hb S and beta+ thalassemia among Israeli Arabs. Hum Genet. 1985; **70**(2): 119-25.
337. Rahbar S, Blume K. Hemoglobinopathies in the Los Angeles area. Hemoglobin. 1983; **7**(3): 291-5.
338. Rahgozar S, Poorfathollah AA, Moafi AR, Old JM. Beta s gene in Central Iran is in linkage disequilibrium with the Indian-Arab haplotype. Am J Hematol. 2000; **65**(3): 192-5.
339. Ramesh M, Balakrishna A, Veerraju P. Sickle cell haemoglobin and glucose-6-phosphate dehydrogenase deficiency among Dhobis of Visakhapatnam, Andhra Pradesh, India. Anthropologischer Anzeiger; Bericht uber die biologisch-anthropologische Literatur. 1993; **51**(2): 173-7.

340. Ramesh M, Veerraju P. Sickle cell haemoglobin and glucose-6-phosphate dehydrogenase deficiency among Rellis of Visakhapatnam, Andhra Pradesh, South India. Anthropologischer Anzeiger; Bericht uber die biologisch-anthropologische Literatur. 1997; **55**(3-4): 289-93.
341. Rao PM, Blake NM, Veerraju P. Genetic studies on the Savara and Jatapu Tribes of Andhra Pradesh, India. Hum Hered. 1978; **28**(2): 122-31.
342. Rao PR, Goud JD. Sickle-cell haemoglobin and glucose-6-phosphate dehydrogenase deficiency in tribal populations of Andhra Pradesh. Indian J Med Res. 1979; **70**: 807-13.
343. Rao VR, Sathe MS, Gorakshakar AC, Vasantha K. Genetic heterogeneity and population structure of Gond-related tribes in the Vidarbha region of Maharashtra. Hum Biol. 1992; **64**(6): 903-17.
344. Ravisse P. Recherches sur la siclémie chez les Pygmées de l'Afrique Equitoriale Française. L'Anthropologie. 1952; **56**: 491-3.
345. Reddy PH, Modell B. Reproductive behaviour and natural selection for the sickle gene in the Baiga tribe of central India: the role of social parenting. Ann Hum Genet. 1996; **60**(Pt 3): 231-6.
346. Reddy PH, Petrou M, Reddy PA, Tiwary RS, Modell B. Hereditary anaemias and iron deficiency in a tribal population (the Baiga) of central India. Eur J Haematol. 1995; **55**(2): 103-9.
347. Reyes Cruz G, Hernandez Acasiete M, Ruiz Reyes G. [Identification of a focus of beta-thalassemia in Tamiahua, Veracruz]. Rev Invest Clin. 1990; **42**(3): 189-92.
348. Reys L, Manso C, Stamatoyannopoulos G, Giblett E. Genetic studies on southeastern Bantu of Mozambique. II. Serum groups, hemoglobins and red cell isozyme phenotypes. Humangenetik. 1972; **16**(3): 227-33.
349. Rizzotti G. Falcemia c malattia falcemia. Prime osservazioni circa la loro diffusione nella regione di Addis Abeba. Arch Ital Sci Med Trop Parassitol. 1955; **36**: 555-63.
350. Roberts DF, Boyo AE. Abnormal haemoglobins in childhood among the Yorba. Hum Biol. 1962; **34**: 20-37.
351. Roberts DF, Lehmann H. A search for abnormal haemoglobins in some southern Sudanese peoples. Br Med J. 1955; **1**(4912): 519-21.
352. Roberts DF, Papiha SS. Les polymorphismes genetiques des Sukuma (Tanzania). L'Anthropologie. 1978; **82**: 565-74.
353. Ropero P, Molina L, Gonzalez FA, Villegas A. [Incidence of sickle cell disease in Equatorial Guinea.]. Medicina clinica (Barcelona). 2009.
354. Rowley PT, Loader S, Sutera CJ, Walden M, Kozyra A. Prenatal screening for hemoglobinopathies. I. A prospective regional trial. Am J Hum Genet. 1991; **48**(3): 439-46.
355. Ruffie J, Lefevre-Witier P, Benabadji M, vergnes H, Marty Y, Blanc H, et al. Geneticx markers of blood in some populations of North Sahara (1967). Yearbook of Physical Anthropology 1976. 1977; **20**: 181-202.
