Background Paper prepared for the Global Assessment Report on Disaster Risk Reduction 2013

Global Exposure Database for GAR 2013

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Global Assessment Report on Disaster Risk Reduction - GAR 2013

Contents

Introduction

Exposure is the collection of the elements at risk that are subject to potential losses (ISDR 2009a) or that may suffer damage due to the hazard impact. Disasters risk assessment models use building counts, as well as statistic aggregations of buildings at different areal units, for physical damage estimations.

The Global Exposure Database for GAR 2013 or simply GED-13[1], *aims to create an open global building and population inventory suitable mainly for earthquake and cyclones probabilistic risk modeling using the CAPRA[2] platform.*

The development of GED -13 is based on a top-down or "downscaling" approach where national/regional socio-economic, and building type information are transposed onto a regular grid using a geographic population distribution model as proxy.

The GED-13 is composed by five essential thematic elements (See Figure 1).

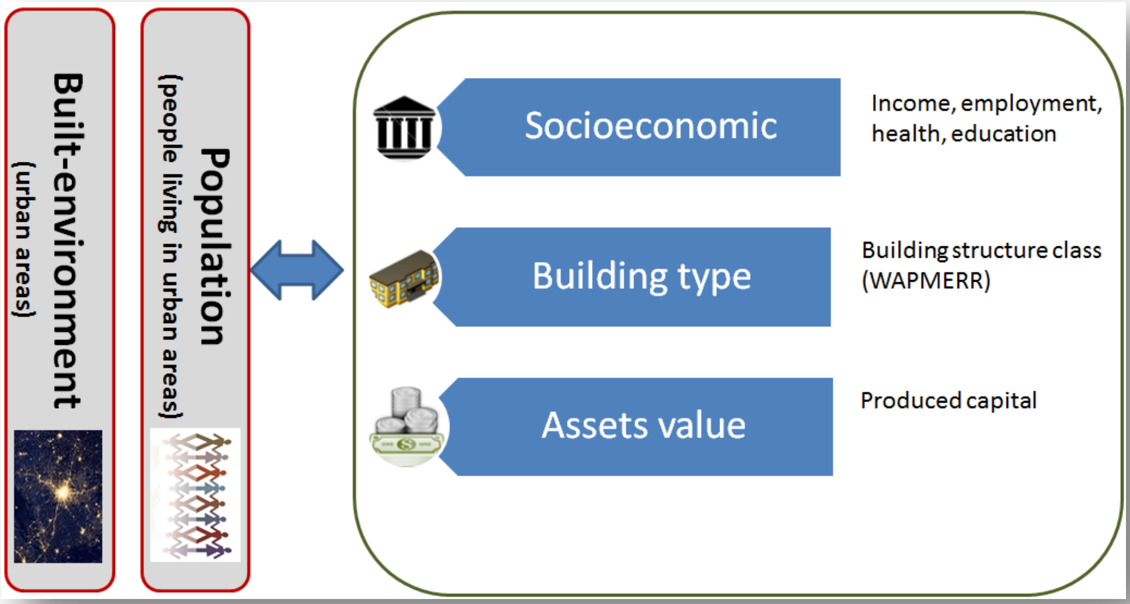

Figure 1 the five thematic main components of GED-13

The Built-environment (urban areas) and the Population constitute the geospatial elements of the database, the first element includes the delimitation of the analyzed surfaces and the second one the number of people living in those areas. The socio-economic part incorporates four sectors: income, employment, health and education. The building type information for each country and settlement size corresponds to the classification used by WAPMERR (2012). The assets value represents the value of the infrastructure, machinery, and, building contained in an urban area within a country. Once disaggregated at cell level, the assets value is then redistributed in a proportional way across the different elements (socioeconomic and building type) of the GED-13

[1] The GED-13 is named BDEM in the CIMNE Technical report (CIMNE, 2013)
[2] http://www.ecapra.org

Spatial analyses have been carried at 30'' resolution (around 1km at equator) and the final output has been transposed onto a global reference grid of approximately 5x5 km with the aim to reduce the size of the database (number of records) as well as reducing the time for further calculations. Moreover given that most of the original data have been disaggregated from a national scale, a resolution of 5km seems more realistic, than a finer one. Finally this resolution is enough accurate to calculate risk for earthquakes and cyclones hazards.

The exposure is represented as a value of a group of buildings in each 5x5 km cell. The four socio-economic sectors were used for estimating the characteristics of the buildings at sub-national level in accordance with the size of each urban area. The distribution of building type is related with the population that lives in each typology and not with the number of buildings in each one of the construction types. The produced capital (assets value) is distributed for each sector and building type per each cell of the 5x5 km grid, according to the relative people who are living inside, taking also into account two supplementary elements: the occupation density and the unitary cost per sector.

This report is complementary to those created by CIMNE team (CIMNE, 2013) and it will focus especially on:

- Describe the sources of geospatial and of socio-economic data
- Explain the methodology and algorithms used to develop geospatial data
- Underline the approach(s) used to estimate missing data
- Show the overall data workflow

Please refer to the CIMNE (2013) technical report for a detailed description of algorithms used to integrate the socio economic indicators in the GED-13,

Built-up environment and population

Introduction

To clearly and univocally define an urban area is not a trivial task, especially at global scale. The UN Population Division in the World Urbanization Prospectus not uses their definition of urban population but follows those proposed by each country. An Urban agglomeration refers to "the population contained within the contours of a contiguous territory inhabited at urban density levels without regard to administrative boundaries". The "urban density" in turns is not clearly delineated and often is related to the country definition. A density greater than 500 inhabitants per km2 is utilized as threshold to delimitate urban agglomerations by Eurostat.

In our contest, the more plausibly definition at global scale is those based on physical attributes: urban areas are places that are dominated by the "built environment". The built environment includes all non-vegetative, human-constructed elements, such as buildings, roads, runways, etc. (i.e. a mix of human-made surfaces and materials), and 'dominated' implies coverage greater than or equal to 50% of a given landscape unit. (Schneider 2010)

Finally, in this contest when we bear on urban areas or urban agglomerations we implicitly refer to the above definition of built-up environment.

Data sources

Built-up environment

At present time, “The MODIS 500-m global map of urban extent “ or “MODIS500, processed by Schneider et al, (2009) represents the best spatially consistent, standardized and medium scale global information layer to delimitate the built environment.

For future developments, a very interesting alternative could be find in the Global Human Settlement Layer (GHSL) developed and maintained by the Joint Research Centre (JRC)[3], once its process will be achieved.

The “urban area” class from MODIS 500 were selected and used as reference to build the urban mask for GED; it will be successively employed to extract the population living in those areas.

Gridded population distribution

Gridded population datasets is an another way to model and represents the distribution of people on the earth surface, based on a regular grid, where each cell indicate the number of people living on it

Presently only three (complete) global gridded population data sets are available: LandScan developed by The Oak Ridge National Laboratories (ORNL), (Bright, 2002; Budhendra et al., 2002), GPW and GRUMP from SEDAC (2012). LandScan refers to the concept of “ambient population”, a time-weighted average (over 24 hours) of the number of people in each cell, while other grids usually locate each person in his/her dwelling. LandScan, does not use very high-resolution population input data, but uses an extensive model to reallocate people on a 30 arc second grid (approx. 1km equator) on global scale coverage.

