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Atlas of the Human Planet 2016

Mapping Human Presence on Earth with the Global Human Settlement Layer

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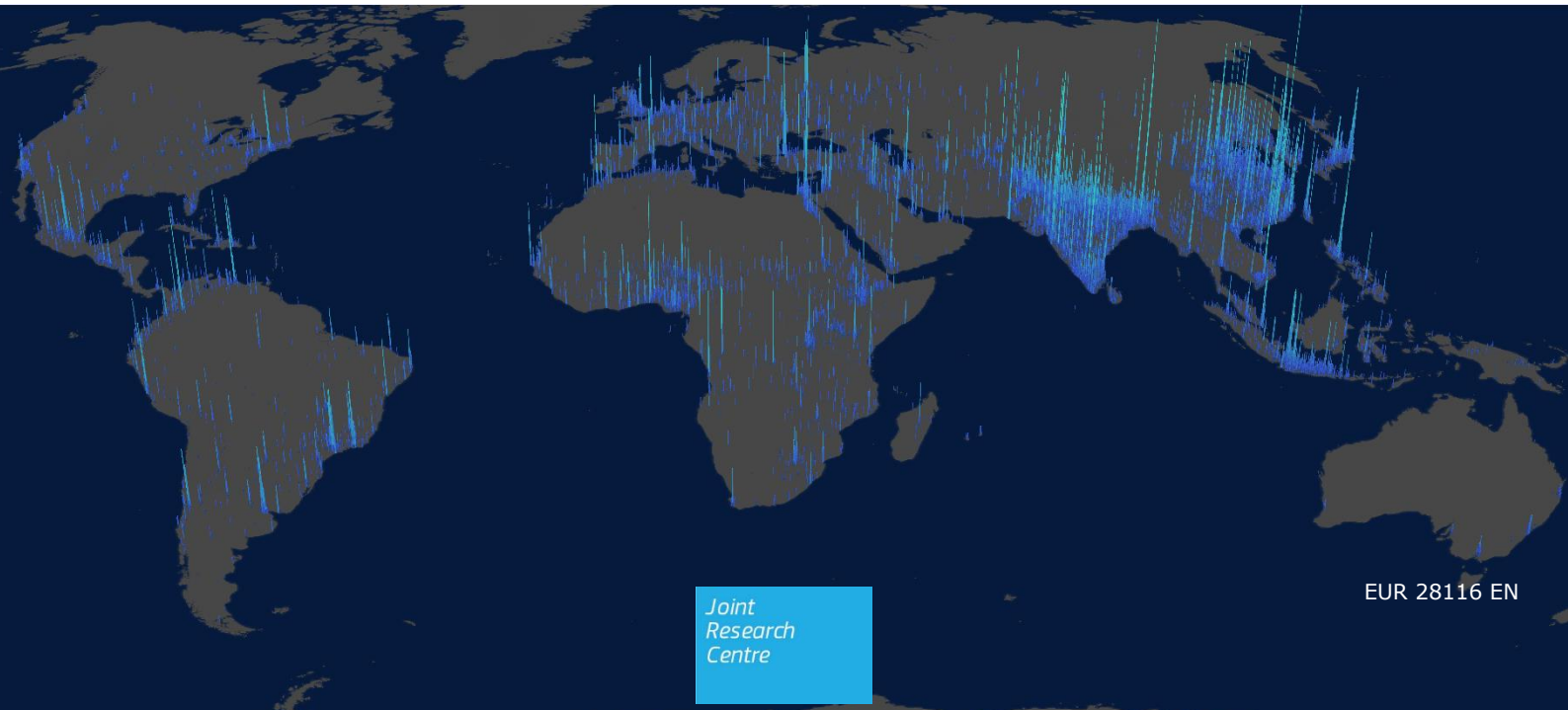

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Title Atlas of the Human Planet 2016. Mapping Human Presence on Earth with the Global Human Settlement Layer

Abstract
Mapping Human Presence on Earth with the Global Human Settlement Layer
The Atlas of the Human Planet presents the key findings of the analysis of the Global Human Settlement Layer (GHSL). This data set reports about the growth of built-up and population in the last 40 years (1975-2015) at an unprecedented level of detail. The information supports the international frameworks of the Agenda 2030.

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Foreword

The world in 2016 is a very different place than it was when the first UN Habitat Conference was held in the 1970s, when the first data of the Global Human Settlement Layer baseline was being developed. This first edition of the Atlas of the Human Planet shows us just how much has changed since that time. In the mid-70s, the world's population was 4.1 million and was mostly rural. Today, almost 4 million people are urbanites – more than half of humanity.

