** DRAFT** Not for Citation or Circulation **

The Global Distribution of Infant Mortality: A subnational spatial view

Adam Storeygard*
Deborah Balk**
Marc Levy**
Glenn Deane***

21 September 2006

For consideration for the Population Association of America Annual Meeting 2007

* Department of Economics, Brown University, Providence, RI 02912. Correspondence to: adam_storeygard@brown.edu
** CIESIN (Center for International Earth Science Information Network), Columbia University, PO Box 1000, Palisades, NY 10964
*** Department of Sociology, University at Albany, State University of New York 12222

Abstract

Using data from household surveys, vital statistics and other administrative sources, we compile a spatially explicit dataset detailing infant mortality rates in over 10,000 national and subnational units worldwide, benchmarked to the year 2000. Although their resolution is highly variable, subnational data are available for over 90% of non-OECD population. Concentration of global infant deaths is higher than implied by national data alone. Assigning both national and subnational data to map grid cells so that they may be easily integrated with other geographic data, we generate infant mortality rates for environmental regions, including biomes and coastal zones, by continent. Rates for these regions also show striking refinements from higher resolution data. Possibilities and limitations for related work are discussed.

Acknowledgments

We thank Sonya Ahamed, Melanie Brickman, Janina Franco, Jukay Hsu, Maura Kak, and Laura Pisoni for research assistance, and Gregory Booma, Julia Koschinsky, Maria Muñiz, Lynn Seirup, and Gregory Yetman for helpful comments and suggestions. We acknowledge funding to CIESIN/Columbia University from the United Nations Millennium Project and the Poverty Mapping Project of the PHRD Fund of the Japanese Government to the World Bank.

Much inquiry in demography as well as development studies has closely examined trends and determinants in infant and child mortality. It has been well established that mortality is determined by a suite of biological, socioeconomic (Trussell and Hammerslough, 1983; McMurray, 1997; Agha, 2000), demographic (Boerma and Bicego, 1992; Rao et al., 1997;; Gupta and Baghel, 1999; Whitworth and Stephenson, 2002), and environmental factors (Balk et al, 2004; Root, 1997; Ronsmans, 1995; Curtis and Hossain, 1998; Patz et al., 2000; Pitt and Sigle, 1997; Root, 1999; Woods, 2003). The suite of observable effects may depend on the unit of analysis (individuals, neighborhoods, countries, etc.) but there is theoretical agreement that in most places, all of these classes of factors have some significant role to play. Demographic surveys have made it possible to examine aspects of each of these factors to one degree or another. However, environmental factors are still usually measured using a very limited set of variables such as households' access to potable water and sanitation. One reason for this is that the means for identifying broader ecological factors (such as aridity) would require measurement techniques beyond the capacity of most survey research teams. However, relevant data about environmental factors are often collected independently in a georeferenced framework which allows them to be linked to demographic data if the latter are spatially expressed.

National infant mortality rates (IMR) are reported for nearly every country in the world (UNICEF 2004; Figure 1).[1] For a sizable minority of countries, representing the vast majority of world population, subnational estimates are also available. Despite the fact that demographic surveys have collected data that would foster subnational disaggregation for over twenty years, little work has been done to compare measures subnationally across countries in a spatial framework (Balk et al. 2004), and none that we are aware of on a global scale. As spatially-explicit data and geographic information systems (GIS) software to process them become more widely available and sophisticated, it has become easier to place these estimates in a spatial context.

In addition to providing an opportunity to consider mortality in connection with spatially explicit environmental characteristics (e.g., rainfall, temperature, crop production, farming systems, elevation, slope etc.), a spatial context allows us to formally consider the ways in mortality is concentrated on a global scale. Using national level data, for example, Black and colleagues (2003), find that half deaths of all deaths to children up to age 5 are concentrated in just six countries of the world (i.e., India, Nigeria, China, Pakistan, Democratic Republic of Congo, and Ethiopia) and very high rates of mortality are concentrated not only in Africa, but primarily in sub-Saharan Africa. Spatially-explicit mortality data allow us to further quantify that spatial concentration, as well as determine what ecological features may be associated with different mortality regimes.

Compared to many other development indicators, the definitions and measurements associated with infant mortality (i.e., deaths and live births) are well standardized across countries.[2] Furthermore, methods to adjust national rates to account for reporting and

[1] UNICEF (2004) reports values for all countries and statistical country-equivalents with populations over one million except Taiwan and Puerto Rico. Herein, "countries" refers to countries with sovereign authority as well as country-equivalents for which the United Nations Statistics Division reports data.

[2] Some problems remain. For example, several central Asian countries continued to generate rates based on the Soviet definition of a live birth (i.e. including still births) after 1991 (Wuhib et al. 2003; Olenick, 1998).

definitional differences across countries are now well established (Hill and Yazbeck 1994, Hill et al. 1997).

This paper describes the methods used to construct a global, spatially explicit, subnational dataset of infant mortality. The resulting dataset contains 10,370 spatially-referenced estimates of infant mortality in c. 2000. Additionally, a descriptive analysis of that dataset, including an exploration of the spatial patterns of infant mortality is presented here. Examples of potential applications with other development indicators are briefly given. Finally, the paper concludes with a discussion of the potential for constructing successive cross-sections in this spatially explicit manner.

Data & Methods

Two disparate types of data were combined: mortality estimates for named geographic areas and geographic data associating a spatial extent to these areas. We refer to the mortality estimates alone as tabular data when they are not linked to geographic features.

First, subnational infant mortality estimates were collected for 77 countries, comprising 80% of the world population (90% of non-OECD population), and national data for another 119, as shown in Table 1. Many of the national data are for developed countries where search effort was lower because absolute regional differences are expected to be lower.[3]

Source information about the 77 subnational countries is shown in Table 2. Data are reported for a year within the period 1996-2003 for 69. For the remaining 8, data from as far back as 1990 were used. The most common subnational data sources were the Demographic and Health Surveys (DHS; 44 countries) and Multiple Indicator Cluster Surveys (MICS; 5 countries). Mortality is estimated in these surveys using a synthetic-cohort direct estimation procedure (Rutstein 2003) and the Brass Logit indirect method of estimation (United Nations, 1983), respectively.[4]

For the remainder of subnational countries, data were reported in national Human Development Reports or by national statistical offices or ministries of health. Of these, ten report based on vital registration data, eight use indirect methods of various kinds, one uses direct estimation, and nine do not report the method used.

Table 2 also indicates the number of reporting units for each country. Forty-five countries are specified at the first administrative level (i.e., equivalent to province), and an additional 27 are specified somewhat more coarsely, though still with substantial subnational resolution. The remaining five countries have data at higher resolution than the first administrative level. Three developing countries—Brazil, China and Mexico—had estimates of infant mortality available at a very high-resolution (i.e. at the county level or better), based on various indirect

[3] This is not to dismiss the potential interest in subnational variation that might occur in more developed countries. In the United States, the 1998 rate for the District of Columbia is more than twice that for eight states.

[4] There are rare exceptions. In Mauritania, the DHS reports results based on the Brass method (North model) because of time data quality concerns (ONS and ORC Macro 2001). The source adjustment described below is intended to While some such as Adetunji (1996) caution against combining estimates based on both methods,

methods. The China estimates are based on an empirical Bayesian estimation procedure and results appear comparable to that of the Brass Logit method (Cai, 2005). Eighty-nine percent of the units in the global collection represent a unit from one of these three countries. Outside these three countries, countries with any subnational data have data for a mean of 13.5 (median 8) subnational units per country.

For all countries with no available subnational data, national values were taken from UNICEF (2004). Most of these are either small or developed, with only nine non-European, non-OECD countries with an estimated 2000 population of over ten million (19 over 5 million).

Second, because the year and source of the subnational estimates vary by country, they were adjusted to be consistent with the UNICEF (2004) national estimates for the year 2000. UNICEF has constructed a time series that adjusts nationally reported rates using multiple surveys to account for reporting, computational and definitional differences (Adetunji 1996, Hill and Yazbeck 1994, Hill et al. 1997). This agreement on definitions and consistent means of temporal adjustment facilitates comparisons at a continental or global scale where data have been collected over a range of years, and several organizations within the UN system have come to use the UNICEF estimates (Haishan Fu, UNDP, personal communication).

The IMR value $r_{c,y,s,x}$ for country *c*, year *y* from source *s*, at scale *x* (0 = national; 1 = subnational) were scaled to y=2000 national rates from s = 0 (UNICEF). The subnational values are denoted as vectors because the same adjustment is applied to all subnational values in the same country.

Given: $\overrightarrow{r_{c,y,s,1}}$, $r_{c,2000,0,0}$ and $r_{c,y,s,0}$, we seek $\overrightarrow{r_{c,2000,0,1}}$:

Source adjustment: $$\overrightarrow{r_{c,y,0,1}} = \frac{\overrightarrow{r_{c,y,s,1}} r_{c,y,0,0}}{r_{c,y,s,0}}$$

Temporal adjustment: $$\overrightarrow{r_{c,2000,0,1}} = \frac{\overrightarrow{r_{c,y,0,1}} r_{c,2000,0,0}}{r_{c,y,0,0}}$$

Combining both adjustments, $r_{c,y,0,0}$ cancels, leaving:

$$\overrightarrow{r_{c,2000,0,1}} = \frac{\overrightarrow{r_{c,y,s,1}} r_{c,2000,0,0}}{r_{c,y,s,0}}$$

In effect, subnational differentiation from the national source year is applied to the national base rate for 2000 reported by UNICEF. This has clear drawbacks: changes in the late nineties were likely to have been disproportionately felt in certain areas of a country. However, we consider this loss in precision not significant enough to avoid attempting consistent subnational estimation, and further research should be undertaken—as subnational data are more commonly reported—to quantify the error introduced by adjustments of this nature.