LandScan is a reasonable option for GED needs, indeed, we already used it since the 2007 edition of GAR, but we have to keep in mind that, it has two main, not negligible, inconveniences:

- The in-deep methodology and complete algorithms are not published.
- Its license does not allow it to be distributed, such as all other GAR datasets, to the public domain.

Following the same methodology used in the past edition of GAR, the population figures in LandScan were adjusted to match with UN official data and re-calculated for years 2007 and 2010. Most of socio-economic data that will be further employed in GED refers to 2007. For this reason also population data in LandScan will be set to 2007.

Refine the” urban mask”

The “urban area” class from MODIS500 were selected and used as reference to build the urban mask this mask will be successively employed to extract the population living in those areas.

[3] http://ghslsys.jrc.ec.europa.eu/index.php

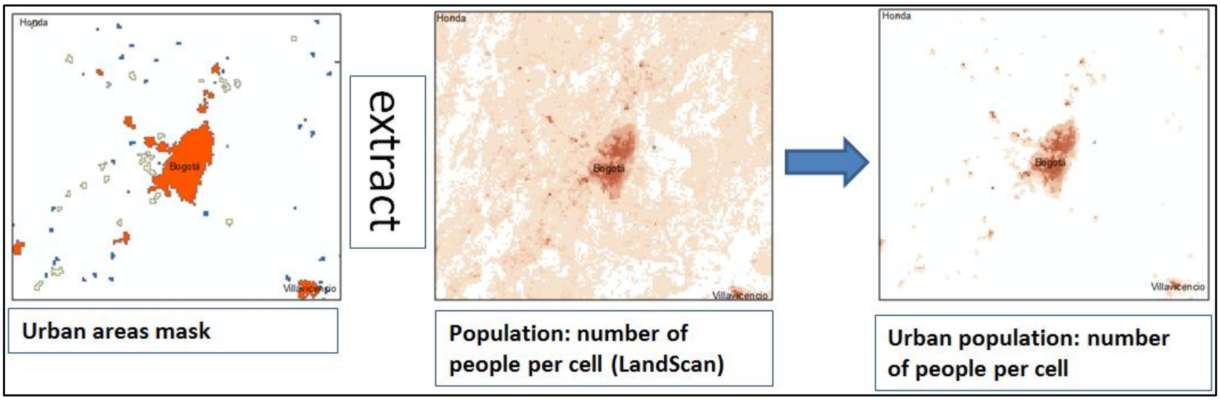

Figure 2from total to population living in urban area (region of Bogotá, Colombia)

The following figure illustrates respectively the urban mask (blue) and the contiguous cells that contain at least 500 inhabitants for the region of Dhaka in Bangladesh and Paris. Results for Paris and more generally for all OECD countries and most of developing countries are satisfactory: the urban mask fit more than 90% cells containing at least 500 inhabitants (red). Worst correspondence has been founded especially in Bangladesh where large sectors highly density populated remains excluded from “urban areas” by MODIS500 mask. This is principally related to remote sensing incertitude, together probably with a different downscaling approach used during LandScan development.

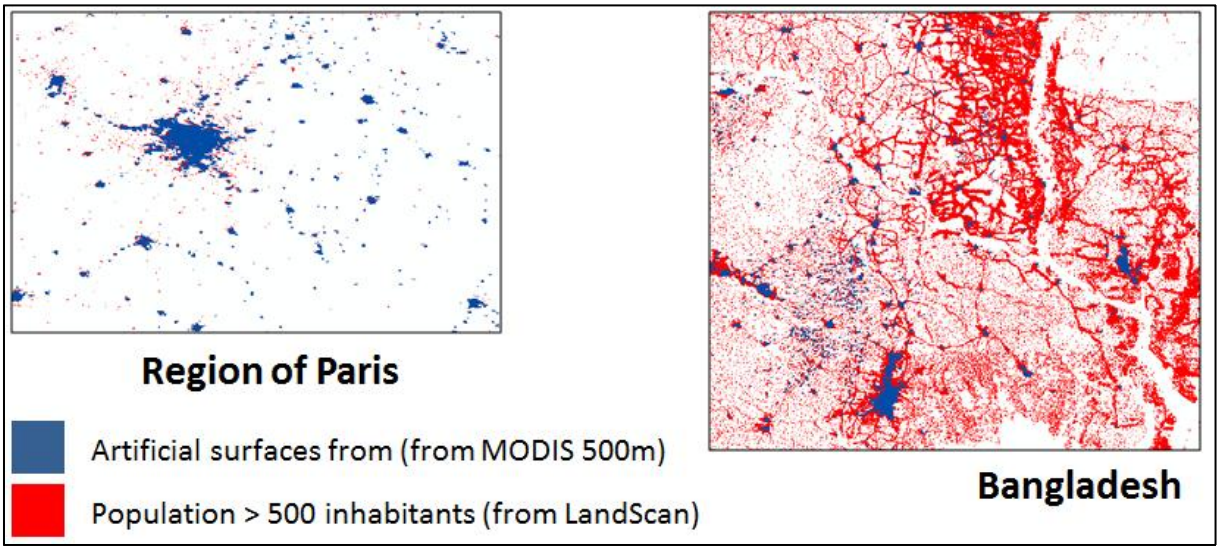

Figure 3 Built-up areas and population density

In Case of Bangladesh we lost a considerable amount of people. In order to avoid this inconvenience, we define a new improved mask of urban agglomeration as follows:

1. We keep all the cells belonging to the “urban area” class from MODIS500
2. We keep also the clusters of contiguous cells with at least 2000 inhabitants per cell from LandScan

OECD and the European Commission consider in their definition of city (EU, 2011) grid cells with a density of at least 1’500 inhabitants per km2, for European cities. At global scales our tests suggest to use a more conservative value of 2000 inhabitants per cell.

The final output includes a global raster of population living in urban agglomerations at approximately 1x1 km resolution.

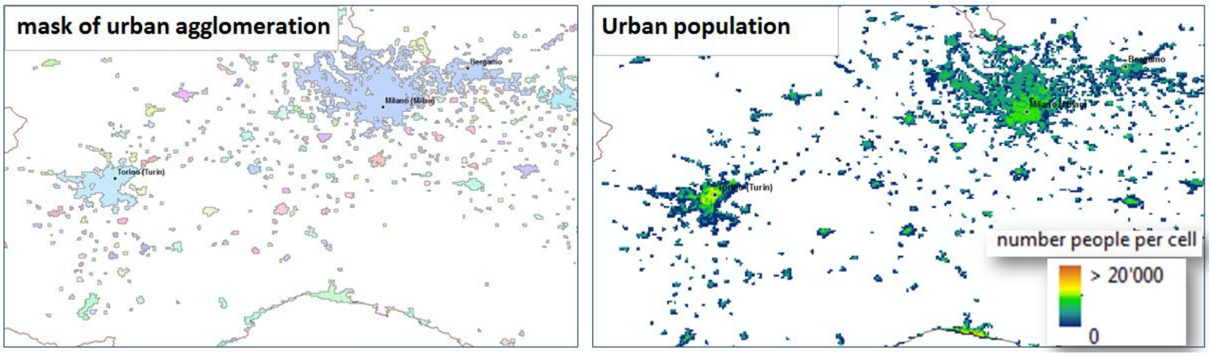

Figure 4 Example of outputs for northern Italy: built-up areas and urban population

Establish the “complex type” and data aggregation onto a regular 5x5 km grid

Characterize the urban settlements based on their size according to Satterthwaite (2006) classification where:

- Complex type 1: >= 20’000 inhabitants : Upper urban
- Complex type 2: between 20’000 and 2’000 inhabitants: Lower urban
- Complex type 3: <= 2’000 inhabitants: Rural.

