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ENVIRONMENT AND NATURAL RESOURCES WORKING PAPER

[ GEO-SPATIAL DATA AND INFORMATION ] ENVIRONMENTAL MANAGEMENT ASSESSMENT AND MONITORING GLOBAL ENVIRONMENTAL CHANGE

# Mapping global urban and rural population distributions

## Estimates of future global population distribution to 2015

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# Annex
# Estimates of future global population distribution to 2015

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Acknowledgments for this annex

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http://sedac.ciesin.columbia.edu/gpw
http://www.fao.org/geonetwork/srv/en/main.search
http://povertymap.net/

ANNEX

# 1. INTRODUCTION

There is considerable interest in the future distribution of human population. The United Nations Population Division produces biannual updates to its medium-term projections of population (UN, 2003) to insure that researchers and policy makers have the most recent information upon which to base their analysis and policies. The UN (and other projection–making organizations, see review in O'Neill *et al.*, 2001) project population at the national level only, despite the fact that there is evidence to believe that future population growth, on average, is more likely to occur in urban areas than rural ones (e.g. UN, 2002). A recent National Research Council study has called for much greater attention to be paid toward understanding spatial issues in understanding future urbanization (NRC, 2003). In the near term, however, there are no formal demographic forecasts of population that are spatially explicit. This exercise is a stop–gap measure to address a short-term scenario: If the current rates of population growth, as observed in the decade prior to 2000, continue for 15 years, what would the distribution of population look like in the year 2015?

The *Gridded Population of the World: Future Estimates, 2015 (GPW2015)* provides estimates of the world's population, by country and continent, for the year 2015 and converts the distribution of human population from sub-national units to a series of 2.5 arc-minute quadrilateral grids. This 2015 data product is entirely derived from the spatial and population input data used to construct the Gridded Population of the World version 3 (GPWv3) (CIESIN and CIAT, 2005). This is comprised of administrative boundary and associated population data.

The 2015 gridded population data was derived from almost 400,000 administrative units. For most countries of the world, roughly 75 percent of them, subnational estimates of population from the two most recent censuses (c. 1990 and 2000) were used as the basis of the extrapolation. Sub-national rates of growth for the 1990–2000 interval were then applied, in five–year increments, as described in more detail below. Population estimates are projected to the year 2015 using the same simple extrapolation methods as the GPWv3 and prior GPW databases (Deichmann, Balk and Yetman, 2001; Tobler *et al.*, 1997).

The purpose of our 2015 projection is to show a scenario of future spatial distribution for the population at a subnational resolution. However, it assumes a continuation of recent demographic patterns and is not suitable for generating national population totals in and of itself. The UN method for projecting population (UN, 2001) follows a cohort-component methodology and incorporates more information about the baseline population (e.g. age structure) and future population trends (e.g. expected fertility and mortality). Therefore, our 2015 total population estimates are adjusted at the national level to the United Nations 2015 population projections.