Third, each tabular data point was assigned to a geographic boundary based on source material associated with the data or other maps of administrative regions. For most countries, appropriate spatial data are commonly available or easily constructible from public domain sources such as ESRI (2002). Other countries required the proprietary subnational boundary collections used to create the Gridded Population of the World (CIESIN and CIAT 2005). The average size (in population and area terms) of a unit with an associated IMR estimate is indicated in Table 1. The value depends both on the size of the country and the number of units (i.e., first-level administrative units are much larger in India than they are neighboring Bangladesh because India is geographically much larger).

Fourth, because the administrative polygons are irregular and of highly varying resolution, these polygons were converted to a uniform grid. This has one main analytic advantage, in that like many geographic datasets, like most other population parameters reported for administrative polygons, this infant mortality surface is subject to the modifiable areal unit problem (MAUP; Openshaw and Taylor 1979). Discretizing a phenomenon that is continuous (or in this case, varying at a far higher resolution) is an arbitrary process. In the case of the infant mortality data, we are faced with a dataset with one value for Afghanistan, and over 4,000 for Brazil. Should one wish to analyze, for example, the relationship between the IMR and biophysical or environmental variables, such as the average elevation, using the reporting units, one would generate a single value for the entire country of Afghanistan, and one for a neighborhood of Rio de Janeiro. In other words, gridding allows for flexibility in accounting for variation in the right-hand side of a causal model predicting mortality even in areas where mortality data are locally uniform. However, it cannot increase information density, and as such, appropriate statistical models are required to account for this autoreplication.[5]

Because infant mortality is a rate, scaling it to alternate geographies requires decomposition into a numerator (live births) and denominators (deaths). Births (B) were estimated using national crude birth rates (CBR) from the UN Population division and high-resolution population (P) estimates from CIESIN and CIAT (2005): B = CBR * P. The national CBR data add error to the subnational IMR distribution, but in general, regional fertility varies less within a country than infant mortality at this scale, so the estimates are still worth producing. In a sample of 101 DHS, the unweighted coefficient of variation between regions within each country is higher for IMR than CBR in all but 8 surveys. In a subsample of 28 with readily available population data for weighting from CIESIN and CIAT (2005), only four are similarly anomalous. Deaths (D) are calculated analogously (D = IMR * B). Grids of births, deaths and rates were calculated at 0.25 degree and 2.5 minute resolution, corresponding to approximately 772 and 21 square kilometers, respectively.

Results

The resulting dataset (CIESIN 2005a) is mapped in Figure 2. Granularity in the dataset is most clearly evident in Mexico, China and Brazil. However, even in sub-Saharan Africa, a western Sahel high mortality pattern emerges more clearly than within the national data. Figure 3 highlights the subnational distribution within each country. It is evident that variation increases with unit density, as one would expect. However, the high resolution of the data for Brazil and China is only part of the reason for their large ranges, since 99% and

[5] See for example Balk et al (2006).

92% of the units fall within the central 95% of their respective ranges. Further, Mexico has a standard deviation that is one third of Thailand's, despite having over thirty times as many units. Having an ability to detect which subnational regions have disproportionately high infant mortality rates is a valuable tool for policy and research. Increasing the subnational resolution is an aid towards this goal.[6]

In addition to knowing where rates of mortality are disproportionately high, as Figure 4 shows, these data can also be seen in terms of absolute numbers of infant deaths. Rates are shown in different colors, while darkness represents deaths. From this map, it is evident that a large fraction of the world's deaths occur in India, despite the fact that its rates are lower than those of several countries in Sahelian and Central Africa, and the fact that there is considerable variation in rates of mortality within India. This exercise serves as an important reminder that both absolute numbers and rates of infant deaths matter, however, in discussing spatial patterns we limit ourselves to discussing rates because they are more comparable across different sized units.

Spatial Patterns

Our findings are consistent with those of Black et al (2003) in that half of all infant deaths, like half of all child deaths, are concentrated in the same six countries. However, the present dataset allows us to further quantify the spatial concentration of infant mortality. Using a 0.25 degree unit of analysis, within these six countries, 55.9% of deaths are concentrated within 10.0% of land area that holds 34.4% of their combined population. Expanding to the 20 countries with the most deaths, it takes 3.2% of world land area (holding 28.4% of world population) to reach half their deaths - this gives 1.72 billion persons in 4.15 million square kilometers, 50% of these 20 countries' population in 11% of their area. At a global scale, half of all deaths are concentrated in 2.5% of global populated land area holding 29.3% of global population. In contrast, the most concentrated half of world population lives on 2.9% of populated land area, but accounts for 38.2% of infant deaths. It is well known that people are highly concentrated spatially in areas that are desirable for various reasons. What is interesting here is that deaths are consistently more concentrated than people, no matter whether we consider all countries or the six or 20 with the most deaths. At the global scale, this can best be seen by the fact that it takes 2.5% of global land area to find half of all infant deaths, 14% less than the 2.9% required to find half of global population.

Spatial data also allow us to formally consider the degree to which deaths are concentrated by calculating measures of spatial autocorrelation. We calculated Global Moran's I (Moran 1950) statistics and Local Indicators of Spatial Autocorrelation (LISA) maps (Anselin 1995).[7] The Moran's I values in Table 3 indicate the strength of spatial autocorrelation for selected regions. In all continents, there is a high degree of spatial autocorrelation—that is, greater

[6] Clearly there is an upper limit to the spatial resolution because small denominators produce unstable rates, but at present most of the data, expressed only at the first subnational unit, do not come close to such a limit.

[7] Specifically, we used the Empirical Bayesian (EB) method of Assuncao and Reis (1999) in order to account for highly varying denominators for the rates under study. Our weights matrices are based on "queen" contiguity. Contiguity matrices are named based on an analogy to chess. Units are rook contiguous if they share an edge, bishop contiguous if they share a vertex, and queen contiguous if they share either. Because contiguity is required, all islands are removed from this portion of analysis.

than 0.50. In the map in Figure 5, units are placed in one of four categories if their LISA values are significant at 5% after 9999 iterations in Geoda software (Anselin 2006). LISA maps identify clusters of mortality regimes. Dark red indicates places of high IMR surrounded by neighbors with high IMR. Conversely, dark blue represents clusters of low mortality. Light shades of red and blue represent (respectively) high and low spatial outliers, places with neighbors of an opposing mortality regime. Grey indicates places with neither high nor low IMR clusters (but which could either be mid-range IMR clusters or moderately opposing IMR regimes).

On a global scale (Figure 5), virtually all of Africa is a high mortality cluster, along with a swath of Asia extending in a band of varying width from northern Uzbekistan to central Vietnam. Only parts of northeastern Brazil and one province of Bolivia stand out as significant high-high clusters in the Americas. North America, Europe, the southern cone of South America, and much of coastal China constitute the majority of the largest low-low clusters, not surprisingly. China also has the highest concentration of low-high and high-low clusters. Even among the countries identified as the top six contributors to global infant mortality by the study of Black and colleagues--India, Nigeria, China, Pakistan, Congo (DRC) and Ethiopia--mortality is clustered differentially. In China, for example, the highest share of mortality occurs in western and south western regions.

Only when the rest of the world is excluded are more significant subnational patterns seen in Africa, with low mortality clusters in the north and south extending as far inward as Sudan and Zimbabwe, respectively, as shown on the continental-scale LISA map in Figure 6. Throughout Africa, subnational patterns emerge, and we would expect more to be revealed were subnational data available everywhere: some of countries entirely included in the high mortality clusters are represented by national-level data only (e.g., Congo, Cote d'Ivoire, Liberia).

The LISA maps also demonstrate that the value of disaggregation can increase beyond the first administrative level. Mexico (Figure 7) has data available for both states (first-level) and municipios (second-level). The first-level data mask clusters of high IMR most strikingly in southwestern portion of Chihuahua state. The state-level data also mask the analogous low-mortality regimes found along the Mexican side of border with the United States, and around Mexico City.

Spatial Co-variates

Why do these spatial patterns matter? Not only does assessment of patterns assist in targeting policy interventions, but spatial delineation of demographic phenomena allow for a systematic determination of spatial co-variation.

While a full multivariate model exploring the spatial correlates of infant mortality is undertaken elsewhere (Balk et al., 2006), some preliminary observations about the variation of infant mortality across environmental zones is in order. Here we consider IMR disaggregated by biome—that is, major habitat types or ecoregions (Figure 8; Olson et al, 2001, Olson and Dinerstein, 1998)—and distance to sea-coast, a factor that has been previously identified as having strong association with GDP per capita (Mellinger et al, 2000), which in turn is known to influence child mortality outcomes (Hill and Pebley, 1989, Reher and Sanz-Gimeno, 2000).

We calculated estimated IMR values for each biome by continent, using both the present dataset (shown in Table 4) and one based on national IMR values (not shown), both using a 0.25-degree unit of analysis. The two largest biomes in Africa, “tropical and subtropical moist broadleaf forest” and “tropical and subtropical grassland, savanna, and shrubland”, home to over 75% of births in the continent, have remarkably similar rates above the continental average, with several of the remaining biomes much lower. Deserts show strikingly lower rates than in other biomes, but they account for a small share (less than 4%) of all births on the continent and predominate in relatively well-off northern Africa. In Asia, however, deserts—accounting for more than 1/6 of the births—have a higher rate than any other biome. Deserts similarly experience much higher than average mortality in South America and Europe.

Some of the smaller biomes—especially those found on most or all continents—exhibit clear and consistent patterns. “Montane grassland and shrubland” and “mangroves” have significantly above-average mortality. Similarly, “flooded grasslands and savannah” have lower IMR than average in all continents (except in Europe), perhaps because these regions are hospitable to agriculture and raising livestock.

When this analysis is done with national-level IMR data, there are striking differences, especially in Asia, where the IMR for “temperate broadleaf and mixed forest” increases by more than 25%. In the same reanalysis, IMR in South American deserts decreases by over 20%, because of muted correlation with high rates in northeastern Brazil.

Coastal proximity also shows several clear patterns. Figure 9 shows IMR by continent and by distance between cell centroid and the nearest sea-coast in deciles.[8] In Africa and Asia, IMR is positively correlated with distance to coast; though the farthest decile has somewhat lower IMR than the next two in Africa and five in Asia. In both of these continents, the tenth decile has far fewer cells, and includes portions of some relatively advantaged (in economic terms) locations, such as oil-rich Northern African nations.