This classification scheme was suggested and utilized by WAPMERR (2012) in the characterization of building structural typology

Final outputs of this steps includes 153’477urban settlements(patches) for the whole surface of the Earth, once transposed onto a regular grid (5x5) the number of records become 293’174

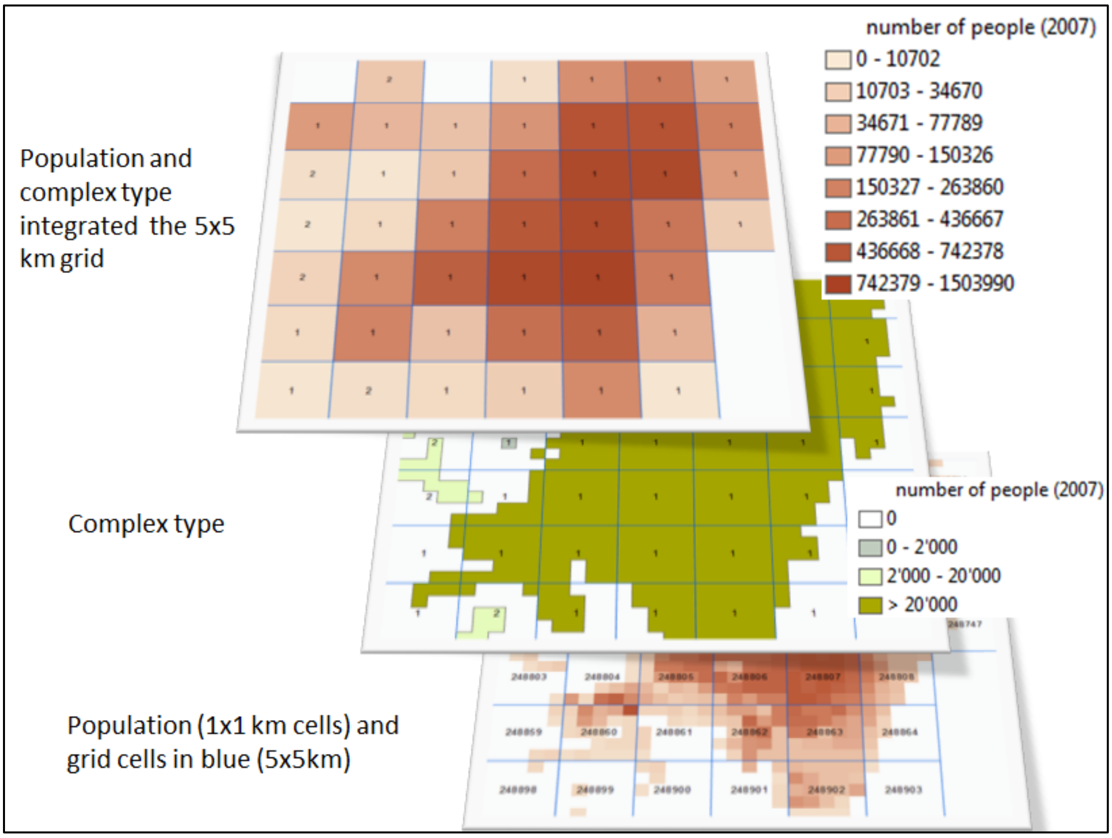

Figure 5: complex type and aggregation

Socio-economic indicators

Introduction

We used a set of socio-economic indicators at national level (grouped in Table 1) used as proxies, in order to estimate the characteristics of the buildings in accordance with the levels of complexity of each urban area.

A first group of indicators includes resident population subdivided in four classes, based on the income per capita, according with the World Bank (WB) classification.

A second group including non-residents is subdivided by economic activities (industry, services and government), health coverage (number of hospital beds in public/private) and education for private and public sectors (number of pupils)

Data sources

We applied four discriminatory criterions in order to select the source of our data:

- We use data where comparisons between countries are possible.
- We use data that are internationally recognized as accurate
- We use data only provided by the original producer.
- We use data that are publicly available.

Sector	Socio-economic indicator	Official data sources

Population		country population in 2007	UN WPP 2011[4]
		country population in 2010	
Residents	Income	% of people living below 1005 $	WDI 2012[5]
		% of people living between 1005 $ and 3975 $	
		% of people living between 3975 $ and 12275 $	
		% of people living above 12276 $	
Non residents	Employment	% of people employed in agriculture	WDI 2012, ILO 2012[6], UNSD 2012[7]
		% of people employed in industry	
		% of people employed in services	
		% of people employed in government	
		number of employed / total population	
	Health	number of beds per 1000 people private	WDI 2012
		number of beds per 1000 people public	
	Education	number of pupils (private)/total population	UNESCO 2012[8]
		number of pupils (public)/total population	

Table 1 the 15 socio-economic indicators and their sources

Generally International Organizations (IO) satisfy these options

Socioeconomic statistical data are commonly released as relatively continuous time series including at least the last 20 years. 2007 was for far the most complete year for a majority of indicators and it was chosen as base year.

Estimate missing data

A first set of 114 countries includes those for which all the indicators were complete and not need any estimation.

A second group of 104 economies comprise those where estimation for missing data was necessary, or in other words they not have complete data from official international statistics such as: FMI, World Bank , UN Statistical Division, OECD, Eurostat, ILO, UNESCO and in case of Caribbean also CEPALSTAT

In these cases in order to evaluate the missing values four different methodologies were employed (in order of preference):

1. Data have been searched through national statistical offices: this case was particularly used for France" DOM-TOM" by using INSEE.
2. Data come from "global" unofficial databases such as the CIA Factbook[9] that was extensively used in various cases and other Gazetteers.
3. Data have been estimated using proxies (eg GDP versus capital stock).

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4 UN WPP 2011 : World Population Prospects, the 2010 Revision. http://esa.un.org/wpp/Excel-Data/population.htm
5 WDI : World Bank. World Development Indicators. http://databank.worldbank.org/data/databases.aspx
6 ILO : International Labor Organisation, LABORSTA. http://laborsta.ilo.org/
7 UNSD : UN Statistical Division. http://unstats.un.org/unsd/environment/qindicators.htm
8 UNESCO : Institut for Statistics : http://stats.uis.unesco.org/unesco/tableviewer/document.aspx?ReportId=143
9 https://www.cia.gov/library/publications/the-world-factbook/

4. Data were assumed as equivalent per countries considered as “similar” in terms of geographic position, development, economy, sovereigns.