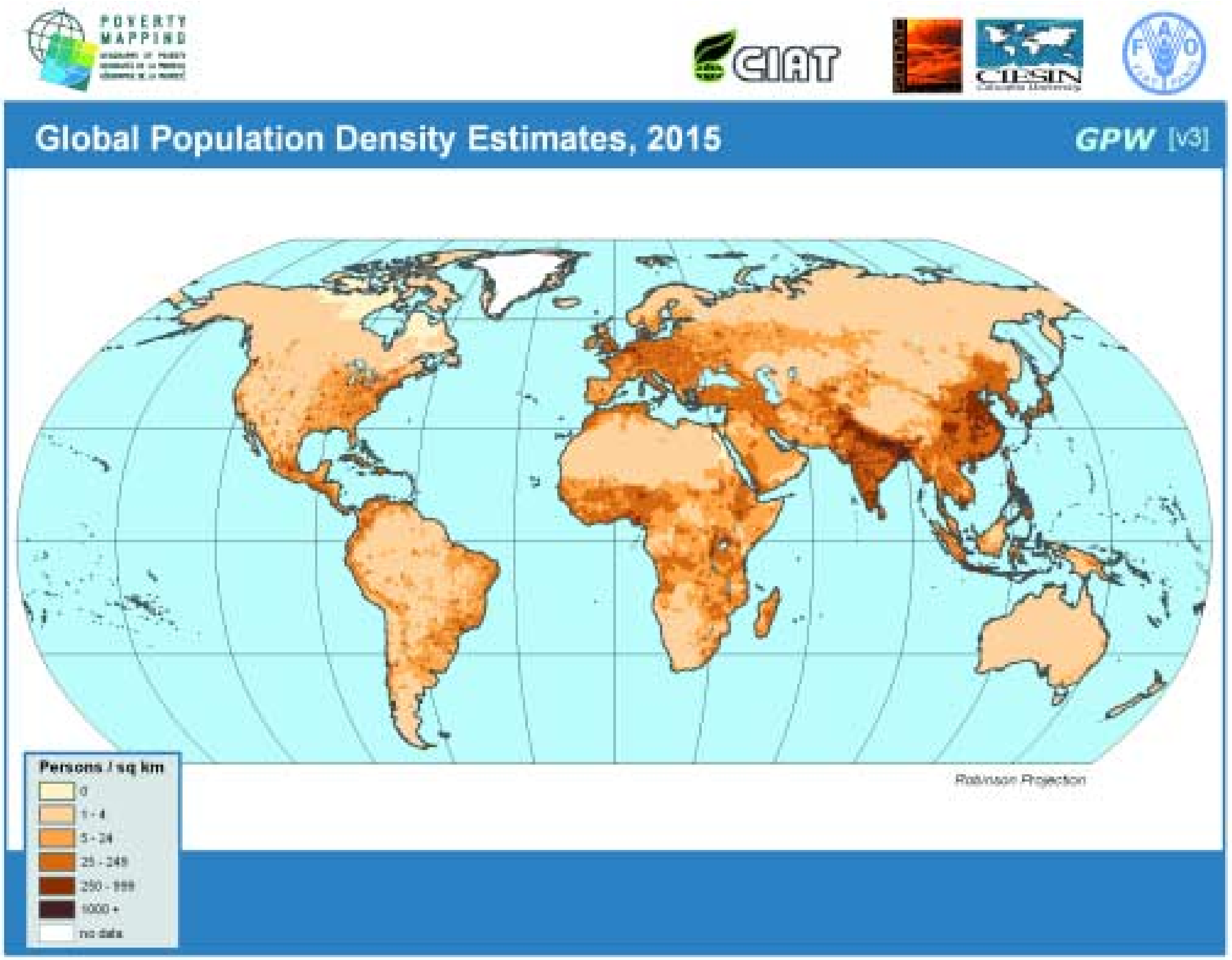
An adjustment factor (A) is applied to our administrative unit population totals ($Pop_{NSO2015}$) via the following calculation, where $Pop_{UN2015}$ represents the UN medium variant projected population for 2015:

$$A = 1 + \frac{(Pop_{UN\ 2015} - Pop_{NSO\ 2015})}{Pop_{NSO\ 2015}}$$

The results of this method are shown in Map 1.1. As in the present, the most densely populated places are south and southeast Asia. Similarly, there are expected to be very densely populated regions of Africa (notably in Nigeria, and east Africa), in Brazil, parts of Central America (including an already dense Mexico City region) and North America (particularly the coastal portions of the urban north east and Los Angeles areas). Europe also continues to be densely populated.

MAP 1.1

**Global population density in 2015**




*Source:* Center for International Earth Science Information Network (CIESIN), Columbia University; Food and Agricultural Organization (FAO) and Centro Internacional de Agricultura Tropical (CIAT)

ANNEX

# 2. INPUT DATA DESCRIPTION

As previously stated, the input data for the 2015 database mirrors that in GPWv3. The specificity of these inputs varies greatly by country due to factors such as: date of most recent census, administrative level at which population and spatial data are released, degree to which the boundaries and population inputs match spatially, the relationship between the number of administrative units and the country land area, among other influences. All inputs are divided between two categories: boundary data and population data, as described in more detail below.