The relationship is for the most part flat or weak in South America and Europe, and in North America is opposite from that which expected. This result for North American is explained by the compositional nature: poor North American countries are much smaller and more disproportionately coastal than the large North American countries—Canada and the United States. In South America, the top two to three deciles are almost entirely in Brazil, a relatively wealthy country and the one with by far the highest resolution data on the continent.

Recommendations for Future Work

This analysis has shown that subnational patterns of infant mortality are distinguishable from national-level patterns, spatial clustering is prominent, and that there are explicit pattern in

[8] Oceania is omitted from this analysis as it includes a disproportionate number of small countries and few or none with cells in the second-half of the coast-distance deciles.

some biophysical or geographic correlates of mortality. There is ample room for future work in the analysis of spatial patterns, correlates and determinants of mortality and related socio-demographic characteristics. Some analytical work already underway (Balk et al., 2006) will consider multivariate relationships between IMR and potential biophysical determinants, including elevation, climate and soils.

Another area of future work is further data development. Clearly subnational infant mortality data with greater consistency (i.e., reconciling across methods of IMR calculation and across years of observation) and of higher resolution across all countries would be ideal. Higher-order subnational units of the kind we have here for Mexico, Brazil and China would be ideal where population sizes are large enough to generate stable rates. In some instances, such data are available but not in a spatially consistent fashion or for an area of the world (such as Europe and North America) that were not strongly an object of this particular group of researchers.

Even using the coarse survey regions described here, mapping other indicators may provide significant insights with relatively little effort. The methods required to develop this dataset are largely transferable to other similarly well-defined indicators such as those describing fertility or anthropometric status. While reporting regions for IMR are occasionally coarser than those for other rates, they are usually the same in the major international household surveys, and so the same data aggregation techniques and GIS boundary data can be used to map them. Under-nutrition, believed to be the underlying cause of a substantial proportion of child deaths (Black et al 2003), has already been georeferenced—as estimates of underweight (CIESIN 2005b) and stunted (FAO 2004) children—though means for scaling across survey years have not yet been developed so that these data represent a period of observation rather a single target year. Work on other indicators such as immunization rates and access to safe water has not progressed as far, in part because of differences in definition across surveys, but an increasing number are available online via DHS' StatMapper Service (http://statmapper.mapsherpa.com/). They are critical for establishing equity especially within the framework of the United Nations Millennium Development Goals and other development objectives.

With investments in the geospatial data to accompany historic surveys, changes occurring at a subnational scale—both in terms of the survey regions and associated biophysical or spatial characteristics (e.g., drought, infrastructure)—can be investigated over time, to reconsider classical demographic issues in a new light and investigate new ones.

Data Dissemination

The data described here are freely available for download from http://www.ciesin.columbia.edu/povmap/ds_global.html.

Figures

Tables

References

Adetunji, J A (1996). Infant mortality levels in Africa: does method of estimation matter? *Genus* 52(3-4): 89-106 (Jul-Dec 1996).

Anselin, L (1995). Local Indicators of Spatial Association — LISA, *Geographical Analysis* 27: 93-115.

Anselin, L., I. Syabri, and Y. Kho. (2006). GeoDa: An Introduction to Spatial Data Analysis, *Geographical Analysis* 38, 5–22.

Assuncao, R. and Reis, E. A. (1999). A new proposal to adjust Moran's I for population density. *Statistics in Medicine*, 18:2147-2161.

Balk, D, T Pullum, A Storeygard, F Greenwell and M Neuman (2004). "A Spatial Analysis of Child Mortality in West Africa" *Population, Space and Place* 10 (3): 175-216

Balk, D, G Deane, M Levy, A Storeygard, and S Ahamed (2006). "The Biophysical Determinants of Global Poverty: Insights from an Analysis of Spatially Explicit Data" Paper presented at the Annual Meetings of the Population Association of America, April 2006, Los Angeles.

Black, Robert E, Saul S Morris and Jennifer Bryce (2003). Where and why are 10 million children dying every year? *Lancet* 361:2226-2234, 2003.

Center for International Earth Science Information Network (CIESIN), Columbia University; 2005a Global subnational infant mortality rates [dataset]. CIESIN, Palisades, NY, USA. Available at: http://www.ciesin.columbia.edu/povmap/ds_global.html

---. 2005b. Global subnational rates of child underweight status [dataset]. CIESIN, Palisades, NY, USA. Available at: http://www.ciesin.columbia.edu/povmap/ds_global.html

Center for International Earth Science Information Network (CIESIN), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT). 2005. Gridded Population of the World Version 3 (GPWv3): Land Area Grids. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw

Cai, Yong. (2005). National, Provincial, Prefectural and County Life Tables for China Based on the 2000 Census. CSDE Working Paper, University of Washington. http://csde.washington.edu/downloads/05-03.pdf

ESRI Data & Maps [CD-ROM]. (2002). Redlands, CA: Environmental Systems Research Institute.

Food and Agriculture Organization of the United Nations (FAO) 2003. Chronic undernutrition among children: an indicator of poverty. Rome: FAO.

Fujii, T. 2004. Micro-level estimation of child malnutrition indicators and its application in Cambodia. Invited presentation at 2004 ESRI International User Conference. San Diego, CA.

Hill, K. and A. Pebley. 1989. Child Mortality in the Developing World, *Population and Development World,* 15(4): 657-687.

Hill, K. and A. Yazbeck, 1994. Trends in child mortality, 1960-90: Estimates for 83 developing countries, background paper number 6 to World Development Report 1993, October 1994.

Hill, K., R. Pande and G. Jones, 1997. Trends in child mortality in the developing world: 1990 to 1995, UNICEF staff working papers, Evaluation, Policy and Planning Series, UNICEF, New York.

Levy, Marc A., Suresh Babu, and Kirk Hamilton (2005). Ecosystem Conditions and Human Well Being, Chapter 5 in *Millennium Ecosystem Assessment, Conditions and Trends of World's Ecosystems*, ed. Hassan, R, R Scholes and N Ash. Washington, DC: Island Press.

Mellinger, A, J D Sachs, and J Gallup (2000). Climate, Coastal Proximity, and Development" *Oxford Handbook of Economic Geography*, ed. G L Clark, M P Feldman, and M S Gertler, Oxford: Oxford University Press.

Moran, P A P, 1950. Notes on continuous stochastic phenomena, *Biometrika* 37:17-23.

Office National de la Statistique (ONS) [Mauritanie] et ORC Macro. 2001. Enquête Démographique et de Santé Mauritanie 2000-2001. Calverton, Maryland, USA : ONS et ORC Macro.

Olenick, I (1998) Among Uzbekistani Women, Little Difference Exists Between Actual and Desired Levels of Fertility, *International Family Planning Perspectives* 24(1), 43-44 (March 1998).

Olson, D.M., and E. Dinerstein (1998). The Global 200: a representation approach to conserving the Earth's most biologically valuable ecoregions. *Conservation Biology* 12:502-515.

Olson, D.M., E. Dinerstein, E.D. Wikramanayake, N.D. Burgess, G.V.N. Powell, E.C. Underwood, J.A. D'Amico, H.E. Strand, J.C. Morrison, C.J. Loucks, T.F. Allnutt, J.F. Lamoreux, T.H. Ricketts, I. Itoua, W.W. Wettengel, Y. Kura, P. Hedao, and K. Kassem. (2001). Terrestrial ecoregions of the world: A new map of life on Earth. *BioScience* 51(11): 933-938.

Openshaw, S and Taylor, PJ, 1979. A million or so correlation coefficients: three experiments on the modifiable areal unit problem. In: N. Wrigley, ed. Statistical Applications in the Spatial Sciences. London: Pion, 127-44.

Reher, D. and A. Sanz-Gimeno 2000. Mortality and economic development over the course of modernization: An analysis of short-run fluctuations in Spain, 1850-1990, Demography 54(2):135 -152.

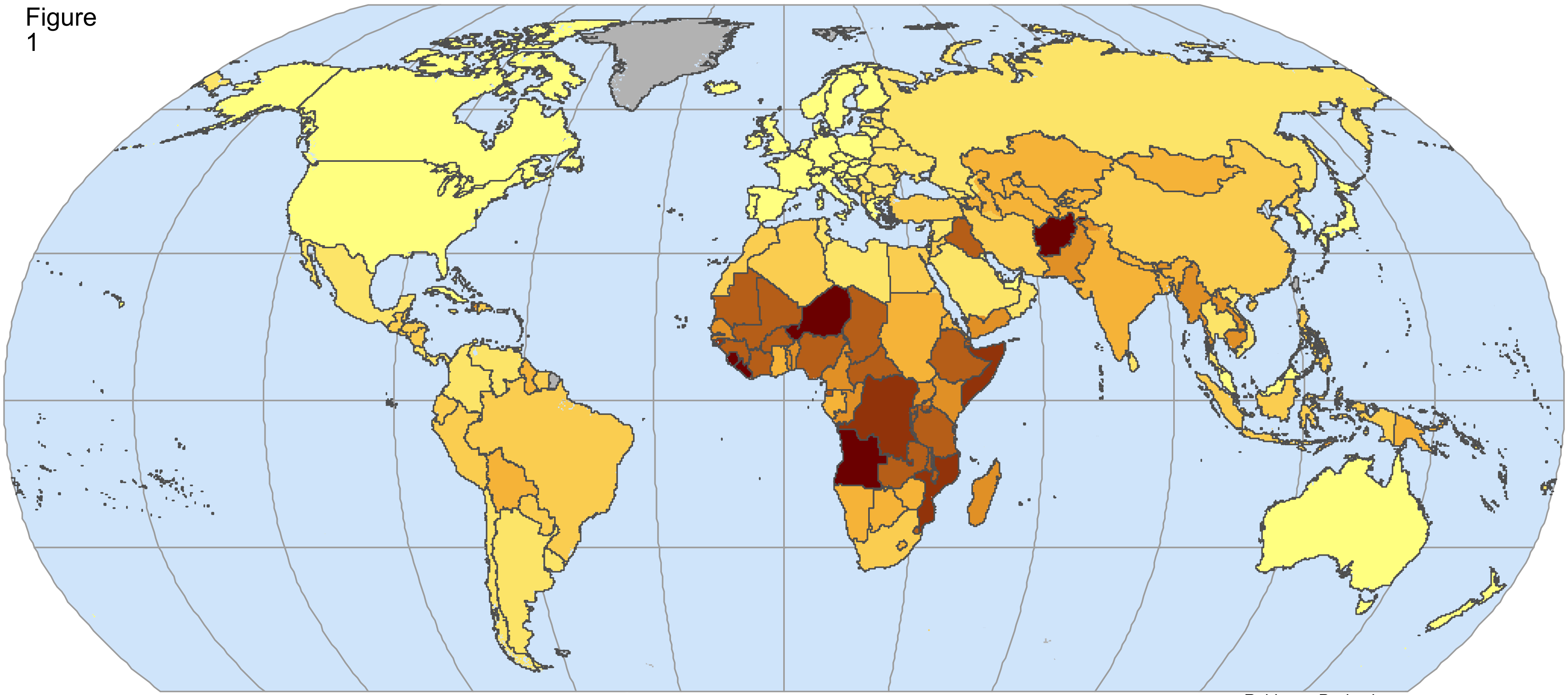
Rutstein SO and Rojas G (2003) Guide to DHS Statistics. Demographic and Health Surveys Calverton, Maryland, USA : ORC Macro, September 2003. http://www.measuredhs.com/pdfs/Guide_DHS_Statistics.pdf