Downscaling data

The detailed algorithms created by CIMNE to manipulate and transfer these variables at subnational scale (5x5 grid cells) can be consulted in their report (CIMNE 2013) where the following steps are descripted:

- Population distribution by income level (step 4)
- Estimation of a population by their occupation (step 5, 6)
- Estimation of the health service capacity (step 7)
- Estimation for the capacity of the education services (step 8)

More generally, the algorithm to transpose a socioeconomic parameter at national scale to the grid cell using the population as proxy corresponds to:

$$SE(x,y) = \frac{SE(adm)}{\sum_{(adm)} Pop(x,y)} * Pop(x,y)$$

Where SE(x,y) is the value of socio-economic parameter per cell having x,y coordinates; SE(adm) corresponds to the value of socio-economic parameter per administrative unit (general country level) Pop(x,y) represents the population living in the cell (extracted from LandScan).

Building structure typology

An essential element of GED consists in the population distribution into building types for different size categories of settlements.

The World Agency of Planetary Monitoring & Earthquake Risk Reduction (WAPMERR) provided us all the information concerning the construction types in each country for three size categories of settlements: major urban, minor urban, and rural, according to the Satterthwaite (2006) classification.

It is important to underline that the distribution of structural types was carried out according with the population that lives in each of them and not in accordance to the number of construction type per number of buildings.

Data sources

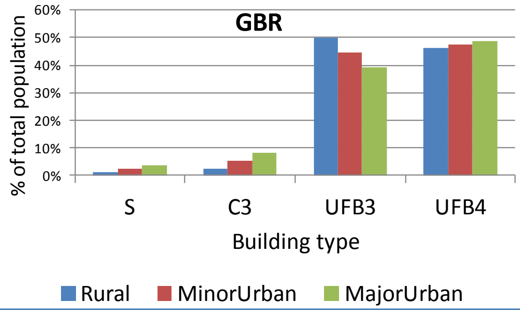
The sources for building types were: 40% from census data, 25% from the WHE/PAGER[10] project, 25% based on research, 9% based on UN reports, and 1% on HAZUS[11] data.

For the smallest and largest categories of settlements, WAPMERR utilized the distributions of people into PAGER construction types.

[10] WHE, World Housing Encyclopedia, http://ww.world-housing.net
[11] http://www.fema.gov/hazus

PAGER categories

W	WOOD
UFB1	UNREINFORCED BRICK MASONRY in mud mortar without timber posts
UFB3	Unreinforced fired brick masonry, cement mortar, timber flooring, timber or steel beams and columns, tie courses (bricks aligned perpendicular to the plane of the wall)
UFB4	Same as UFB3, but with reinforced concrete floor and roof slabs
RM1	REINFORCED MASONRY BEARING WALLS with Wood or Metal Deck Diaphragms
RM2	Reinforced Masonry Bearing Walls with Concrete Diaphragms
C1	DUCTILE REINFORCED CONCRETE MOMENT FRAME
C1L	Low-Rise
C1M	Mid-Rise
C3	NONDUCTILE REINFORCED CONCRETE FRAME WITH MASONRY INFILL WALLS
C3L	Low-Rise
C3M	Mid-Rise
S	STEEL
S3	Steel Light Frame
S4	Steel Frame with Cast-in-Place Concrete Shear Walls



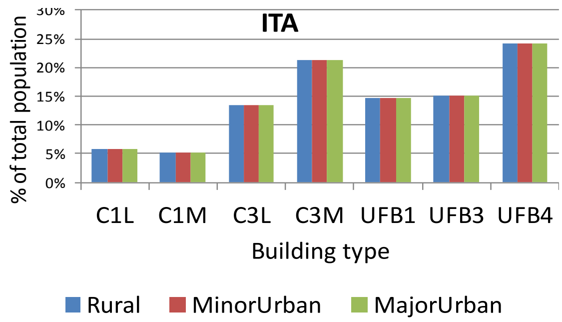


Figure 6 Example of output for building typology for United Kingdom and Italy.

We must also undertake to distribute the information provided by WAPMERR in residential/non-residential use also be the level of complexity. This is carried out in regards to reasons calculated based on the information found in the structural systems distribution catalogue for residential/non-residential use (Jaiswal et al, 2010).

Data integration

The generic algorithm to downscaling national building types to cell size is

$$BC(x,y) = BC(Adm\%) * pop(x,y)$$

Where BC(x,y) is the number of people living in a determinate building type per cell, and BC(adm%) is the percentage of total population who is living in a determinate building type at country level.

Asset values

The estimation of a "value" can be perceived using two different approaches: as a flow or as a stock. In the past editions of GAR (2009 and 2011) the economical exposure was based on the concept of flow: a stream of benefits deriving from the asset – income / GDP / expenditure. In the context of natural disasters, stocks represent the usual choice of unit for measuring exposure. This is especially true considering that a natural disaster could cause asset damage greater than the annual flow… GDP represents average annual productivity. Total earthquake loss from any single earthquake is not limited by GDP and it can exceed the GDP of a country, such as happened with Haiti earthquake in 2000. Thus, the total earthquake loss can be proportional to GDP, but the proportion appears to be country-specific.

Data sources

For GAR 2013 our aim is to map at a sub-national level the world's capital stock in the urban areas, or the so called produced capital by the World Bank (2006).

Our approach was outlined by PricewaterhouseCoopers (PwC). They compared it with alternative methodologies and data sources, examined assumptions which have been identified as potential cause for concern, and considered how to expand the sample size of counties included in GAR2013 (PwC 2013)

Finally, the World Bank methodology and data (World Bank, 2011) appear to be the most consistent method of measuring produced values at an international level, at the present time.

The World Bank furnish a dataset for 152 countries that provides broad estimates of the current (2005) capital stock of machinery and structures, based on the Perpetual Inventory Method (PIM) and historical Gross Capital Formation (GCF) data. Furthermore, the World Bank scale-up this estimate by 24% to account for the value of Urban Land. Produced capital tends to be the most readily understood form of capital due to its tangibility and the quality of data collected on investment levels.

Within the country level data the WB also publish the detailed methodology and used algorithms

Estimate missing data

Unfortunately data provided by World Bank not cover the totality of Countries/territories (218) included in the GED for GAR2013. We have to consider how to expand the produced capital for the remaining 66 economies (Figure 7).

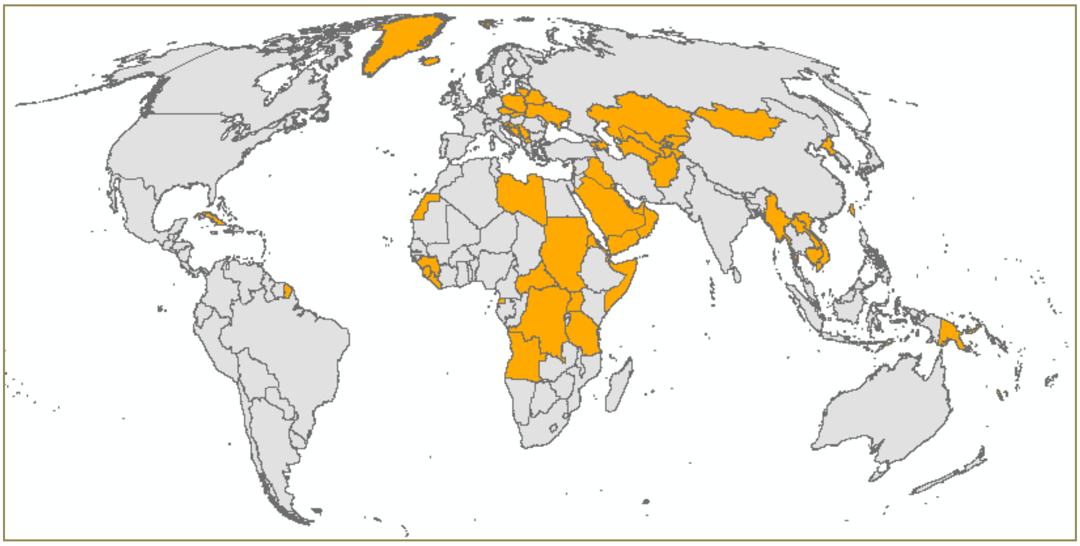


Figure 7 Missing data on capital per countries (orange color) from the WB database