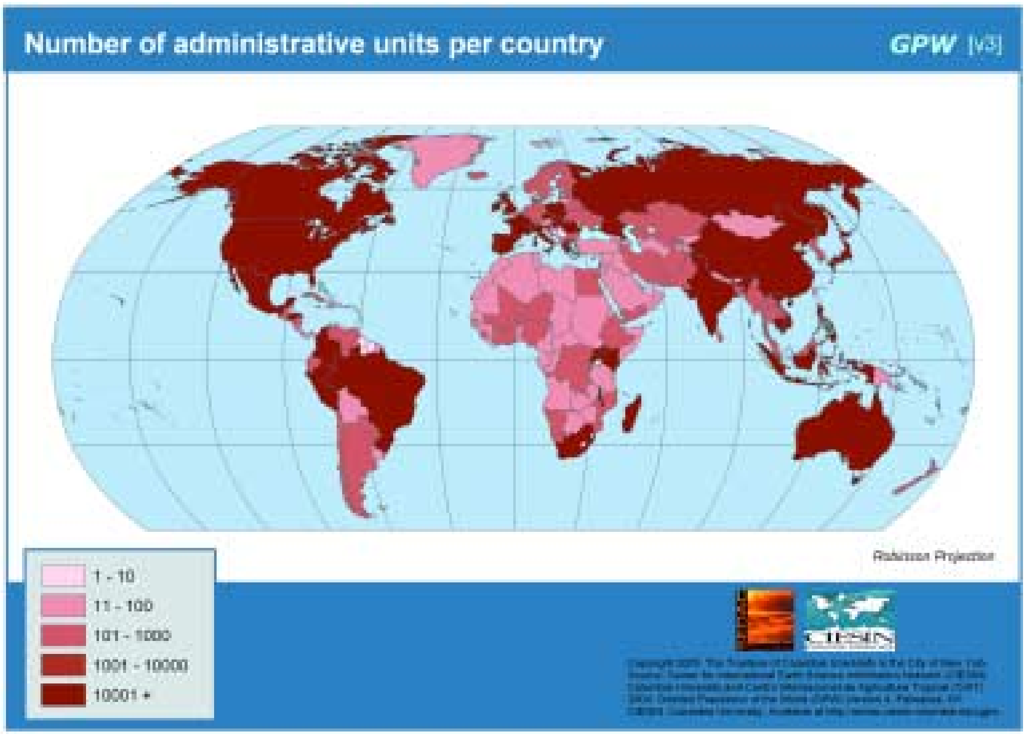
## 2.1 BOUNDARY INPUT SOURCES

Geographic Information System (GIS) data sets of either administrative or statistical (census) reporting units are produced by national statistical and mapping agencies, research projects, and commercial data vendors. GPWv3 relied on a combination of publicly available boundary data sets and additional boundaries from commercial data vendors or statistical agencies that sell spatial data on license. The level of the spatial inputs utilized in GPWv3 was constrained to the level for which matching population data was available, which varies substantially by country. Levels are commonly ranked from low to high, where the lowest level (level one), refers to the first subnational administrative level below the national one, with higher levels representing subsequently finer administrative levels within each country.

In general, while there is no consistent pattern between countries with regard to the number of administrative units, there tend to be higher levels available for more developed countries. Differences in administrative levels that can be used to generate our estimates are due in part, to data availability – i.e., population and spatial inputs for the highest-level units are not always available or usable. In addition, the designation of administrative units is sometimes ambiguous. Often, administrative units are based on historic boundaries that are based on geographic and political features that were once historically important but which no longer translate to necessarily meaningful divisions. It also should be noted that for statistical data-reporting, some countries utilize geographic regions that serve no administrative purpose and therefore do not match the administrative boundaries. As demonstrated by Map 2.1, the number of administrative units included in GPWv3 varies greatly between countries and is not necessarily proportional to the land area of a nation.

MAP 2.1

**Number of administrative units included in GPWv3, by country**




The degree of resolution of administrative units provides a good representation of this variability in the number of administrative units. Resolution is calculated as:

$$\sqrt{\text{(country area) / (number of units)}}$$

Resolution is to some extent determined by the geographic size and average population density of a country. Smaller countries have a relatively higher resolution even before adjusting for the number of administrative units. In other words, the national extent of a small country may already be smaller than an administrative unit of another country. Slovenia is an example of a small country with one of the highest resolutions both because of geographic size and number of units. Conversely, many countries with vast, mostly uninhabited areas tend to have large administrative units resulting in very low resolution (e.g. Mongolia, Libya).

Additionally, the presence of relatively densely distributed populations generally necessitates a larger number of administrative units than a more sparsely populated country of equivalent size. This results in higher relative resolution. For example, India is much more densely populated and has higher resolution than similarly sized, but sparsely populated Algeria.

Low resolution can be a result of inadequate data, in which higher resolution administrative units boundaries exist, but were simply not available for this project. It can also stem from a combination of data quality, geographic and population density issues. As a comparison, Mongolia and Saudi Arabia have similarly low resolution, but for different reasons.

These two countries are similar in geographic size, but Mongolia has approximately one tenth the population size of Saudi Arabia. The measure of average persons per administrative unit for Mongolia was 108 in 2000, but 672 in Saudi Arabia. Since we would expect higher resolution in more highly populated areas, the data quality for Saudi Arabia is considered to be inferior to that of Mongolia. For Saudi Arabia, more detailed administrative units would help considerably in the precise representation of population distribution.

Table 2.1 demonstrates the countries with the highest and the lowest available resolution (excluding countries and areas smaller than 10,000 square kilometres in size, many of which consist of only one administrative unit).

TABLE 2.1

**Countries with the highest and lowest available resolution**

| 10 lowest resolutions | Km | 10 highest resolutions | Km |
|---|---|---|---|
| Saudi Arabia | 386 | Slovenia | 0.01 |
| Chad | 298 | Malawi | 1.84 |
| Mongolia | 265 | Switzerland | 3.21 |
| Angola | 264 | South Africa | 3.54 |
| Libyan Arab Jamahiriya | 254 | France | 3.66 |
| Svalbard | 246 | Slovakia | 3.87 |
| Algeria | 219 | Ireland | 4.09 |
| Sudan | 171 | Portugal | 4.49 |
| Yugoslavia | 159 | Indonesia | 4.65 |
| Botswana | 156 | Hungary | 5.23 |

Within a given country, the mean resolution (across administrative units) depends considerably on a combination of geographic and demographic characteristics, some of which have been described above. Thus, mean resolutions are not always comparable between countries. For example, level-three administrative units in Canada can vary from a small, densely populated city-district to large tracts of uninhabited land whereas the same administrative level in the continental United States varies much less in area.