United Nations. 1983. Manual X. Indirect Techniques for Demographic Estimation, (New York: United Nations Department of International Economic and Social Affairs) Population Studies, no 81 (ST/ESA/SER.A/81)

UNICEF 2004. End-Decade Database on Child Mortality. www.childinfo.org

Wuhib T, McCarthy BJ, Chorba TL, Sinitsina TA, Ivasiv IV, McNabb SJ (2003) Underestimation of infant mortality rates in one republic of the former Soviet Union. *Pediatrics*. 2003 May;111(5 Pt 1):e596-600.

Figure 1



Measures of Poverty

Infant Mortality Rates

By Country

Figures are for 2000 based on UNICEF (2003)

Infant mortality rate, 2000
(deaths per 1000 live births)

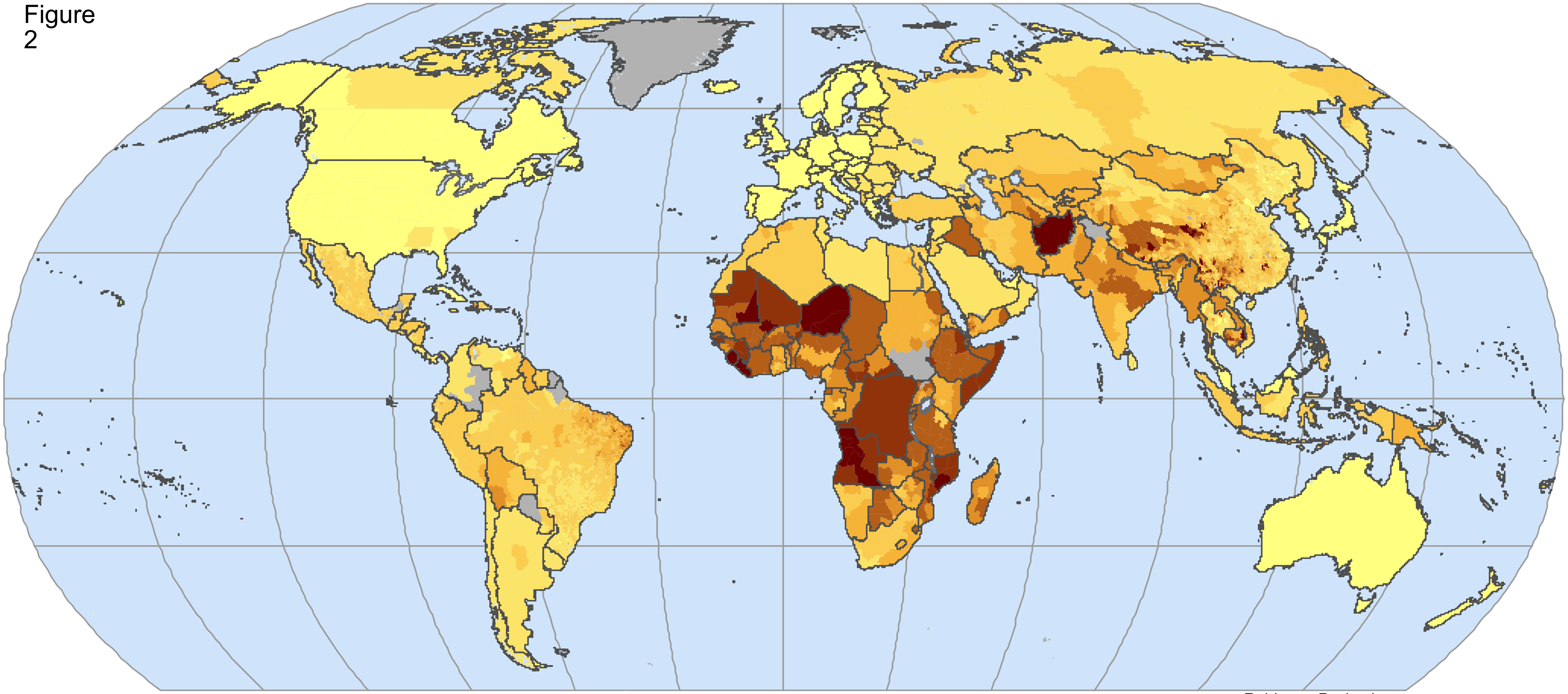
- < 9.1
- 9.1 - 25.0
- 25.1 - 50.0
- 50.1 - 75.0
- 75.1 - 100.0
- 100.1 - 125.0
- 125.1 - 150.0
- 150.1 <
- no data

National Boundary

Subnational boundaries have been removed from countries for clarity.

Source: Center for International Earth Science Information Network (CIESIN). Columbia University. Global subnational infant mortality rates; maps and further documentation available at: http://www.ciesin.columbia.edu/povmap

Figure
2



Robinson Projection

The World

By Subnational Administrative Level

Measures of Poverty

Infant Mortality Rates [IMR]

Subnational mortality rates are adjusted to 2000 using national trend data.
Original data for 96% of countries are from 1995 or later. All data are from 1990 or later.

Infant mortality rate, 2000 (deaths per 1000 live births)

- < 9.1
- 9.1 - 25.0
- 25.1 - 50.0
- 50.1 - 75.0
- 75.1 - 100.0
- 100.1 - 125.0
- 125 - 150.0
- 150.0 <
- no data
- National Boundary

Subnational boundaries have been removed from countries for clarity.

CIESIN
Columbia University

Source: Center for International Earth Science Information Network (CIESIN). Columbia University. Global subnational infant mortality rates; maps and further documentation available at: http://www.ciesin.columbia.edu/povmap