The International Institute for Applied Systems Analysis (IIASA[12]) provided us a list of 35 countries extracted from his unpublished internal database. This was very useful especially for those countries where economical official statistics provided by OI are missing. We used IIASA data for 10 countries. Annex 1 includes a per country full list indicating methodology and sources for produced capital estimations.

[12] http://www.iiasa.ac.at/

The missing data on produced capital for the rest of countries/territories were evaluated following the approach outlined by PwC (2013): they suggest three main methodologies as follows in order of decreasing robustness

a) Apply the World Bank algorithms using World Bank Gross Capital Formation[13] (GCF) data

b) Apply the World Bank algorithms using data on Gross Fixed Capital Formation (GFCF) from the IMF[14] and EconoStats[15]

c) Apply the World Bank algorithms on GCF: GFC data are calculated by using a fixed ratio between GDP and GFC

Third methodology has been applied exclusively on smaller countries/territories where only GDP data were available. Considering countries/territories having less than 5 mio inhabitants, around 80% of GDP GCF ratio fall between 2.5 and 5.5. The average ratio of 4.57 will be used, but the results should therefore be treated with caution.

We have to keep in mind that in order to apply the World Bank algorithms we need a continuous time series of GCF or GFCF or GDP including the last 20 years data. Unfortunately for few countries/territories this kind of information is not available from IO. In this case we estimate directly the produced capital using the formula:

$$PC(capita\ terr) = \frac{GDP(terr)}{GDP_{(cnty)}} * PC(capita\ cnty)$$

Where $PC_{(capita\ terr)}$ is the unknown produced capital per capita of the territory, $GDP_{(terr)}$ and $GDP_{(cnty)}$ correspond to the GDP of the territory and the related country respectively, and $PC_{(capita\ cnty)}$ is the produced capital per capita of the country

This methodology has been applied only for those countries where relationships (political, economic…) are proven as in the case of overseas territories and their sovereigns eg UK and Gibraltar or French "DOM-TOM".

Downscaling data

The downscaling process consists to transfer the produced capital from administrative unit (country) to the 5x5 grid cells. In order to refine the process and keep a more realist snapshot of the distribution of economic pattern of the country, we will use the GDP at sub-national level as a proxy.

The employed proxy is the global dataset of GDP, with subnational gross regional product (GRP)[16] for 74 countries, compiled by the World Bank Development Economics Research Group (DECRG) and already utilized in the past GAR editions.

Basically the process consists to evaluate a coefficient of variation between the national values of GDP (capita) and those at subnational level. In other words the coefficient indicates how much a cell

[13] http://data.worldbank.org/indicator/NE.GDI.TOTL.CD
[14] http://elibrary-data.imf.org/
[15] http://www.econstats.com/ifs/NorGSc_OAC_8_Y.htm
[16] Data available on: PREVIEW Global Risk Data Platform http://preview.grid.unep.ch/

will differs from the national average of produced capital. The coefficient of variation has been calculated using the following equation:

$$CV\%(x,y) = \frac{GDPc(x,y)}{GDPc(adm)} * 100$$

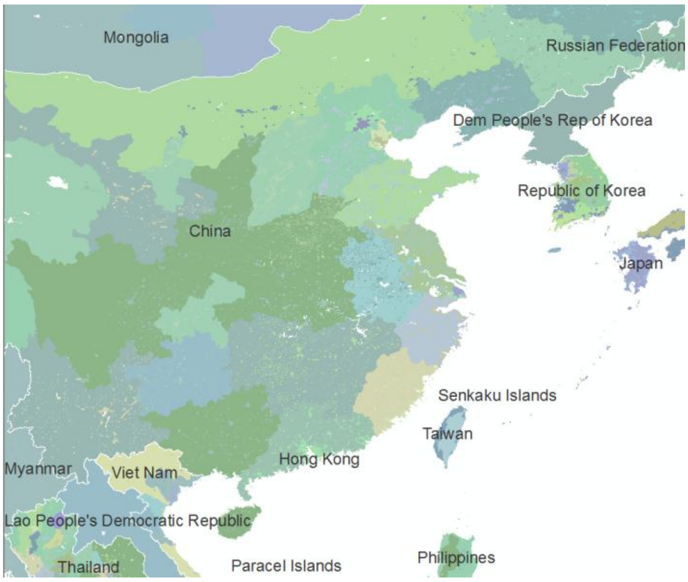
Where CV%(x,y) is the coefficient of variation for the cell located at x,y coordinates, GDPc (x,y) the GDP per capita per cell and GDPc(adm) the value of GDP capita at subnational level.

Therefore the produced capital is downscaled at cell level using population and thus multiplied by the already calculated coefficient (see next equation).

$$PC(x,y) = [PCc(adm) * Pop(x,y)] * \; GDPc\%(x,y)$$

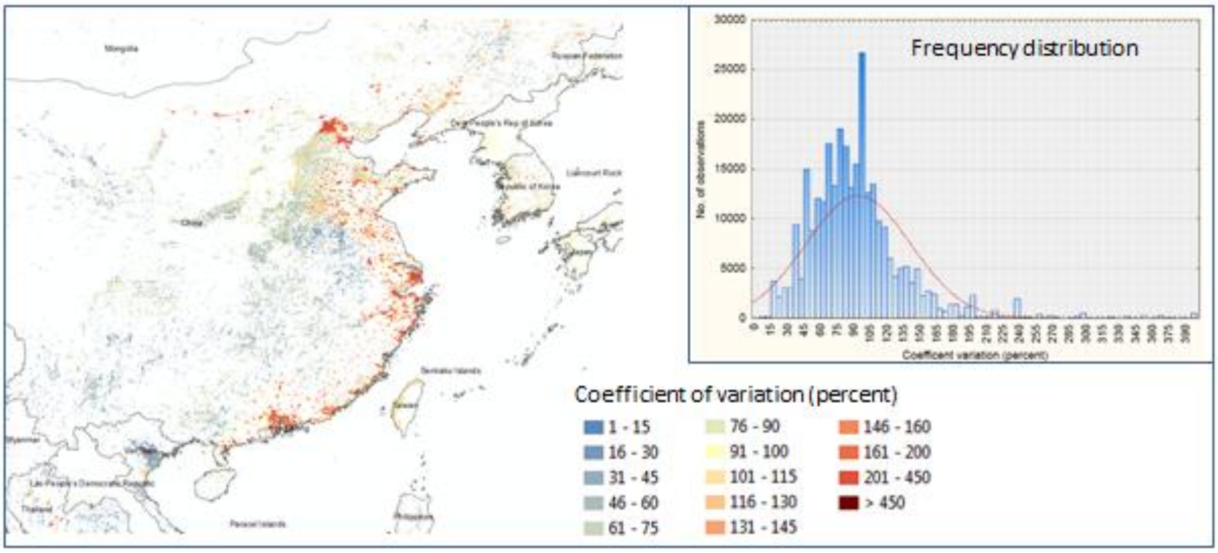
Where PC (x,y) is the produced capital at cell size, PCc(adm) is the capital per capita at national level, Pop(x,y) the population of the cell.