By continent, the average level and total number of administrative units used are shown in Table 2.2. There are clear differences, with Europe, Oceania, and North America having higher average resolutions. All continents, however, have some countries with high-resolution data, leading to a large number of units for each continent. As compared to the first version of GPW, undertaken a decade ago, there is nearly a 20 times improvement in GPWv3.

TABLE 2.2

**Average level and total number of administrative units, by continent**

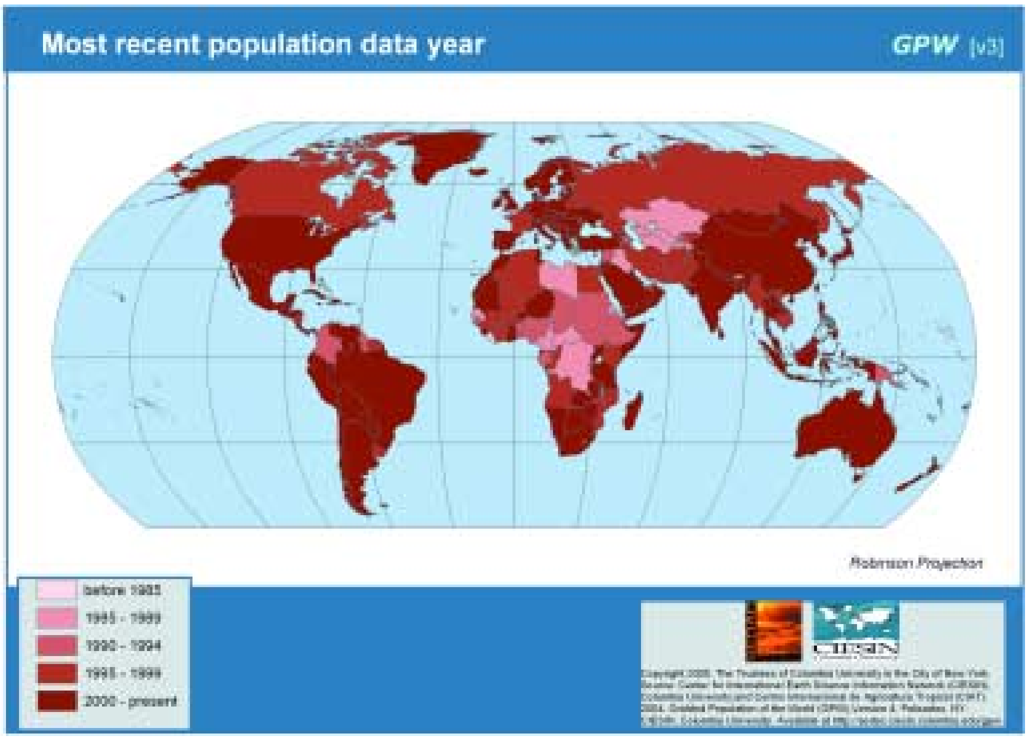
| 10 lowest resolutions | Mode of administrative Levels | Sum of the Number of units | Average Resolution | Average Persons per unit |
|---|---|---|---|---|
| Africa | 2 | 109,172 | 16 | 7 |
| Asia | 2 | 99,781 | 18 | 36 |
| Europe | 2 | 98,926 | 15 | 7 |
| North america | 2 | 74,527 | 17 | 6 |
| Oceania | 1 | 2,191 | 62 | 14 |
| South america | 2 | 15,150 | 34 | 22 |
| World total | 2 | 399,747 | 18 | 15 |

## 2.2 POPULATION INPUT SOURCES

Population data were collected for each country via national statistical agencies and census bureaus. The most recent year and most detailed administrative level were acquired whenever possible. A large portion of the data was publicly available, however it was also necessary to purchase population information for many areas. Population data constraints such as censuses occurring in different years and inconsistent data availability result in disparities related to the most recent population data year employed for each country. This is illustrated by Map 2.2 below.