Figure 3

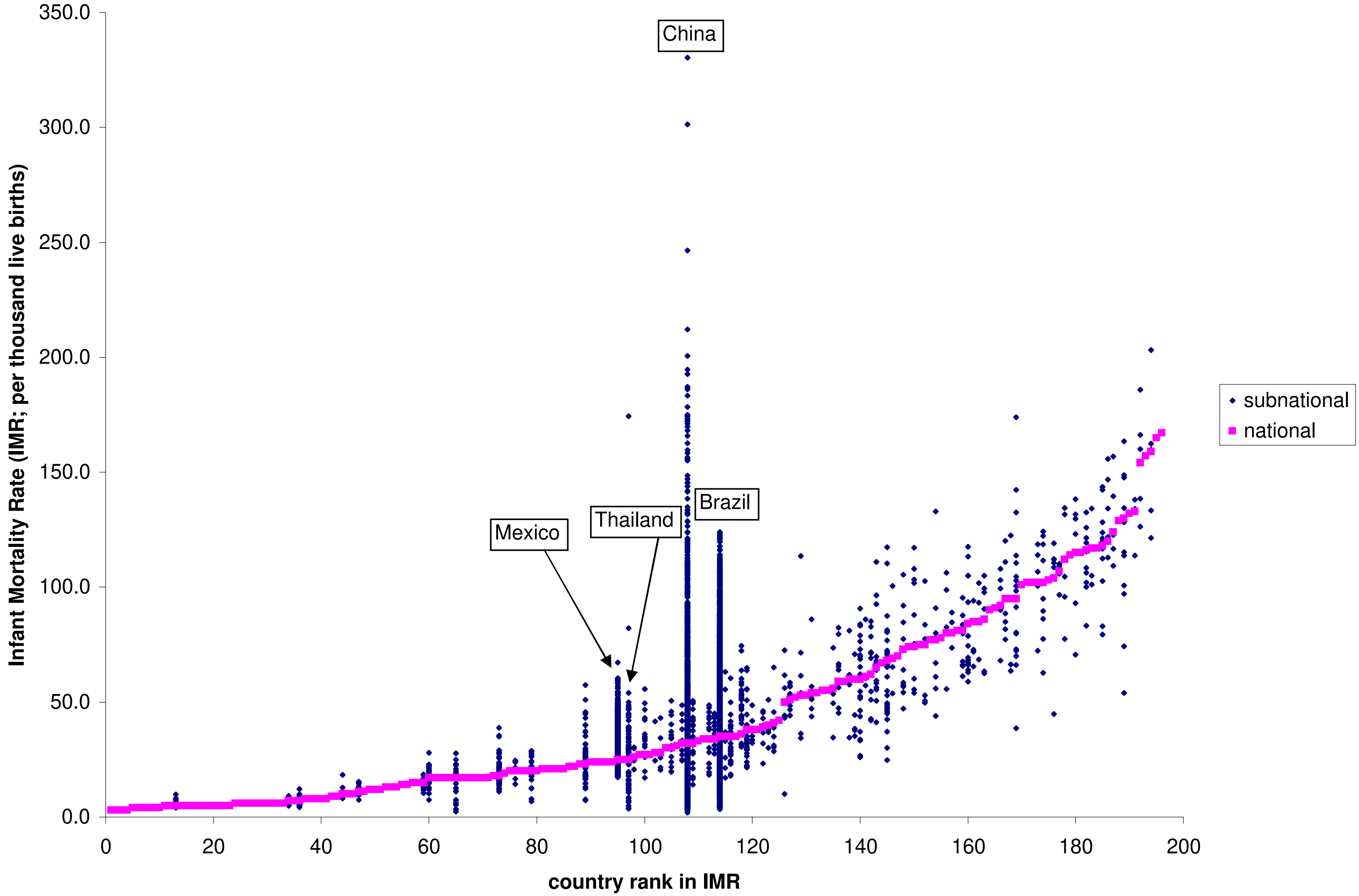
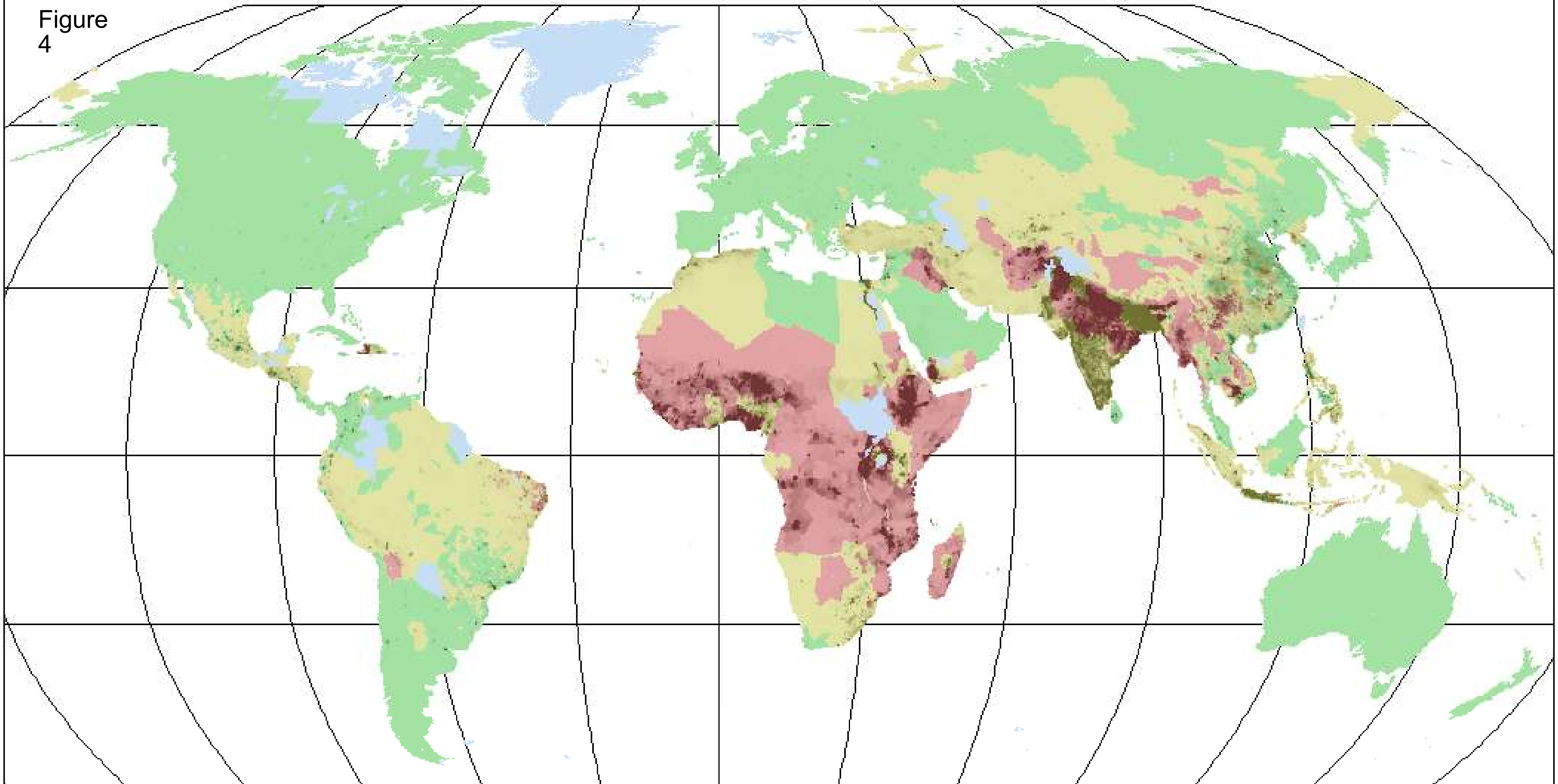

China
Brazil
Thailand
Mexico
subnational
national
Infant Mortality Rate (IMR; per thousand live births)
country rank in IMR
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
0
20
40
60
80
100
120
140
160
180
200