356. Sadek SH. Sickle cell trait in North Nigeria. J Trop Med Hyg. 1974; **77**(3): 61-4.
357. Saha N, Kirk RL, Shanbhag S, Joshi SH, Bhatia HM. Genetic studies among the Kadar of Kerala. Hum Hered. 1974; **24**(2): 198-218.
358. Saha N, Kirk RL, Shanbhag S, Joshi SR, Bhatia HM. Population genetic studies in kerala and the nilgiris (South West India). Hum Hered. 1976; **26**(3): 175-97.
359. Saha N, Patgunarajah N. Phenotypic and quantitative relationship of red cell acid phosphatase with haemoglobin, haptoglobin, and G6PD phenotypes. J Med Genet. 1981; **18**(4): 271-5.
360. Saha N, Tay J, Piplai C, Gupta R, Roy SK. Genetic studies among the sedentes and migrant Oraons of eastern India. Am J Phys Anthropol. 1988; **76**(3): 321-30.
361. Salazar Leite A, Jorge Janz G, Gandara AF. Relatorio da Missao do Instituto de Medicina Tropical a Angola (1954) Em colaboracao com a Missao de Prospeccao de endemias de Angola. An Inst Med Trop (Lisb). 1954; **12**: 129-254.
362. Salzano FM. Incidence, effects, and management of sickle cell disease in Brazil. Am J Pediatr Hematol Oncol. 1985; **7**(3): 240-4.
363. Salzano FM, Tondo CV. Hemoglobin types of Brazilian Indians. Am J Phys Anthropol. 1968; **28**(3): 355-9.

364. Samuel AP, Saha N, Omer A, Hoffbrand AV. Quantitative expression of G6PD activity of different phenotypes of G6PD and haemoglobin in a Sudanese population. Hum Hered. 1981; **31**(2): 110-5.
365. Sansarricq H, Marill G, Portier A, Cabannes R. Les hemoglobinopathies en Haute Volta. Sangre (Barc). 1959; **30**: 503-11.
366. Santos David JH. A Drepanocitamie e a Anthropologica. Lisbon; 1960.
367. Santos-David J, Moura Pires F, Trincao C. Abnormal haemoglobins in the District of Lunda and the neighbouring District of Songo, Angola. Man. 1962; **62**: 48.
368. Saraswathy KN, Sachdeva MP. G6PD deficiency, sickle cell trait, haptoglobin and transferrin polymorphisms among Koyadoras and Nayakpods of Andhra Pradesh. Anthropologist. 2008; **10**(2): 163-5.
369. Sarr JB, Pelleau S, Toly C, Guitard J, Konate L, Deloron P, et al. Impact of red blood cell polymorphisms on the antibody response to *Plasmodium falciparum* in Senegal. Microbes Infect. 2006; **8**(5): 1260-8.
370. Saugrain J. [New research on drepanocytosis in Madagascar.]. Bull Soc Pathol Exot Filiales. 1957; **50**(3): 480-6.
371. Schedlbauer LM, Pass KA. Cellulose acetate/citrate agar electrophoresis of filter paper hemolysates from heel stick. Pediatrics. 1989; **83**(5 SUPPL.): 839-42.
372. Schiliro G, Di Gregorio F, Romeo MA, Testa R, Russo A. Incidence of hemoglobin S carriers in Sicily. Hemoglobin. 1986; **10**(1): 95-9.
373. Schuler L, Salzano FM, Franco MHLP, de Melo e Freitas MJ, Mestriner MA, Simoes AL. Demographic and blood genetic characteristics in an Amazonian population. J Hum Evol. 1982; **11**: 549-58.
374. Segbena AY, Prehu C, Wajcman H, Bardakdjian-Michau J, Messie K, Feteke L, et al. Hemoglobins in Togolese newborns: Hb S, Hb C, Hb Bart's, and alpha-globin gene status. Am J Hematol. 1998; **59**(3): 208-13.
375. Selim O, Kamel K, Azim AA, Gaballah F, Sabry FH, Ibrahim W, et al. Genetic markers and anthropometry in the populations of the Egyptian oases of El-Kharga and El-Dakhla. Hum Hered. 1974; **24**(3): 259-72.
376. Sen R, Chakrabarti S, Sengupta B, De M, Haldar A, Poddar S, et al. Alpha-thalassemia among tribal populations of Eastern India. Hemoglobin. 2005; **29**(4): 277-80.
377. Sepha GC, Tiwari SK, Gupta GB, Mehta RS, Agarwal SD, Prasan NG. Problems of haemoglobin anomalies in Raipur (M.P.). J Assoc Physicians India. 1979; **27**(4): 291-7.