MAP 2.2

**Year of the most recent census data available, by country**



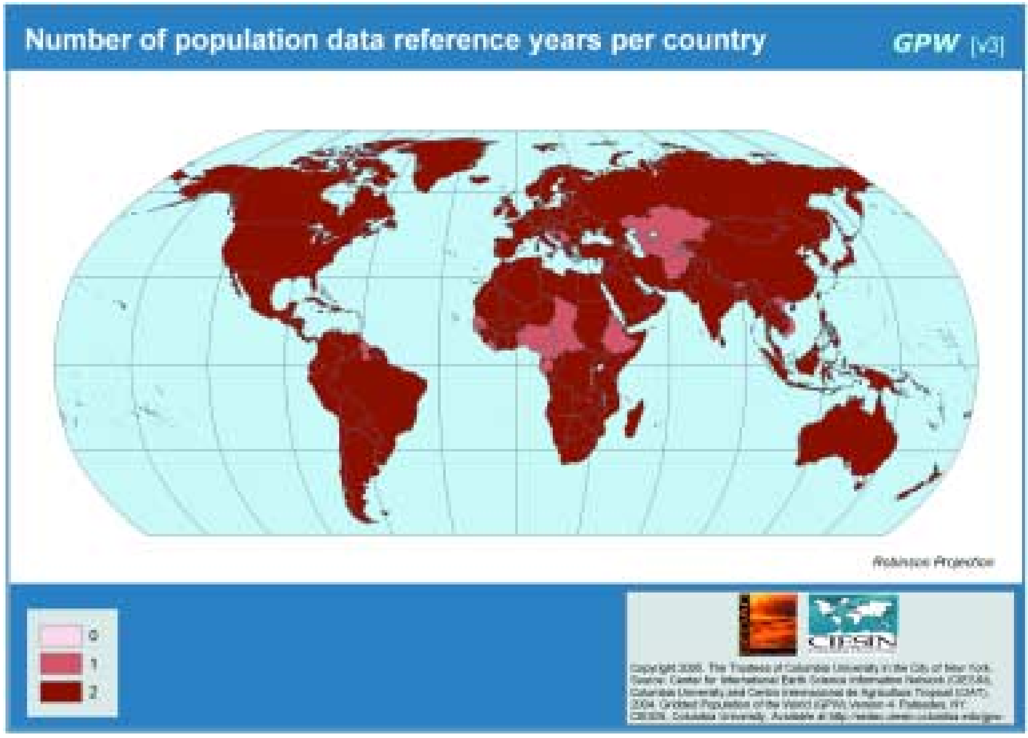
Where possible, two data points were collected as close to the target years of 1990 and 2000 as possible. Obviously, the closer the data points were to 1990 and 2000, the less interpolation was required.

The greatest source of uncertainty in the dataset occurred in cases where the available population data was far from the target years, and where only one population data year was available.

Countries with only one data point occurred most often in areas where new data obtained for GPWv3 was at a higher spatial resolution than in past GPW iterations, thus affecting our extrapolation method (see section 3.2). Map 2.3 displays the number of population data years employed globally.

MAP 2.3

**Number of population data years employed, by country**



# 3. METHODOLOGY

In the following paragraphs we describe the methodology used to create the *GPW2015*, both in terms of the gridding approach used to produce the final raster grids, and in terms of the extrapolation methodology used to calculate the population distribution in 2015.

## 3.1 THE GRIDDING APPROACH

The GPWv3 administrative and population input data were used to produce raster grids demonstrating the estimated number of people residing in each grid cell. When the administrative units are converted to grids it is possible for more than one unit to fall into the same grid cell and for some units to be smaller than a single grid cell. To ensure that no administrative information is lost in the gridding process, we implemented a proportional allocation of population from administrative units to grid cells. Proportional allocation works on the assumption that the variable being modelled – in this case population – is distributed evenly over the administrative unit. Grid cells are assigned a portion of the total population for the administrative unit they fall within, dependent on the proportion of the area of administrative unit that the grid cell takes up. A simple example of proportional allocation (also known as areal weighting) would be an administrative unit with a population of 5 000 that is filled exactly with 100 grid cells. For this case, each grid cell would be assigned a population of 50. In the creation of the population grids, the actual implementation of areal weighting uses the administrative unit's population density and the area of overlap between administrative unit and grid cell to calculate each unit's contribution to the cell population total (further description is given in Deichmann *et al.*, 2001, and a comparison between this and other methods is given in Deichmann, 1996).

## 3.2 EXTRAPOLATION METHODOLOGY

The methodology for the extrapolation of population data to 2015 is similar to that used for extrapolating population data in GPWv3 to 1990, 1995, and 2000. In both instances, the population inputs were collected for the most recent years and smallest sub-national units. The majority of these data were obtained via national censuses or official estimates. For the *GPW2015*, the official population estimates were then extrapolated forward by computing an average annual geometric growth rate that was then applied to the most recent population data. Because population numbers do not typically rise or fall in a linear fashion, a geometric growth rate was calculated for these estimates.

The formula employed for calculating the growth rate is:

$$r = \frac{LN\,[(P_2/P_1)]}{(t_2 - t_1)}$$

where, LN = the natural log, P1 and P2= population counts for the first and second reference years, $t_1$ and $t_2$ = time periods 1 and 2.

The forward extrapolations are thereby computed with the following formula:

$$e^{rt} * P_1$$

where, r= the geometric growth rate (as defined above), t= the number of years the initial estimate will be projected forward/backward, $P_1$= population counts for the first reference year.