Figure 4



Infant mortality rate

deaths per thousand live births

- under 25
- 25-75
- over 75
- no data

deaths within quarter-degree grid cell

High : 26568

Low : 0

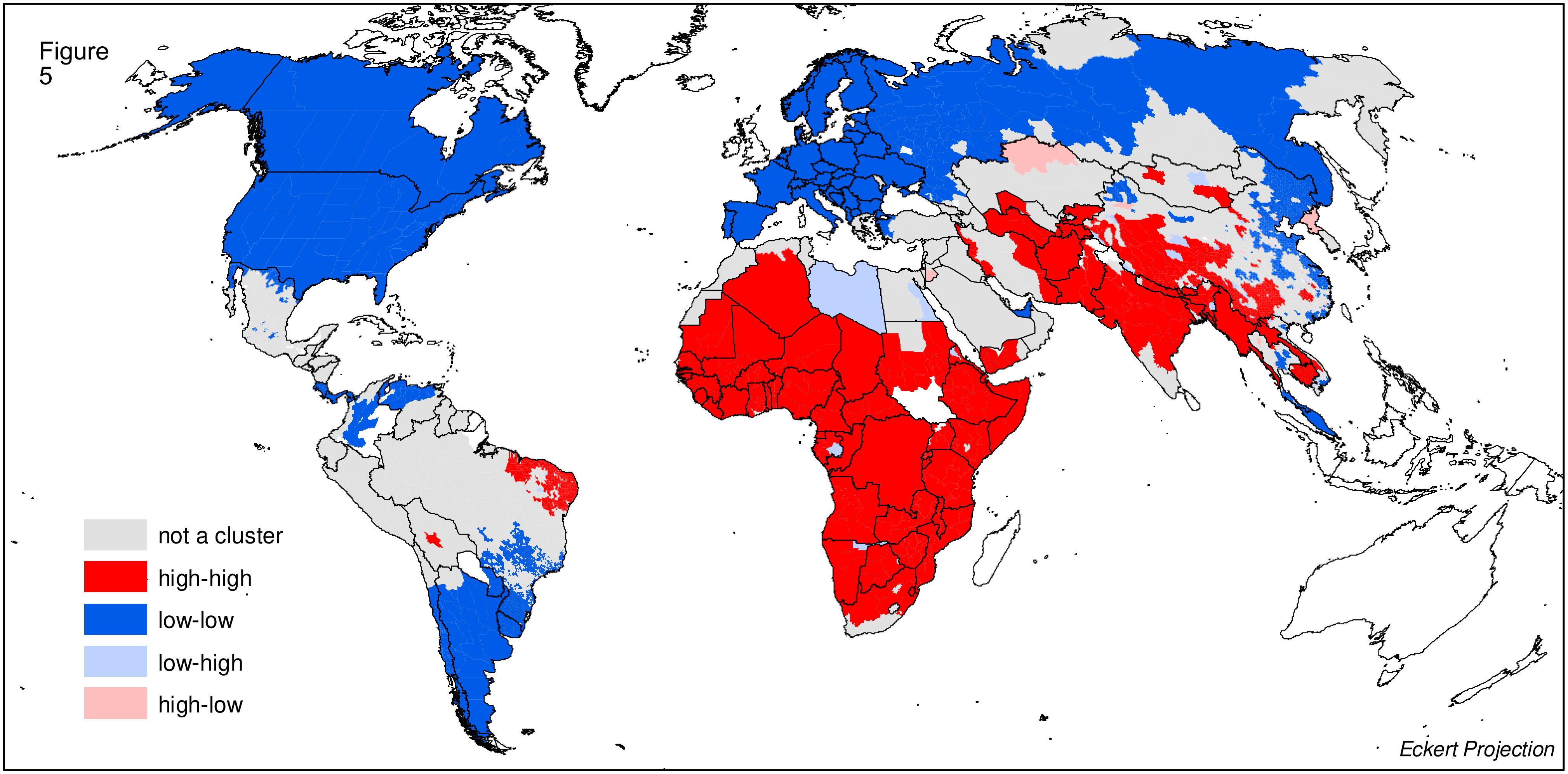


Figure
5
not a cluster
high-high
low-low
low-high
high-low
Eckert Projection

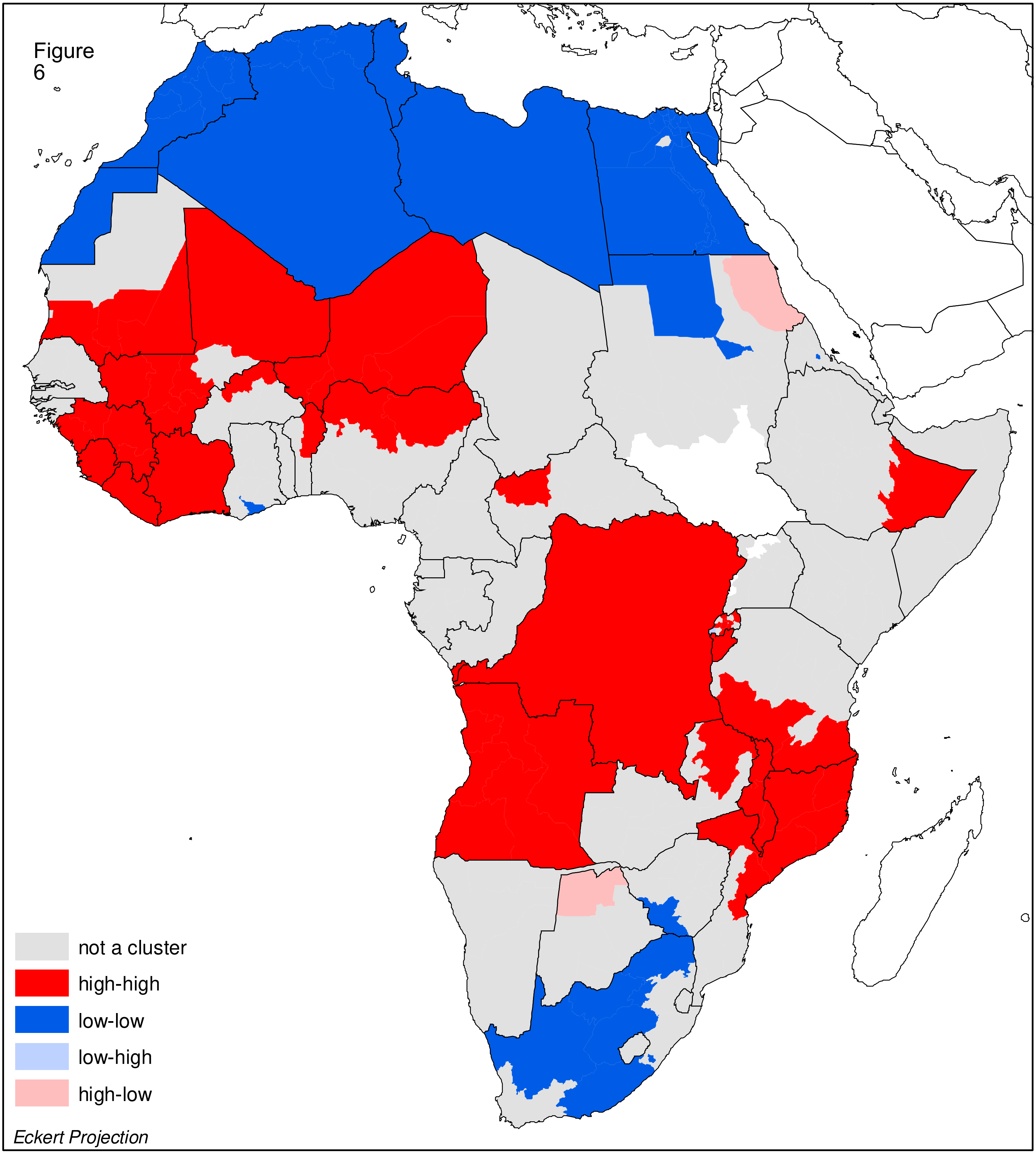


Figure
6
not a cluster
high-high
low-low
low-high
high-low
Eckert Projection

Figure 7

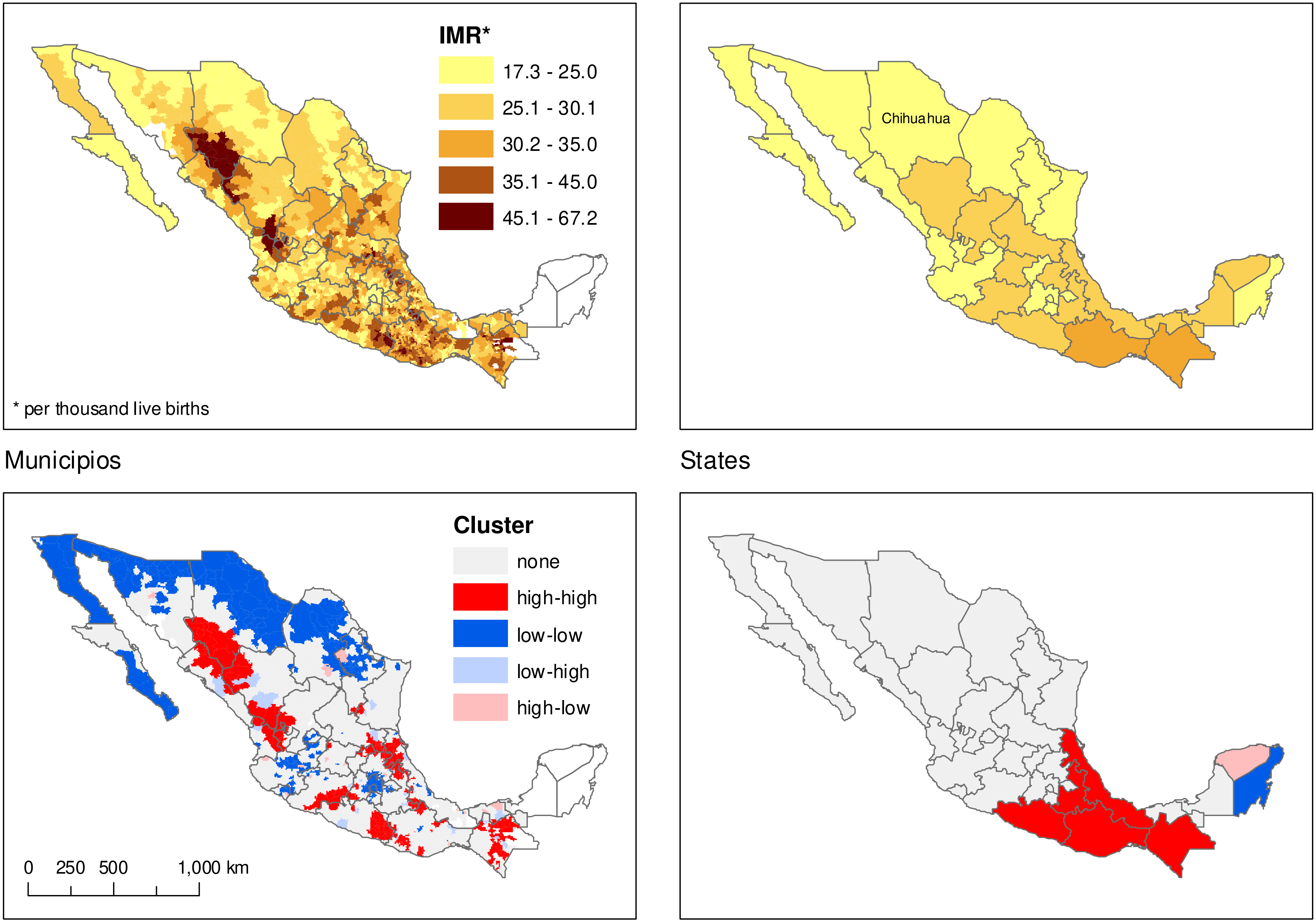
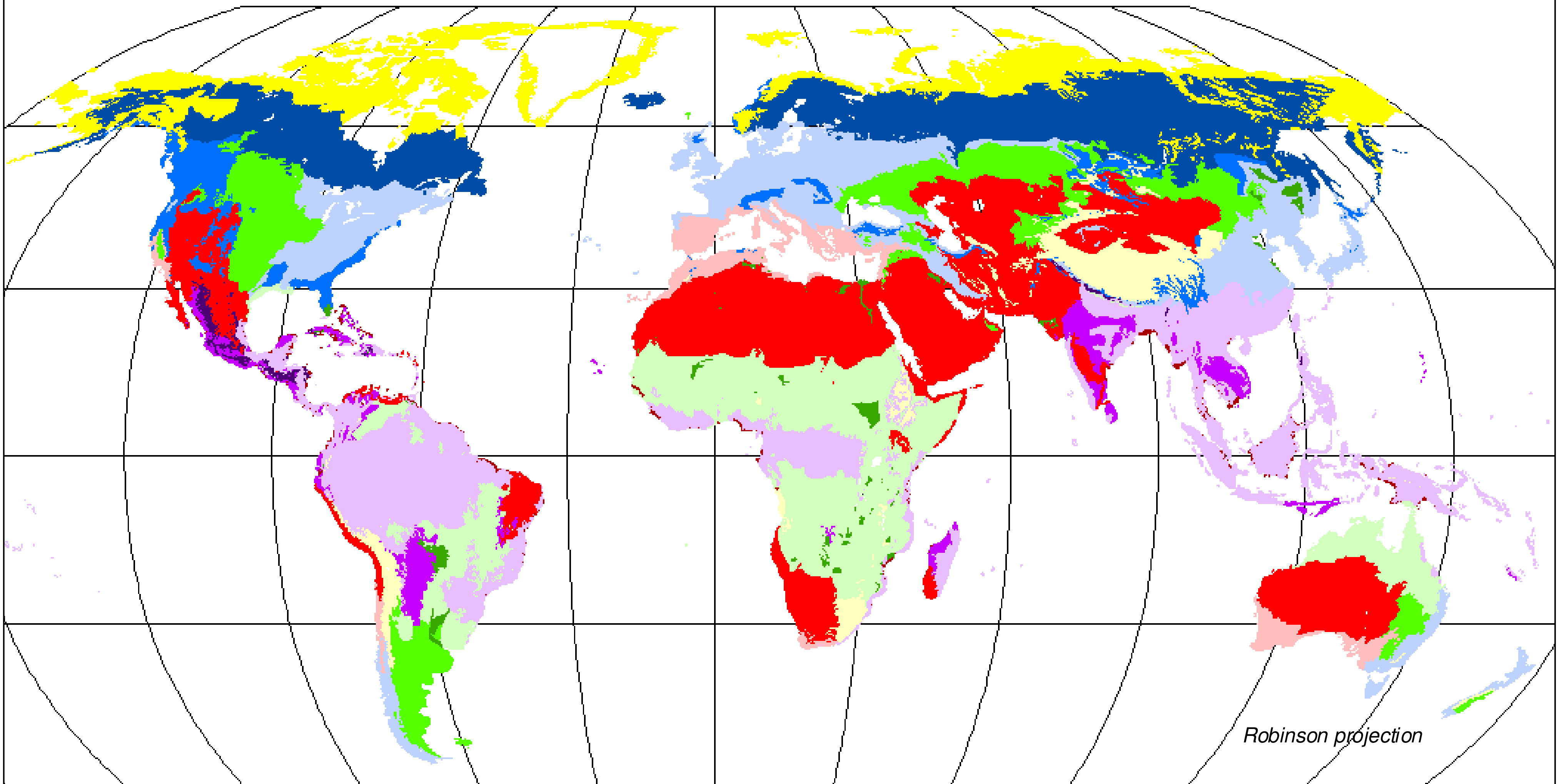