378. Shukla RN, Solanki BR. Sickle-cell trait in Central India. Lancet. 1958; **1**(7015): 297-8.
379. Silva Wdos S, Lastra A, de Oliveira SF, Klautau-Guimaraes N, Grisolia CK. [Evaluation of coverage by a neonatal screening program for hemoglobinopathies in the Reconcavo region of Bahia, Brazil]. Cad Saude Publica. 2006; **22**(12): 2561-6.
380. Silva Wdos S, Lastra A, de Oliveira SF, Klautau-Guimaraes N, Grisolia CK. [Evaluation of coverage by a neonatal screening program for hemoglobinopathies in the Reconcavo region of Bahia, Brazil]. Cadernos de saude publica / Ministerio da Saude, Fundacao Oswaldo Cruz, Escola Nacional de Saude Publica. 2006; **22**(12): 2561-6.
381. Simbeye AG. An analysis of some hemoglobin and haptoglobin phenotypes in Blantyre, Malawi. Am J Hum Genet. 1971; **23**(5): 510-2.
382. Simpore J, Ilboudo D, Damintoti K, Sawadogo L, Maria E, Binet S, et al. Glucose-6-phosphate dehydrogenase deficiency and sickle cell disease in Burkina Faso. Pakistan Journal of Biological Sciences. 2007; **10**(3): 409-14.
383. Singer R, Budtz-Olsen OE, Brain P, Saugrain J. Physical features, sickling and serology of the Malagasy of Madagascar. Am J Phys Anthropol. 1957; **15**(1): 91-124.
384. Sokhna CS, Rogier C, Dieye A, Trape JF. Host factors affecting the delay of reappearance of *Plasmodium falciparum* after radical treatment among a semi-immune population exposed to intense perennial transmission. Am J Trop Med Hyg. 2000; **62**(2): 266-70.
385. Sommer CK, Goldbeck AS, Wagner SC, Castro SM. [Neonatal screening for hemoglobinopathies: a one-year experience in the public health system in Rio Grande do Sul State, Brazil]. Cad Saude Publica. 2006; **22**(8): 1709-14.

386. Spedini G, Capucci E, Rickards O, Fuciarelli M, Giaccaia L, Aebischer ML, et al. Some genetic erythrocyte polymorphisms in the Mbugu and other populations of the Central African Republic with an analysis of genetic distances. Anthropologischer Anzeiger; Bericht uber die biologisch-anthropologische Literatur. 1981; **39**(1): 10-9.
387. Spedini G, Fuciarelli M, Rickards O. Blood polymorphism frequencies in the Tofinu, the "Water Men" of Southern Benin. Anthropologischer Anzeiger; Bericht uber die biologisch-anthropologische Literatur. 1980; **38**(2): 121-30.
388. Spitz AJ. Health and morbidity survey, Seychelles, 1956-57. Bull World Health Organ. 1960; **22**: 439-67.
389. Spivak VA, Sou A, Lutsenko IN. [Distribution of abnormal hemoglobins S and C in the Republic of Guinea]. Genetika. 1992; **28**(8): 159-65.
390. Stirnadel HA, Stockle M, Felger I, Smith T, Tanner M, Beck HP. Malaria infection and morbidity in infants in relation to genetic polymorphisms in Tanzania. Trop Med Int Health. 1999; **4**(3): 187-93.
391. Storey J, Fleming AF, Cornille-Brogger R, Molineaux L, Matsushima T, Kagan I. Abnormal haemoglobins in the Sudan savanna of Nigeria. IV. Malaria, immunoglobulins and antimalarial antibodies in haemoglobin AC individuals. Ann Trop Med Parasitol. 1979; **73**(4): 311-5.
392. Suarez RM, Buso R, Meyer LM, Olavarrieta ST. Distribution of abnormal hemoglobins in Puerto Rico and survival studies of red blood cells using Cr51. Blood. 1959; **14**(3): 255-61.
393. Sukumaran PK, Sanghvi LD, Vyas GN. Sickle cell trait in some tribes of western India. Curr Sci. 1956; **25**: 290-1.
394. Sunna EI, Gharaibeh NS, Knapp DD, Bashir NA. Prevalence of hemoglobin S and beta-thalassemia in northern Jordan. J Obstet Gynaecol Res. 1996; **22**(1): 17-20.