These extrapolations are not meant to be formal projections. As indicated initially, this is an extrapolation method that is commonly used for short-term projections and is not typically employed for longer-term projections because it lacks information useful for the longer-term adjustments to population composition and dynamics. The growth rates are held constant and the populations are accordingly estimated for 2015 without the aid of additional information. In the next section, we address when and under what circumstances adjustments – beyond that of adjusting the national population totals to the UN medium-run project – were made.

# 4. EXTRAPOLATION PROBLEMS AND SOLUTIONS

In a number of instances, outstanding obstacles impeded our use of the above methodology for growth rate and projection calculations. Problems were dealt with on a case-by-case basis. Descriptions of the setbacks we encountered and explanations of our solution procedures are described below.

## 4.1 IRRECONCILABLE BOUNDARY DIFFERENCES

In general, geographic boundaries are not static. Unfortunately, however, if an administrative unit changes size or shape between two data years it is impossible to use the above method to calculate a population growth rate for that particular unit. Thus, when faced with irreconcilable boundary differences between two data years, we implemented a three-tiered approach for determining a growth rate to be used in the population projections:

(a) Whenever viable, we created hybrids of the administrative unit polygons (and their associated population figures) in order to form matching subnational datasets for two time periods. In instances where hybrids were created, our administrative units do not match those politically defined by the country of origin, but are still spatially and demographically accurate.

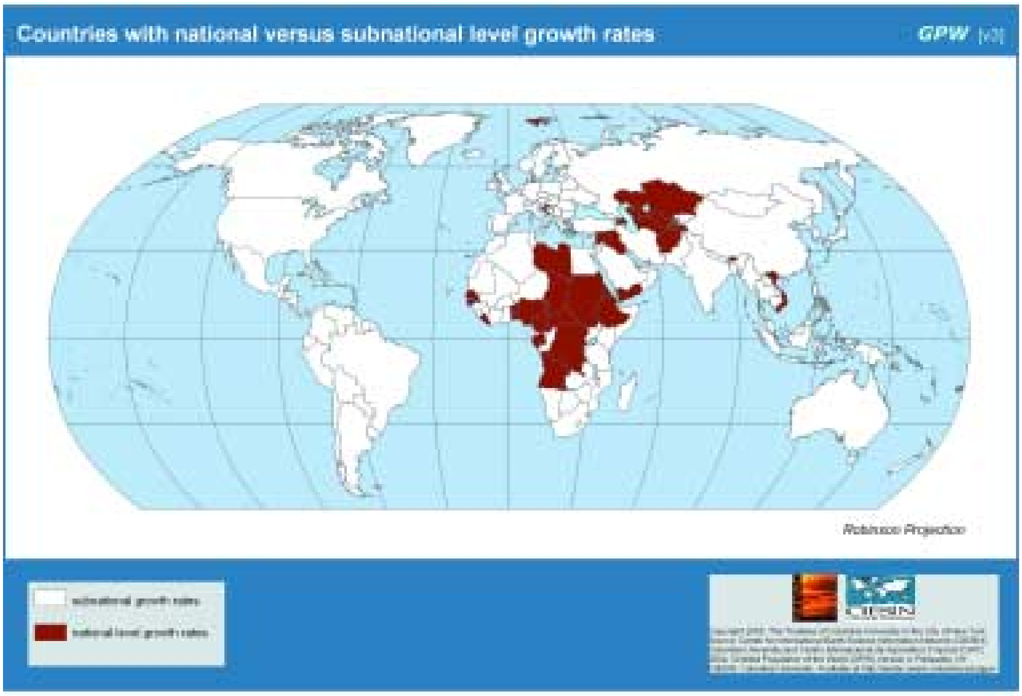
(b) If a polygon-based hybrid was impractical, the next step was to consider using a coarser administrative level to calculate the growth rate. For example, if there were substantial boundary changes at the second administrative level, but the first administrative level remained unchanged, then a growth rate was computed at the first administrative level and applied to the higher resolution data.

(c) When neither option (a) nor (b) were feasible, national level growth rates were calculated using United Nations population estimates and projections (UN, 2001). These rates were then uniformly applied to the most detailed and recent subnational data at our disposal. In cases were we suspected the data to be largely erroneous, United Nations derived growth rates were implemented as well.

Map 4.1 illustrates countries for which we used subnational growth rates or, where necessary, national growth rates.

MAP 4.1

**Number of countries for which sub-national versus national growth rates were used**




## 4.2 MIXED ADMINISTRATIVE LEVEL SPATIAL AND POPULATION DATA

Administrative and population data are often collected and released by separate governmental offices as well as in unconnected years. Because the two types of data are not published together, a matched dataset at the lowest available administrative level may be unattainable. In this situation, two potential data scenarios occur:

(a) *The population data are at a smaller administrative level than the spatial data*. When this situation transpired, it was necessary to aggregate the population data to the coarser level of the spatial data. As a result, we were unable to use the more detailed level of population data and will continue to be incapable of doing so until spatial data are made available at the same level. For example, if we had population estimates for the Delaware counties of Kent, New Castle, and Sussex but only had spatial boundaries for the state of Delaware, it would be necessary to combine the population figures up to the state level.