Intermediate and final outputs are illustrated in the three figures below.



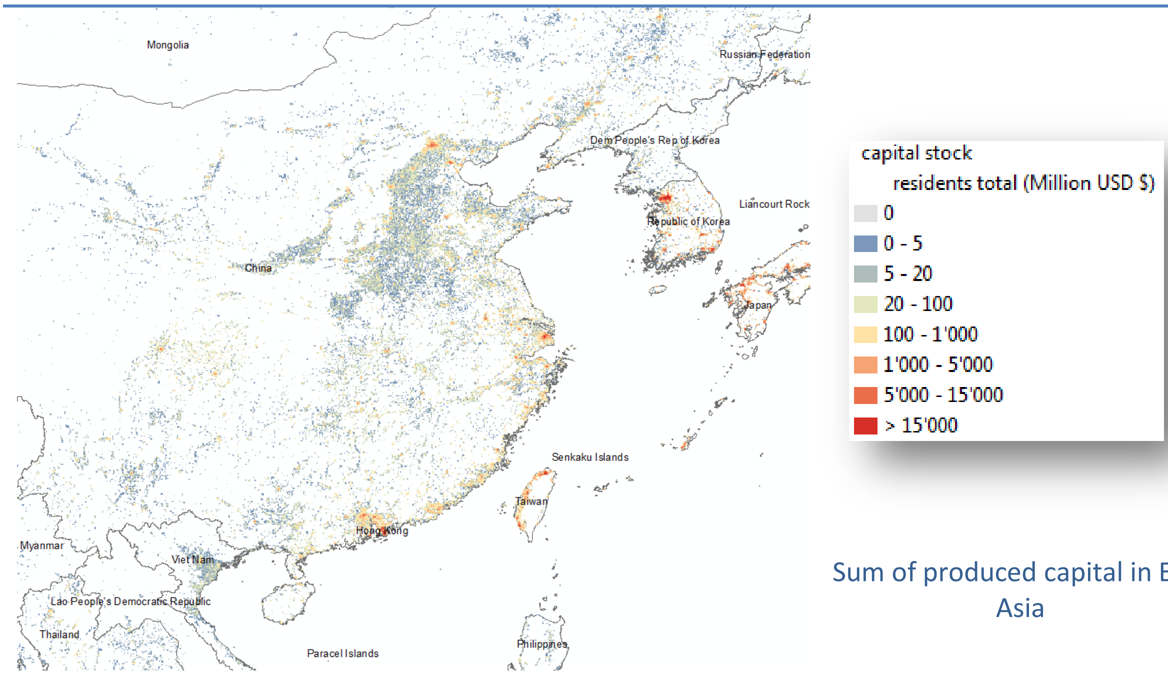
Subnational subdivisions of the gross regional product (GRP) per capita in East Asia

Figure 8 Maps of GDP per capita regional subdivision in East Asia.



Coefficient of variation of GDP per capita between regional and national values.

Figure 9 GDP capita variations from national average for East Asian Region



Sum of produced capital in East Asia

Figure 10 final map of capital distribution in East Asia

The total exposed value of each country corresponds to the physical stock capital distributed at a sub-national level in accordance with the population distribution and in accordance with the distribution of the GDP at regional level in the country.

Data workflow

Whole data and the downscaling algorithms proposed by the CIMNE team, together with new ones have been integrated in a PoestgeSQL/PostGIs database environment. This powerful open source solution allows the management and analyses of very large spatial and non-spatial datasets.

The following data workflow (Figure 11) explains the major steps of the development of the GED.13. Inputs/outputs are generally (spatially enabled) tables. It is important to underline that all the process is dynamic and controlled by user-built PostgreSQL functions , that incorporate the majority of the algorithms discussed here and in the CIMNE report.