395. Suzuki A, Hamano S, Shirakawa T, Watanabe K, Endo T, Sharma S, et al. The distribution of hereditary erythrocytic disorders associated with malaria, in a lowland area of Nepal: a micro-epidemiological study. Ann Trop Med Parasitol. 2007; **101**(2): 113-22.
396. Swindler DR. The absence of the sickle cell gene in several Melanesian societies and its anthropologic significance. Hum Biol. 1955; **27**(4): 284-93.
397. Theodoridou S, Alemayehou M, Prappas N, Karakasidou O, Aletra V, Plata E, et al. Carrier screening and prenatal diagnosis of hemoglobinopathies. A study of indigenous and immigrant couples in northern Greece, over the last 5 years. Hemoglobin. 2008; **32**(5): 434-9.
398. Torres-Guerra E, Torres-Guerra T, Valbuena G, Arteaga Vizcaino M, Soto L. [Frequency of sickle-cell anemia in the population of "Cuatro Bocas," Parroquia Ricaurte, Mara municipality, Zulia state, Venezuela]. Invest Clin. 1993; **34**(2): 99-105.
399. Tosun F, Bilgin A, Kizilok A, Arpaci A, Yu?reg?ir GT. Five-year evaluation of premarital screening program for hemoglobinopathies in the province of Mersin, Turkey. Turkish Journal of Haematology. 2006; **23**(2): 84-9.
400. Trabuchet G, Dahmane M, Benabadji M. [Abnormal hemoglobins in Algeria]. Sem Hop. 1977; **53**(16): 879-81.
401. Trincao C. Hemoglobinas anormals nos territoris Portuguessas. Boletim Clínico dos Hospitais Civis de Lisboa. 1957; **21**: 813-27.
402. Trincao C, De Melo JM. Hemoglobin S rates in as heterozygotes. Isr J Med Sci. 1965; **1**(4): 772-6.
403. Trincao C, Pinto AR, de AC, Gouveia E. [Drepanocythemia in the papel tribe of Portuguese Guinea]. An Inst Med Trop (Lisb). 1950; **7**: 125-9.
404. Trowell HC, Raper AB, Welbourn HF. The natural history of homozygous sickle-cell anaemia in Central Africa. The Quarterly journal of medicine. 1957; **26**(104): 401-22.
405. Tshilolo L, Gulbis B, Barlow P, Damis E, Denis-Song R, Ferster A, et al. [Neonatal screening for hemoglobinopathies in the Brussels region]. Rev Med Brux. 1997; **18**(2): 70-3.
406. Tshilolo L, Kafando E, Sawadogo M, Cotton F, Vertongen F, Ferster A, et al. Neonatal screening and clinical care programmes for sickle cell disorders in sub-Saharan Africa: lessons from pilot studies. Public Health. 2008; **122**(9): 933-41.

407. Vafa M, Troye-Blomberg M, Anchang J, Garcia A, Migot-Nabias F. Multiplicity of *Plasmodium falciparum* infection in asymptomatic children in Senegal: relation to transmission, age and erythrocyte variants. Malaria J. 2008; **7**(1): 17.
408. van den Berghe LJ, Janssen P. Maladie a sickle cells en Afrique noire. Ann Soc Belg Med Trop. 1950; **30**: 1553-66.
409. Van der Dijs FPL, Van den Berg GA, Schermer JG, Muskiet FD, Landman H, Muskiet FAJ. Screening cord blood for hemoglobinopathies and thalassemia by HPLC. Clin Chem. 1992; **38**(9): 1864-9.
410. van Heyningen AM, Levenston MJ, Tamminga N, Scoop-Martijn EG, Wever RM, Verhagen AA, et al. Estimated incidence of sickle-cell disease in Aruba and St. Maarten suggests cost-effectiveness of a universal screening programme for St. Maarten. The West Indian medical journal. 2009; **58**(4): 301-4.
411. Vandepitte J, Dherte P. [Inquiry on abnormal hemoglobins in Stanleyville.]. Ann Soc Belg Med Trop. 1959; **39**: 711-5.
412. Vandepitte J, Motulsky AG. Abnormal haemoglobins in the Kasai province of the Belgian Congo. Nature. 1956; **177**(4512): 757.
413. Vella F. Abnormal haemoglobins, thalassaemia, and erythrocyte glucose-6-phosphate dehydrogenase deficiency in Singapore and Malaya. Oceania. 1962; **32**: 219-25.