*or*

(b) *The spatial data are at a smaller administrative level than the population data*. Under these circumstances, the population growth rate for the larger unit could be applied to the smaller spatial units it encompassed. In this scenario, the more detailed geographic level was maintained. For example, if we only had population estimates for the state of Delaware but had spatial boundaries for counties of Kent, New Castle, and Sussex, we could calculate a Delaware growth rate and apply this same rate to each of the three counties.

### 4.3 PARTICULARLY HIGH POPULATION GROWTH RATES

Local area estimates of population are bound to have higher levels of error than larger units: rapid growth appearing in a small region would be absorbed by estimates of a larger region; and small area rates of growth may be unlikely to persist in the long-run. Rather, they may be localized in space and time. Even over a ten-year period highly localized growth may not be sustained. Thus, there is an optimal level of the administrative data at which to apply rates of growth, neither too coarse nor too fine. In general, if a country has very high-resolution data (such as level four or five), we do not use that information as the basis of the growth rate, rather we use a coarser unit (e.g., counties rather than tracts in the US) and apply those growth rates for the units that nest beneath it.

We used a benchmark growth rate of five percent, because such a high level of growth is unusual for large administrative units (e.g. countries). Similar benchmarks have been implemented by the World Bank in a comparable exercise, in the *World Development Report* (WDR, 2002).

(a) If population growth rates were higher than five percent for *less than* ten percent of all administrative units in a given country, growth rates were manually set to the five percent benchmark for the administrative units concerned.

(b) If population growth rates were higher than five percent for *more than* ten percent of all administrative units in a given country, we suspected that the data were too flawed or unreliable to use; and United Nations–derived growth rates were implemented as explained in section 4.1c of this annex.

ANNEX

# 5. CONCLUSION

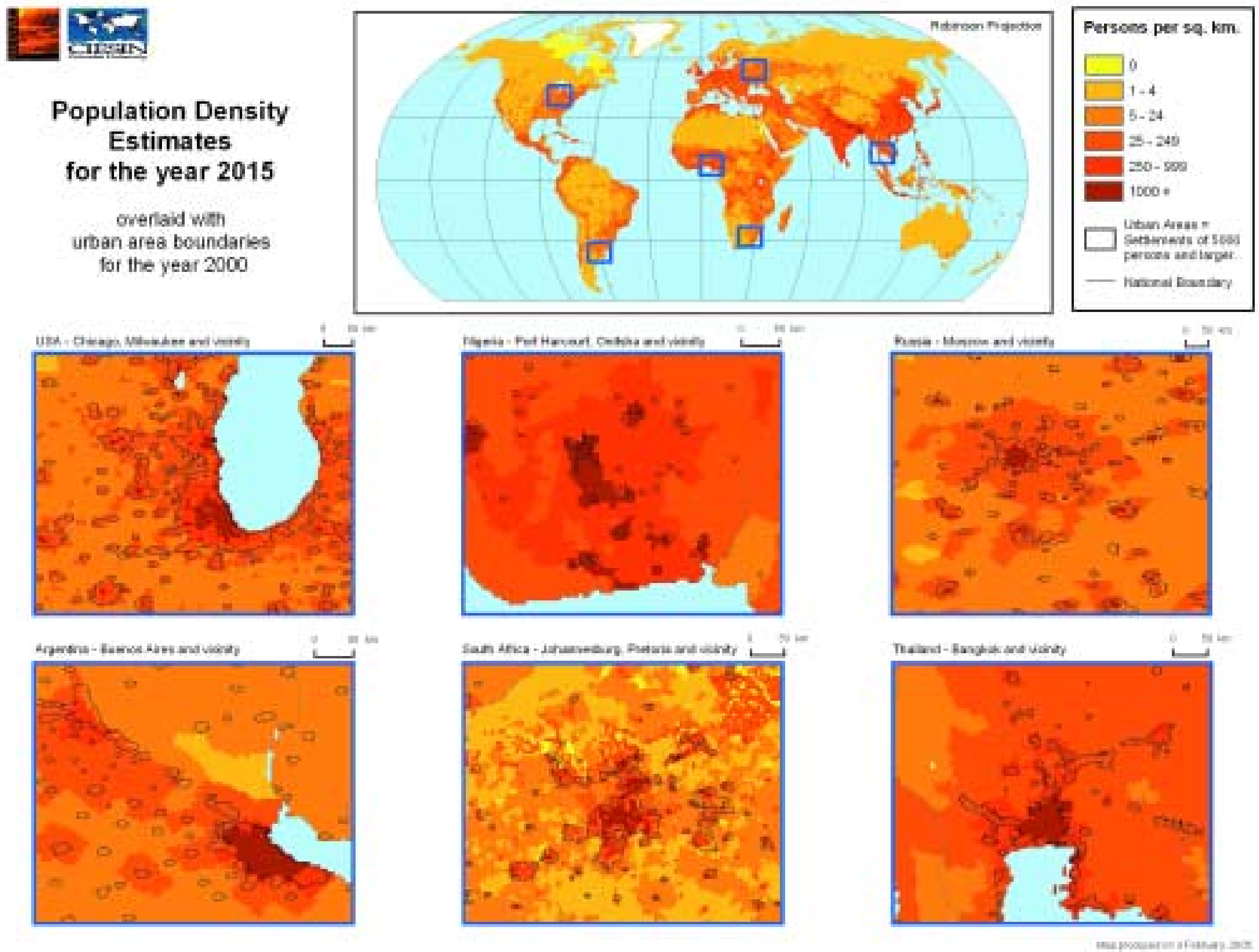
The *Gridded Population of the World: Future Estimates, 2015* is a useful tool in conjunction with the UN 2015 projections as it shows a future scenario of the spatial distribution of populations. As already stated outright, this method has limitations for even short-run forecasting. Future investments should include further data development such that more rigorous estimates of future population, along with estimates of associated uncertainty, can be made at a subnational level.