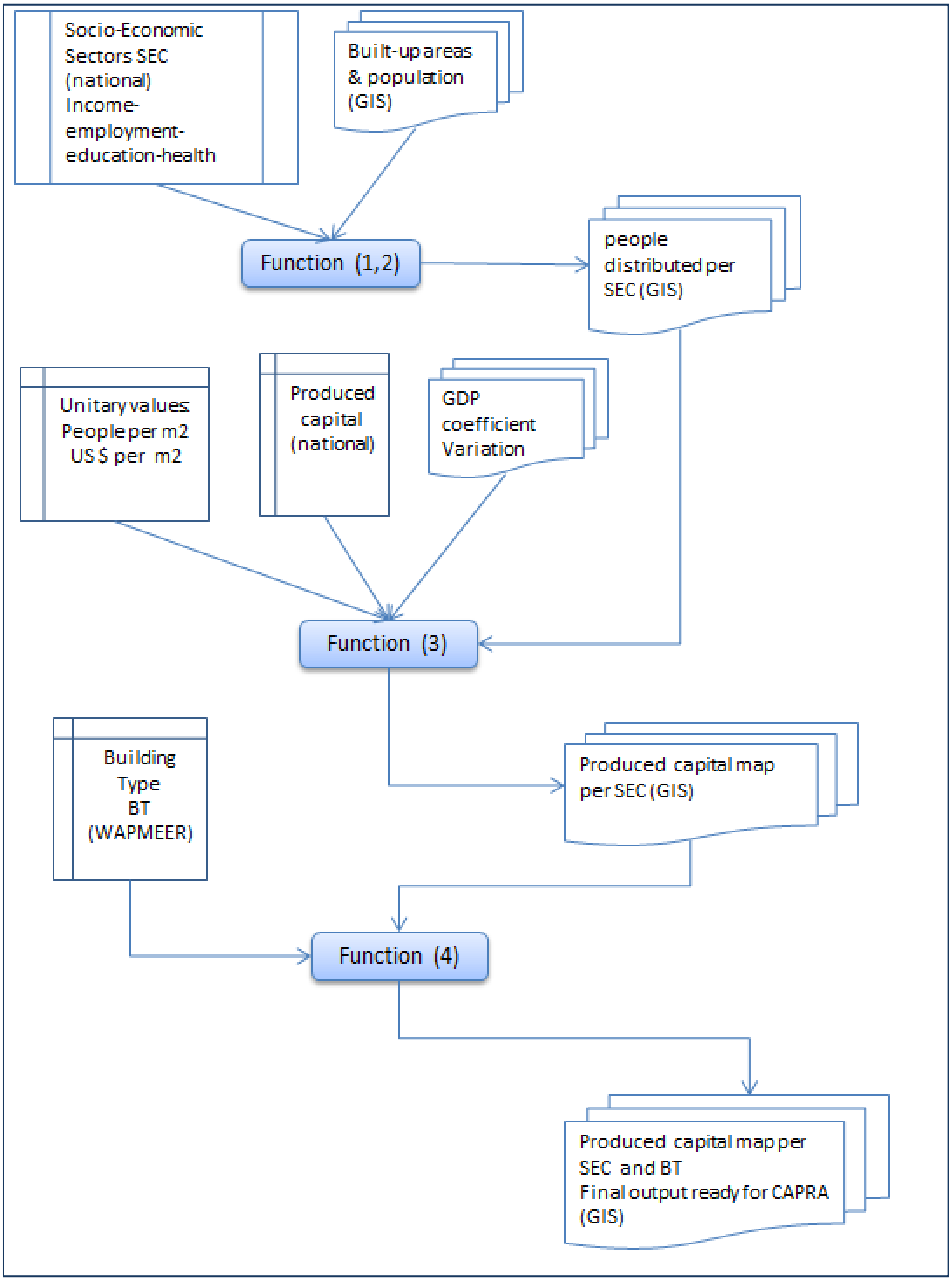


Figure 11 data workflow inside the PostgreSQL environment

Main outputs

Each record (exposed value)in the GED-13 represents a certain building structural type of certain income level/sector in a certain urban area with a special point representation in the centroid of the 5x5 cell (Figure 12).

Starting from mid-May 2013 exposure outputs will be publicly available on the Preview platform at: http://preview.grid.unep.ch/

Urban Area ID	Income Level or Sector	Building type	VALFIS [USDx10^6]
200247	Low Income	S5	$ 496,646
200247	Low Income	C1	$ 7,449,689
200247	Low Income	C1L	$ 7,449,689
200247	Low Income	C2	$ 496,646
200247	Low Income	C2M	$ 2,483,230
200247	Low Income	C3	$ 7,449,689
200247	Low Income	M2	$ 993,292
200247	Low Income	UFB3	$14,899,377
200247	Low Income	UCB	$ 4,966,459
200247	Low Income	UNK	$ 2,979,875
200247	Middle Income	S5	$ 822,740
200247	Middle Income	C1	$12,341,105
200247	Middle Income	C1L	$12,341,105
200247	Middle Income	C2	$ 822,740
200247	Middle Income	C2M	$ 4,113,702
200247	Middle Income	C3	$12,341,105
200247	Middle Income	M2	$ 1,645,481
200247	Middle Income	UFB3	$24,682,210
200247	Middle Income	UCB	$ 8,227,403
200247	Middle Income	UNK	$ 4,936,442
200247	High Income	S5	$ 45,026
200247	High Income	C1	$ 675,384

Figure 12 exposure output in CAPRA compatible format.

References

Bright, E.A., (2002) LandScan Global Population 1998 Database: Oak Ridge, TN 37831, Oak Ridge National Laboratory.

Budhendra, B., Bright, E.A., Coleman, P., and Dobson, J., (2002) LandScan: Locating People is What Matters: Geoinformatics, v. 5, p. 34-37.

CIMNE (2013) Probabilistic modeling of natural risks at the global level: Technical report prepared for GAR 2013 available at:

Jaiswal, K., Wald, D., & Porter, K. (2010). A Global Building Inventory for Earthquake Loss Estimation and Risk Management. Earthquake Spectra, 26(3), 731. doi:10.1193/1.3450316

European Union (2011): Cities of tomorrow: Challenges, visions, ways forward. European Commission, Directorate General for Regional Policy Unit C.2 - Urban Development, Territorial Cohesion Wladyslaw Piskorz.
http://ec.europa.eu/regional_policy/conferences/citiesoftomorrow/index_en.cfm

ISDR (International Strategy for Disaster Reduction) (2009a) United Nations international strategy for disaster risk reduction. terminology on disaster risk reduction. http://www.unisdr.org/we/inform/terminology.

ISDR (International Strategy for Disaster Reduction) (2009b) Global assessment report on disaster risk reduction. http://www.preventionweb.net/english/hyogo/gar/report/index.php?id=9413.

ORNL. (2007). LandScanTM global population distribution data (Raster dataset). US: Oak Ridge National Laboratory, U.S. Department of Energy. Retrieved from http://www.ornl.gov/sci/landscan/index.shtml

PwC (2013) Global Risk Assessment Report 2013 - Review of natural disaster valuation methodology and risk modeling. : Technical report prepared for GAR 2013 available at:

Satterthwaite, D (2006) Outside the Large Cities; The demographic importance of small urban centres and large villages in Africa, Asia and Latin America. Human Settlements Working Paper Series Urban Change No. 3. IIED, London.

Socioeconomic Data and Applications Center – SEDAC (2012) Global Rural-Urban Mapping Project (GRUMP) PO Box 1000, 61 Rt 9W, Palisades, NY 10964 USA http://sedac.ciesin.columbia.edu/data/collection/grump-v1

Schneider, A, Friedl, M., & Potere, D. (2009). A new map of global urban extent from MODIS satellite data. Environmental Research Letters, 4(4), 044003. doi:10.1088/1748- 9326/4/4/044003

Schneider, A., Friedl, M. A., & Potere, D. (2010). Mapping global urban areas using MODIS 500-m data: New methods and datasets based on "urban ecoregions." Remote Sensing of Environment, 114(8), 1733–1746. doi:10.1016/j.rse.2010.03.003

UNISDR (2011). GAR11: Global Assessment Report for Disaster Risk Reduction. ISDR, United Nations. Geneva, Switzerland.

UNISDR. (2009). 2009 Global Assessment Report on Disaster Risk Reduction: Risk and poverty in a changing climate. United Nations.

WAPMERR (2012): Approximate Model for worldwide building stock in three size categories of settlements. Technical report prepared for GAR 2013 available at: http://www.preventionweb.net/gar/

World Bank (2006) Where is the Wealth of Nations? : http://go.worldbank.org/2QTH26ULQ0

World Bank (2011). The changing wealth of nations: measuring sustainable development in the new millennium: https://openknowledge.worldbank.org/handle/10986/2252