414. Vella F. Haemoglobin S and sickling in Khartoum Province. Trans R Soc Trop Med Hyg. 1966; **60**: 48-52.
415. Vella F. Hemoglobin variants in Saskatchewan. Clin Biochem. 1967; **1**: 118-34.
416. Vella F. The human hemoglobin variants in Canada. Clin Biochem. 1975; **8**(5): 341-52.
417. Vyas GN, Bhatia HM, Sukumaran PK, Balkrishanan V, Sanghvi LD. Study of blood groups, abnormal hemoglobins and other genetical characters in some tribes of Gujarat. Am J Phys Anthropol. 1962; **20**: 255-65.
418. Walter H, Neumann S, Nemeskeri J. [Population genetic studies on the distribution of hemoglobin S and glucose-6-phosphate-dehydrogenase deficiency in Bodrogkoz (Northeast Hungary)]. Humangenetik. 1965; **1**(7): 561-67.
419. Walters JH, Lehmann H. Distribution of the S and C haemoglobin variants in two Nigerian communities. Trans R Soc Trop Med Hyg. 1956; **50**(3): 204-8.
420. Wambua S, Mwacharo J, Uyoga S, Macharia A, Williams TN. Co-inheritance of alpha+-thalassaemia and sickle trait results in specific effects on haematological parameters. Br J Haematol. 2006; **133**(2): 206-9.
421. Weatherall DJ. Data for Sri Lanka. 2010.
422. Weatherall DJ, Gilles HM, Clegg JB, Blankson JA, Mustafa D, Boi-Doku FS, et al. Preliminary surveys for the prevalence of the thalassemia genes in some African populations. Ann Trop Med Parasitol. 1971; **65**(2): 253-65.
423. Welch SG, Aidley DJ, Barry JV, Carter ND, Culliford BJ, Huntsman RG, et al. Blood group, serum protein and red cell enzyme polymorphisms in a population from the Seychelle Islands. Hum Hered. 1975; **25**(5): 346-53.
424. Wen-pin C, Li-hsia T. Two D-group abnormal hemoglobin found in Mongolian herdsmen. Acta Genet Sin. 1978; **5**(4): 263-9.
425. White JM, Byrne M, Richards R, Buchanan T, Katsoulis E, Weerasingh K. Red cell genetic abnormalities in Peninsular Arabs: sickle haemoglobin, G6PD deficiency, and alpha and beta thalassaemia. J Med Genet. 1986; **23**(3): 245-51.
426. Willcox MC. Thalassaemia in northern Liberia. A survey in the Mount Nimba area. J Med Genet. 1975; **12**(1): 55-63.
427. Willcox MC, Beckman L. Haemoglobin variants, beta-thalassaemia and G-6-PD types in Liberia. Hum Hered. 1981; **31**(6): 339-47.
428. Williams T. Data for Kenya. 2009.
429. Woodd RB, Smith HM, Clarke VA. The blood groups of the Timuri and related tribes in Afghanistan. Am J Phys Anthropol. 1967; **27**: 195-204.
430. Yang YM, Andrews S, Peterson R, Shah A, Cepeda M. Prenatal sickle cell screening education effect on the follow-up rates of infants with sickle cell trait. Patient Educ Couns. 2000; **39**(2-3): 185-9.

431. Yawson G, Marbell EC. Abnormal haemoglobins in 4000 blood donors at Korle Bu. Ghana Med J. 1973; **12**: 22-6.
432. Yorke D, Mitchell J, Clow C, Nuguid E, Cadogan R, Sinclair D, et al. Newborn screening for sickle cell and other hemoglobinopathies: a Canadian pilot study. Clin Invest Med. 1992; **15**(4): 376-83.
433. Yuregir GT, Arpaci A, Aksoy K, Tuli A, Dikmen N, Ozgunen FT, et al. Population at risk for hemoglobinopathies in Cukurova, Turkiye: Need for prenatal diagnosis. Annals of Medical Sciences. 1995; **4**(2): 61-9.
434. Yuregir GT, Kilinc M, Ekerbic?er H, Bilalog?lu N, Tekin N. Screening of hemoglobinopathies in Kahramanmaras?, Turkey. Turkish Journal of Haematology. 2001; **18**(2): 79-83.
435. Zago MA, Costa FF, Tone LG, Bottura C. Hereditary hemoglobin disorders in a Brazilian population. Hum Hered. 1983; **33**(2): 125-9.