When shown with urban area extents for 2000, it is possible to see how the urban areas might grow over the next decade both in spatial extent and in population density compared to the year 2000. Map 5.1 shows scenarios for select urban areas from CIESIN's Global Rural-Urban Mapping Project database. They clearly emerge as much more densely populated than surrounding rural areas. Further improvements in resolution to the underlying population and boundary data will make it possible to gain greater insight in the expected future population of urban areas, and current and future peri-urban areas.

Data constraints result in varying degrees of accuracy in the projected estimates between countries, making comparisons difficult in some circumstances, particularly for parts of Africa and Asia – two regions of high concern for future urban and rural development. Recent investments in more timely, high-resolution, reliable population and boundary data have been made in many countries, such as Malawi, South Africa, Cambodia, Indonesia and Kenya. Using these countries as models for other nations in the same regions to follow, would go a long way to contributing to regional and global efforts to understand current and future population dynamics in urban and rural areas.

MAP 5.1

**Population density projections for the year 2015 with a focus on selected urban areas**



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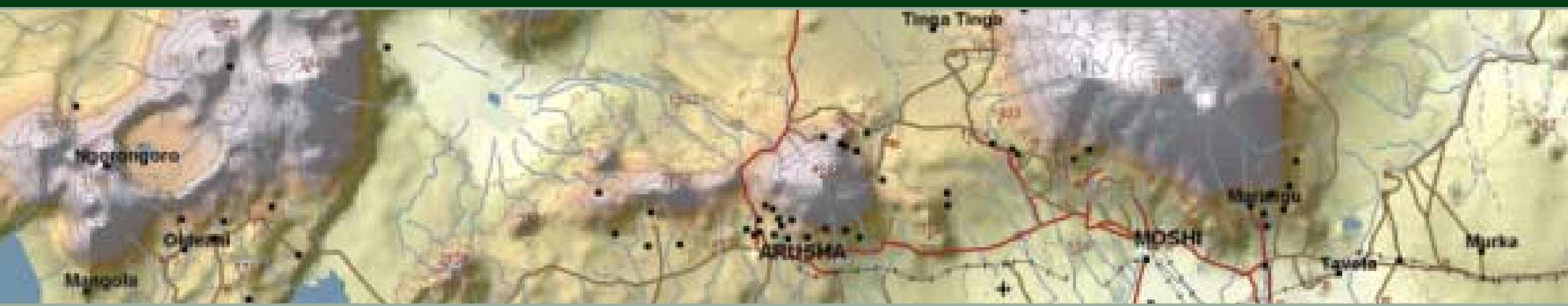
This monograph is part of a series of reports that explain and illustrate methods for applying spatial analysis techniques to investigate poverty and environment links worldwide. Analysing population distribution in relation to poverty and environmental factors is increasingly recognized as a valuable element in decision-making processes related to development issues. Accurately mapping and assessing vulnerable populations can provide a solid basis for recommendations on how best to reduce poverty and improve living conditions in developing countries.

In this report, the various definitions of the terms ‘urban’ and ‘rural’ are reviewed, along with data from the United Nations and other sources, and various georeferenced sources are assessed for their usefulness to the geospatial analysis of population distribution. The report examines two widely used global georeferenced population datasets, reviews recent methodological developments for distinguishing urban and rural populations spatially and presents a method for creating an urban mask and determining variations in the distribution of urban and rural populations, by pixel. The report concludes with a brief discussion of unresolved issues and future challenges. Finally, the Annex details a method for estimating global population distribution to the year 2015 using data from over 375 000 subnational units.

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