Annex 1: Data sources for capital stock

Country/territory	Source
Aruba	GDP WDI
Andorra	Same as Spain
Afghanistan	IIASA
Angola	Wealth WB 2011
Anguilla	GFCF IMF
Albania	Wealth WB 2011
United Arab Emirates	Wealth WB 2011
Argentina	Wealth WB 2011
Armenia	Wealth WB 2011
Antigua and Barbuda	GFCF IMF
Australia	Wealth WB 2011
Austria	Wealth WB 2011
Azerbaijan	Wealth WB 2011
Burundi	Wealth WB 2011
Belgium	Wealth WB 2011
Benin	Wealth WB 2011
Burkina Faso	Wealth WB 2011
Bangladesh	Wealth WB 2011
Bulgaria	Wealth WB 2011
Bahrain	Wealth WB 2011
Bahamas	GFCF IMF
Bosnia and Herzegovina	GDP WDI
Belarus	Wealth WB 2011
Belize	Wealth WB 2011
Bermuda	IIASA
Bolivia	Wealth WB 2011
Brazil	Wealth WB 2011
Barbados	GFC WDI
Brunei Darussalam	Wealth WB 2011
Bhutan	Wealth WB 2011
Botswana	Wealth WB 2011
Central African Republic	Wealth WB 2011
Canada	Wealth WB 2011
Switzerland	Wealth WB 2011
Chile	Wealth WB 2011
China	Wealth WB 2011
Côte d'Ivoire	Wealth WB 2011
Cameroon	Wealth WB 2011
Congo	Wealth WB 2011
Colombia	Wealth WB 2011
Comoros	Wealth WB 2011
Cape Verde	Wealth WB 2011
Costa Rica	Wealth WB 2011
Cuba	GFC WDI
Cyprus	GFC WDI
Czech Republic	Wealth WB 2011
Germany	Wealth WB 2011
Djibouti	GDP WDI
Dominica	Wealth WB 2011
Denmark	Wealth WB 2011
Dominican Republic	Wealth WB 2011
Algeria	Wealth WB 2011
Ecuador	Wealth WB 2011
Egypt	Wealth WB 2011
Eritrea	GFC WDI
Western Sahara	Same as Morocco (half value)
Spain	Wealth WB 2011
Estonia	IIASA
Ethiopia	Wealth WB 2011
Finland	Wealth WB 2011
Fiji	Wealth WB 2011
Falkland Islands (Malvinas)	Same as UK
France	Wealth WB 2011
Micronesia (Federated States of)	GDP WDI
Gabon	Wealth WB 2011
U.K. of Great Britain and Northern Ireland	Wealth WB 2011
Georgia	Wealth WB 2011
Ghana	Wealth WB 2011
Gibraltar	Same as UK
Guinea	Wealth WB 2011
Guadeloupe	From FRA using GDP
Gambia	Wealth WB 2011
Guinea-Bissau	Wealth WB 2011
Equatorial Guinea	GFCF IMF
Greece	Wealth WB 2011
Grenada	Wealth WB 2011
Greenland	GDP WDI
Guatemala	Wealth WB 2011
French Guiana	From FRA using GDP

Guyana	Wealth WB 2011	Marshall Islands	GDP WDI
Hong Kong	Wealth WB 2011	The former Yugoslav Republic of Macedonia	Wealth WB 2011
Honduras	Wealth WB 2011	Mali	Wealth WB 2011
Croatia	Wealth WB 2011	Malta	Wealth WB 2011
Haiti	Wealth WB 2011	Myanmar	Same as Cambodia
Hungary	Wealth WB 2011	Montenegro	GDP WDI
Indonesia	Wealth WB 2011	Mongolia	Wealth WB 2011
India	Wealth WB 2011	Mozambique	Wealth WB 2011
Ireland	Wealth WB 2011	Mauritania	Wealth WB 2011
Iran (Islamic Republic of)	Wealth WB 2011	Montserrat	Same as Jamaica
Iraq	IIASA	Martinique	From FRA using GDP
Iceland	Wealth WB 2011	Mauritius	Wealth WB 2011
Israel	Wealth WB 2011	Malawi	Wealth WB 2011
Italy	Wealth WB 2011	Malaysia	Wealth WB 2011
Jamaica	Wealth WB 2011	Namibia	Wealth WB 2011
Jordan	Wealth WB 2011	New Caledonia	GDP WDI
Japan	Wealth WB 2011	Niger	Wealth WB 2011
Kazakhstan	IIASA	Nigeria	Wealth WB 2011
Kenya	Wealth WB 2011	Nicaragua	Wealth WB 2011
Kyrgyzstan	Wealth WB 2011	Netherlands	Wealth WB 2011
Cambodia	GFCF IMF	Norway	Wealth WB 2011
Kiribati	GDP WDI	Nepal	Wealth WB 2011
Saint Kitts and Nevis	Wealth WB 2011	New Zealand	Wealth WB 2011
Republic of Korea	Wealth WB 2011	Oman	Wealth WB 2011
Kuwait	Wealth WB 2011	Pakistan	Wealth WB 2011
Lao People's Democratic Republic	Wealth WB 2011	Panama	Wealth WB 2011
Lebanon	GFCF IMF	Peru	Wealth WB 2011
Liberia	Wealth WB 2011	Philippines	Wealth WB 2011
Libyan Arab Jamahiriya	GFCF IMF	Palau	GDP WDI
Saint Lucia	Wealth WB 2011	Papua New Guinea	Wealth WB 2011
Liechtenstein	GDP WDI	Poland	Wealth WB 2011
Sri Lanka	Wealth WB 2011	Puerto Rico	GFC WDI
Lesotho	Wealth WB 2011	Dem People's Rep of Korea	IIASA
Lithuania	Wealth WB 2011	Portugal	Wealth WB 2011
Luxembourg	Wealth WB 2011	Paraguay	GFC WDI
Latvia	Wealth WB 2011	French Polynesia	GDP WDI
Macau	Wealth WB 2011	Qatar	GFCF IMF
Morocco	Wealth WB 2011	Réunion	From FRA using GDP
Monaco	GDP WDI	Romania	Wealth WB 2011
Moldova, Republic of	Wealth WB 2011	Russian Federation	Wealth WB 2011
Madagascar	Wealth WB 2011	Rwanda	Wealth WB 2011
Maldives	Wealth WB 2011	Saudi Arabia	Wealth WB 2011
Mexico	Wealth WB 2011	Sudan	Wealth WB 2011

Senegal	Wealth WB 2011
Singapore	Wealth WB 2011
Solomon islands	GFCF IMF
Sierra Leone	Wealth WB 2011
El Salvador	Wealth WB 2011
San Marino	GDP WDI
Somalia	IIASA
Serbia	IIASA
Sao Tome and Principe	IIASA
Suriname	GFC WDI
Slovakia	Wealth WB 2011
Slovenia	GDP WDI
Sweden	Wealth WB 2011
Swaziland	Wealth WB 2011
Seychelles	Wealth WB 2011
Syrian Arab Republic	Wealth WB 2011
Chad	Wealth WB 2011
Togo	Wealth WB 2011
Thailand	Wealth WB 2011
Tajikistan	Wealth WB 2011
Turkmenistan	GDP WDI
Timor-Leste	Same as Indonesia
Tonga	Wealth WB 2011
Trinidad and Tobago	Wealth WB 2011
Tunisia	Wealth WB 2011

Turkey	Wealth WB 2011
Tuvalu	GDP WDI
Taiwan	IIASA
United Republic of Tanzania	GFCF IMF
Uganda	Wealth WB 2011
Ukraine	Wealth WB 2011
Uruguay	Wealth WB 2011
United States of America	Wealth WB 2011
Uzbekistan	Wealth WB 2011
Saint Vincent and the Grenadines	Wealth WB 2011
Venezuela	Wealth WB 2011
British Virgin Islands	Same as UK
United States Virgin Islands	From USA using GDP
Viet Nam	Wealth WB 2011
Vanuatu	Wealth WB 2011
West Bank and Gaza	GFC WDI
Samoa	GDP WDI
Yemen	GFCF IMF
South Africa	Wealth WB 2011
Democratic Republic of the Congo	Wealth WB 2011
Zambia	Wealth WB 2011
Zimbabwe	Wealth WB 2011