IMR*
17.3 - 25.0
25.1 - 30.1
30.2 - 35.0
35.1 - 45.0
45.1 - 67.2
* per thousand live births
Chihuahua
Municipios
States
Cluster
none
high-high
low-low
low-high
high-low
0 250 500 1,000 km

Figure 8

Biomes



1 Tropical and subtropical moist broadleaf forest
2 Tropical and subtropical dry broadleaf forest
3 Tropical and subtropical coniferous forest
4 Temperate broadleaf and mixed forest
5 Temperate conifer forest
6 Boreal forest/Taiga
7 Tropical and subtropical grassland, savanna, and shrubland
8 Temperate grassland, savanna, and shrubland
9 Flooded grassland and savanna
10 Montane grassland and shrubland
11 Tundra
12 Mediterranean forest, woodland, and scrub
13 Deserts and xeric shrubland
14 Mangrove

Figure
9

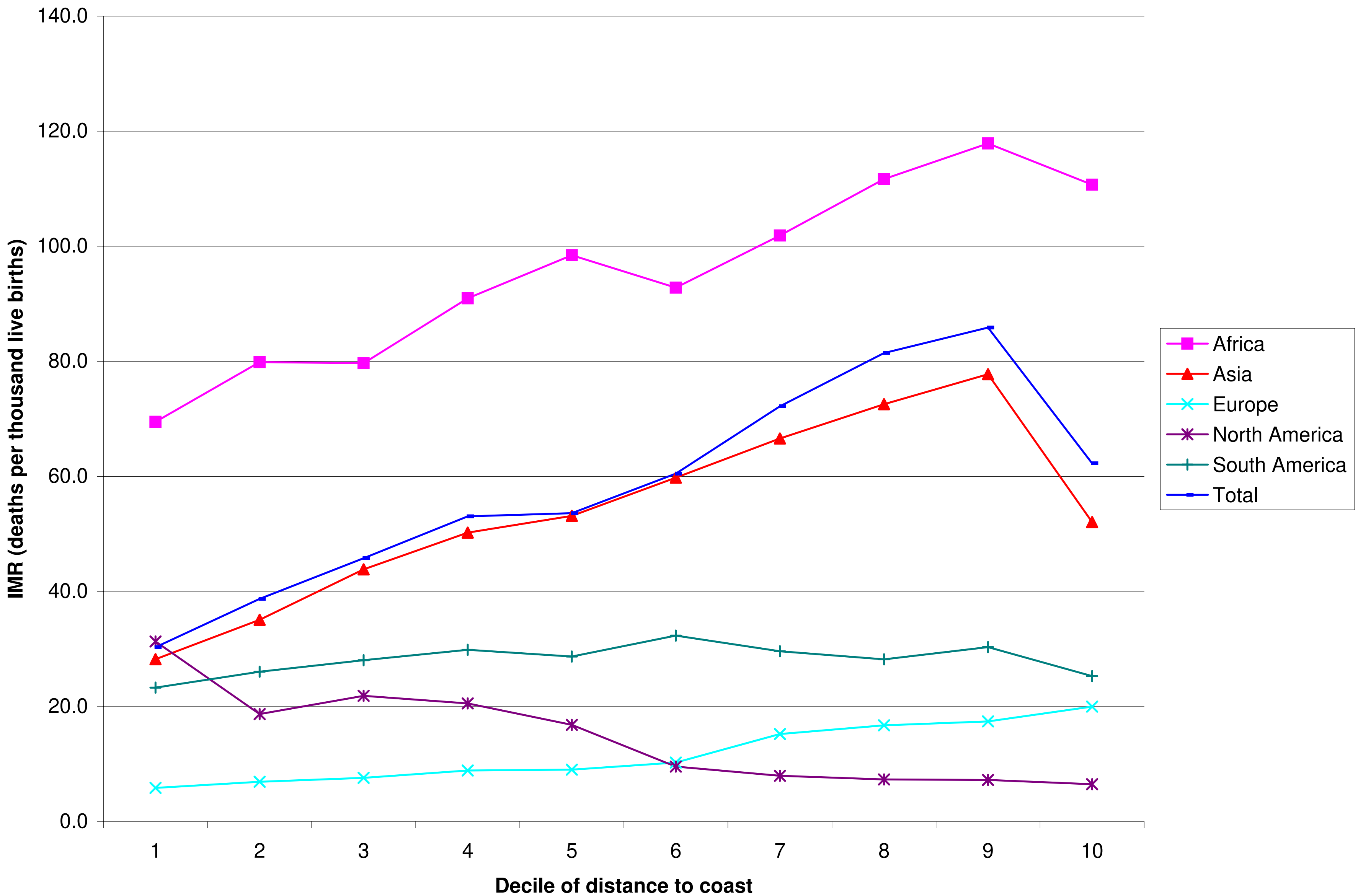

140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
IMR (deaths per thousand live births)
1
2
3
4
5
6
7
8
9
10
Decile of distance to coast
Africa
Asia
Europe
North America
South America
Total

Table 1

Data type	Data units	Countries	Average units per country	% world pop	% non-OECD pop
None (all small islands)	0	44	-	0.5%	0.1%
National	119	119	1	18.8%	10.0%
Subnational excluding Brazil, China, Mexico	998	74	13	55.3%	60.4%
Brazil, China, Mexico	9253	3	3,084	25.4%	29.4%
Any subnational	10251	77	133	80.7%	89.8%
Any data	10370	196	53	99.5%	99.9%
Total	10370	240	43	100.0%	100.0%

Table 2: Countries with subnational data

Continent	Country	National 2000 IMR from UNICEF	Other National IMR	IMR Base Year	IMR Source (abbr.)	National Crude Birth Rate	Units with IMR Data	Missing any IMR Data	popul-ation (000's; 2000)	area (sq km)	popul-ation (000's)/ IMR unit	area/IMR unit	Admin-istrative Level	Method - general
Africa	Algeria	40	40	2000	MICS	22.8	4	No	30291	2302498	7573	575624	0.5	Indirect estimation
Africa	Angola	154	150	2001	MICS	52.3	6	No	13134	1251924	2189	208654	0.5	Indirect estimation
Africa	Benin	95	95	2001	DHS	41.5	6	No	6272	115828	1045	19305	0.5	Direct estimation
Africa	Botswana	74	48	1991	NHDR	30.6	9	No	1541	559502	171	62167	1	Indirect estimation
Africa	Burkina Faso	107	109	1999	DHS	47.8	4	No	11535	275747	2884	68937	0.5	Direct estimation
Africa	Cameroon	95	80	1998	DHS	35.4	4	No	14876	465765	3719	116441	0.5	Direct estimation
Africa	Central African Republic	115	102	1994	DHS	37.7	6	No	3717	622868	620	103811	0.5	Direct estimation
Africa	Comoros	61	84	1996	DHS	36.7	3	No	706	2046	235	682	1	Direct estimation
Africa	Egypt	38	29.2	1998	NHDR	26.6	26	No	67884	968071	2611	37234	1	Vital statistics
Africa	Eritrea	53	57	2002	DHS	39.7	6	No	3659	121863	610	20310	1	Direct estimation
Africa	Ethiopia	116	113	2000	DHS	42.5	11	No	62908	1123714	5719	102156	1	Direct estimation
Africa	Gabon	60	61	2000	DHS	31.6	4	No	1230	265146	308	66286	0.5	Direct estimation
Africa	Gambia	92	92	1993	NHDR	35.8	6	Yes	1303	10838	217	1806	1	Indirect estimation
Africa	Ghana	62	61	1998	DHS	31.9	10	No	19306	231730	1931	23173	1	Direct estimation
Africa	Guinea	112	107	1999	DHS	42.9	5	No	8154	245860	1631	49172	0.75	Direct estimation
Africa	Kenya	77	77	2003	DHS	32.5	8	No	30669	579617	3834	72452	1	Direct estimation
Africa	Madagascar	86	99	1997	DHS	41.6	6	No	15970	592965	2662	98828	1	Direct estimation
Africa	Malawi	117	113	2000	DHS	44.6	3	No	11308	94958	3769	31653	1	Direct estimation
Africa	Mali	124	126	2001	DHS	49.9	6	No	11351	1248137	1892	208023	0.75	Direct estimation
Africa	Mauritania	120	67	2000	DHS	41.8	5	No	2665	1036905	533	207381	0.5	Direct estimation
Africa	Morocco	41	66	1995	DHS	23.2	7	No	29878	669159	4268	95594	0.5	Direct estimation
Africa	Mozambique	130	145.5	1997	DHS	41.2	11	No	18292	777123	1663	70648	1	Direct estimation
Africa	Namibia	56	38	2000	DHS	33.4	4	No	1757	819964	439	204991	0.5	Direct estimation
Africa	Niger	159	136	1998	DHS	55.2	5	No	10832	1157232	2166	231446	0.75	Direct estimation
Africa	Nigeria	102	71	1999	DHS	39.1	5	No	113862	904235	22772	180847	0.5	Direct estimation
Africa	Rwanda	118	117.4	2000	DHS	44	12	No	7609	24349	634	2029	1	Direct estimation
Africa	Senegal	80	69	1997	DHS	37.1	4	No	9421	196151	2355	49038	0.5	Direct estimation
Africa	Somalia	133	132	1999	MICS	52.1	3	Yes	8778	634315	2926	211438	0.5	Indirect estimation
Africa	South Africa	50	42.2	1998	DHS	22.6	9	Yes	43309	1217645	4812	135294	1	Direct estimation
Africa	Sudan	65	68	2000	MICS	33	16	Yes	31095	2492385	1943	155774	0.75	Indirect estimation
Africa	Togo	80	80	1998	DHS	38.5	5	No	4527	57277	905	11455	1	Direct estimation
Africa	Uganda	85	89	2000	DHS	50.7	4	Yes	23300	206968	5825	51742	0.5	Direct estimation
Africa	United Republic of Tanzania	104	94.1	1996	DHS	39.3	6	No	35119	891021	5853	148504	0.5	Direct estimation
Africa	Zambia	102	107.7	1996	DHS	42.2	9	No	10421	745317	1158	82813	1	Direct estimation
Africa	Zimbabwe	73	60	1999	DHS	32.1	10	No	12627	389055	1263	38905	1	Direct estimation
Americas	Argentina	17	17.6	1999	National source	19	24	No	37032	2736391	1543	114016	1	Vital statistics
Americas	Bolivia	59	61	2000	National source	29.3	9	No	8329	1069350	925	118817	1	Unknown
Americas	Brazil	35	49.5	1991	National source	19.7	4477	Yes	170406	8480395	38	1894	2	Indirect estimation

Continent	Country	National 2000 IMR from UNICEF	Other National IMR	IMR Base Year	IMR Source (abbr.)	National Crude Birth Rate	Units with IMR Data	Missing any IMR Data	popul-ation (000's; 2000)	area (sq km)	popul-ation (000's)/ IMR unit	area/IMR unit	Admin-istrative Level	Method - general
Americas	Canada	5	5.5	1997	National source	10.3	12	No	30757	9458886	2563	788240	1	Vital statistics
Americas	Chile	11	10	1999	National source	18.2	28	Yes	15211	721229	543	25758	1.5	Vital statistics
Americas	Colombia	20	24	2000	DHS	22.2	5	Yes	42105	1141569	8421	228314	0.5	Direct estimation
Americas	Costa Rica	10	11.8	1996	National source	19.1	7	No	4024	51015	575	7288	1	Vital statistics
Americas	Cuba	7	7	2000	National source	11.6	15	No	11199	111199	747	7413	1	Unknown
Americas	Dominican Republic	35	37	1999	DHS	23.3	8	No	8373	48092	1047	6011	0.5	Direct estimation
Americas	Ecuador	27	30	1999	National source	23	16	Yes	12646	246700	790	15419	1	Direct estimation
Americas	El Salvador	34	31	1999	NHDR	25.1	14	No	6278	20279	448	1448	1	Unknown
Americas	Guatemala	39	49	1999	DHS	34.2	8	No	11385	108523	1423	13565	0.5	Direct estimation
Americas	Haiti	81	89	2000	DHS	30.3	9	No	8142	26876	905	2986	1	Direct estimation
Americas	Mexico	25	24.9	2000	National source	22.4	2409	Yes	98872	1943018	41	807	2	Indirect estimation
Americas	Nicaragua	34	35	2001	DHS	31.6	17	No	5071	118279	298	6958	1	Direct estimation
Americas	Paraguay	26	36	1990	DHS	29.6	4	Yes	5496	395886	1374	98972	0.5	Direct estimation
Americas	Peru	32	33.6	2000	NHDR	23.3	25	No	25662	1289475	1026	51579	1	Indirect estimation
Americas	United States of America	7	7.2	1998	National source	14.5	51	Yes	283230	9210755	5554	180603	1	Vital statistics
Americas	Uruguay	15	17.8	1997	National source	16.8	19	No	3337	173985	176	9157	1	Vital statistics
Americas	Venezuela	20	20	1997	National source	22.8	22	Yes	24170	911559	1099	41434	1	Vital statistics
Asia	Armenia	32	44	2000	DHS	9.7	11	No	3787	28277	344	2571	1	Direct estimation
Asia	Bangladesh	54	79.7	1999	DHS	28.9	6	No	137439	136305	22907	22717	1	Direct estimation
Asia	Cambodia	95	92.7	2000	DHS	33.9	17	No	13104	179492	771	10558	0.75	Direct estimation
Asia	China	32	26.374	2000	National source	14.5	2367	Yes	1275133	9198103	539	3886	3	Indirect estimation
Asia	India	68	77	1991	NHDR	23.8	31	Yes	1008937	3209716	32546	103539	1	Unknown
Asia	Indonesia	35	47	1999	NHDR	20.7	26	No	212092	1898776	8157	73030	1	Indirect estimation
Asia	Iran (Islamic Republic of)	36	31.7	1996	NHDR	20.3	26	No	70330	1590351	2705	61167	1	Unknown
Asia	Jordan	28	29	1997	DHS	28	3	No	4913	88362	1638	29454	0.5	Direct estimation
Asia	Kazakhstan	60	61.9	1999	DHS	16.2	5	No	16172	2619352	3234	523870	0.5	Direct estimation
Asia	Lebanon	28	26	2000	MICS	19.1	5	No	3496	10328	699	2066	1	Indirect estimation
Asia	Mongolia	60	32.8	2000	National source	22.5	22	No	2533	1546294	115	70286	1	Unknown
Asia	Nepal	69	77	2001	DHS	32.9	5	No	23043	139087	4609	27817	1	Direct estimation
Asia	Pakistan	85	94	1991	DHS	35.9	4	Yes	141256	785320	35314	196330	1	Direct estimation
Asia	Philippines	30	36	1998	DHS	25.3	16	No	75653	295408	4728	18463	1	Direct estimation
Asia	Sri Lanka	17	13.3	2000	National source	16.4	25	No	18924	65830	757	2633	2	Vital statistics
Asia	Thailand	25	7	1997	NHDR	17.3	76	No	62806	513618	826	6758	1	Unknown
Asia	Turkey	38	48	1998	DHS	20.9	5	No	66668	768690	13334	153738	0.5	Direct estimation
Asia	Turkmenistan	75	72	2000	DHS	22.2	6	No	4737	460254	790	76709	1	Direct estimation
Asia	Uzbekistan	51	20	1999	NHDR	21.7	13	No	24881	412914	1914	31763	1	Unknown
Asia	Viet Nam	23	33.1	1999	NHDR	20.2	53	No	78137	328535	1474	6199	1	Indirect estimation
Asia	Yemen	84	80	1997	NHDR	45	17	Yes	18349	415196	1079	24423	1	Unknown
Europe	Russian Federation	18	15.3	2000	National source	8.6	85	Yes	145491	16679998	1712	196235	1	Vital statistics

Table 3
Moran's I for selected regions

region	I
Global	0.7533
Africa	0.6837
Asia	0.5976
Eurasia	0.6013
South Ame	0.8781
North Ame	0.6510
Mexico	0.5402

Table 4 Infant Mortality rates by biome	Infant mortality rates (per thousand live births)													
	Africa		Asia		South America		Europe		North America		Oceania		Total	
Biome	IMR	% of births in continent	IMR	% of births in continent	IMR	% of births in continent	IMR	% of births in continent	IMR	% of births in continent	IMR	% of births in continent	IMR	% of births in continent
Tropical and subtropical moist broadleaf forest	105.1	24.4%	54.0	42.2%	28.0	49.6%		0.0%	35.2	11.5%	58.6	39.7%	59.9	34.1%
Tropical and subtropical dry broadleaf forest	85.9	0.3%	67.0	11.2%	33.3	5.9%		0.0%	26.4	12.5%	18.0	1.4%	61.4	7.8%
Tropical and subtropical coniferous forest		0.0%	71.4	0.5%		0.0%		0.0%	35.3	12.7%		0.0%	44.7	1.1%
Temperate broadleaf and mixed forest		0.0%	23.7	20.2%	11.2	1.3%	8.9	69.6%	7.1	27.0%	6.0	44.4%	18.6	17.7%
Temperate conifer forest	37.2	0.2%	56.4	0.9%		0.0%	9.6	3.5%	7.0	7.1%		0.0%	29.5	1.2%
Boreal forest/Taiga		0.0%	38.5	0.0%		0.0%	13.6	4.7%	5.4	0.3%		0.0%	13.2	0.3%
Tropical and subtropical grassland, savanna, and shrubland	105.6	50.8%	70.2	0.5%	22.1	12.2%		0.0%	7.4	1.4%	11.6	2.2%	99.5	12.9%
Temperate grassland, savanna, and shrubland		0.0%	43.3	2.5%	16.0	6.5%	18.6	7.7%	6.9	9.6%	6.0	2.9%	28.0	2.9%
Flooded grassland and savanna	50.9	4.9%	33.8	0.3%	18.5	1.0%	20.4	0.2%	7.5	0.6%		0.0%	45.8	1.4%
Montane grassland and shrubland	102.0	8.7%	66.3	1.1%	40.1	3.7%	26.9	0.0%		0.0%	47.2	0.4%	89.6	2.9%
Tundra		0.0%		0.0%		0.0%	11.9	0.3%	6.0	0.0%		0.0%	11.3	0.0%
Mediterranean forest, woodland, and scrub	34.5	5.8%	28.4	1.5%	10.7	2.1%	6.1	13.8%	6.9	4.9%	6.0	8.3%	23.0	3.5%
Deserts and xeric shrubland	61.3	3.7%	75.7	17.5%	36.8	15.5%	20.7	0.1%	18.9	11.8%	5.9	0.6%	68.6	12.8%
Mangrove	112.0	1.2%	52.6	1.7%	37.2	2.2%		0.0%	24.7	0.5%	69.4	0.1%	62.3	1.4%
Total	96.6	100.0%	52.7	100.0%	28.1	100.0%	9.6	100.0%	17.8	100.0%	27.4	100.0%	56.7	100.0%