Earth science has also changed since the '70s – the spatial resolution of satellite imagery has increased from around 80 metres to less than 1 metre, spatial and temporal coverages have increased, we have better analysis tools, we can process massive volumes of high-resolution verified data, share measurement techniques and collaborate at a global scale.

The Atlas of the Human Planet provides the most comprehensive view of urbanization dynamics ever presented. Detailed, measurable and globally consistent descriptions of human habitat are now possible making it easier to understand the extent to which humans have changed our world, and also how that change affects us.

This first Atlas of the Human Planet represents a body of knowledge derived from the Global Human Settlement Layer (GHSL), a reference of reliable, reproducible information on human habitations, from village to mega-cities. The baseline data, spatial metrics and indicators related to population and settlements, developed in the frame of the Group on Earth Observations (GEO) Human Planet initiative, provide users with a baseline data platform for monitoring and analysis.

The GHSL resource is a remarkable example of the potential of public data to support global, national and local analyses of human settlements and in particular, support policy and decision making. This application of Earth observations is essential for evidence-based modelling of human and physical exposure to environmental contamination and degradation, as monitored through multilateral environmental agreements; disasters as encompassed by the Sendai Framework for Disaster Risk Reduction; the impact of human activities on ecosystems, as measured by the Convention on Biodiversity and human access to resources, assessed by the Sustainable Development Goals (SDGs).

The availability of high resolution, accurate and open data has enabled a Data Revolution and the implementation of the New Urban Agenda, but the current picture of the human footprint is incomplete. The majority of small and medium-sized settlements, critical for accounting and understanding all the environmental impacts on all people, remain largely invisible.

By the time of UN Habitat IV, two decades from now, I hope that even more data will be free and open, and that the GHSL framework will continue to enable us to address the challenges faced by society. For now, we are at last able to agree on the state of our environment, in order to make intelligent, evidenced-based decisions for sustainable and equitable solutions that recognize the linkages between behaviour and impact on the planet, for the benefit of all humankind.

Barbara Ryan
GEO Secretariat Director

Cities are increasingly recognised for their advantages, instead of only for their problems. Although too many cities are still confronted with poor air quality, cities are now also recognised for their lower energy use and GHG emissions because of the energy efficiency of living and working in dense urban neighbourhoods.

Cities suffer from congestion, but they also offer the benefits of low-carbon mobility, such as walking, cycling and public transport. Sprawl does affect the fringes of cities, but overall city living has a very high land-use efficiency.

Within the European context and beyond, we want to encourage cities to learn from each other. To find the policies that work and determine the context that makes them thrive. Without a harmonised, global definition of cities and settlements, such exchanges are doomed to fail. Even relatively simple questions, such as how large is this city or how dense, cannot be meaningfully answered without such a definition, let alone more complex questions.

The Global Human Settlement Layer (GHSL) provides a consistent time series of high-resolution data on built-up areas covering forty years, as shown by this Atlas of the Human Planet. Global and freely accessible population grids were created by combining GHSL with population data. This in turn allowed the testing at the global level of the degree of urbanisation, a new, people-based definition of cities and settlements. The first intriguing results of this test can also be found in the State of European Cities Report 2016.

Free, open and comparable data are needed to develop both a global definition of cities and common metrics that can support better city level analysis and comparisons. This is where GSHL has already made an extremely valuable contribution. We will continue to invest in the GHSL framework to provide better and easier access to this information and update it with more frequent and higher-resolution data from the European Sentinel 1 and 2 satellites.

I am convinced that the Global Human Settlement Layer represents an important step forwards in acquiring better and more comparable knowledge of cities and settlements in the world. I hope that this first Atlas of the Human Planet inspires more people to explore and use this new source of knowledge.

Eric Von Breska
Director
Directorate-General for
Regional and Urban Policy
European Commission

Acknowledgements

This report is the result of a collaborative process between numerous individuals and institutions.

First of all, we would like to acknowledge work of the ***GHSL project* team**, led by *Martino Pesaresi*, that was working for many years to finally produce the data sets used in this Atlas. In 2016 the team comprises *Donato Airaghi, Christina Corban, Daniele Ehrlich, Stefano Ferri, Aneta Florczyk, Sergio Manuel Carneiro Freire, Fernand Haag, Stamatia Halkia, Andreea Maria Julea, Thomas Kemper, Luca Maffenini, Michele Melchiorri, Panagiotis Politis, Alice Siragusa, Pierre Soille, Vasileios Syrris,* and *Luigi Zanchetta*.

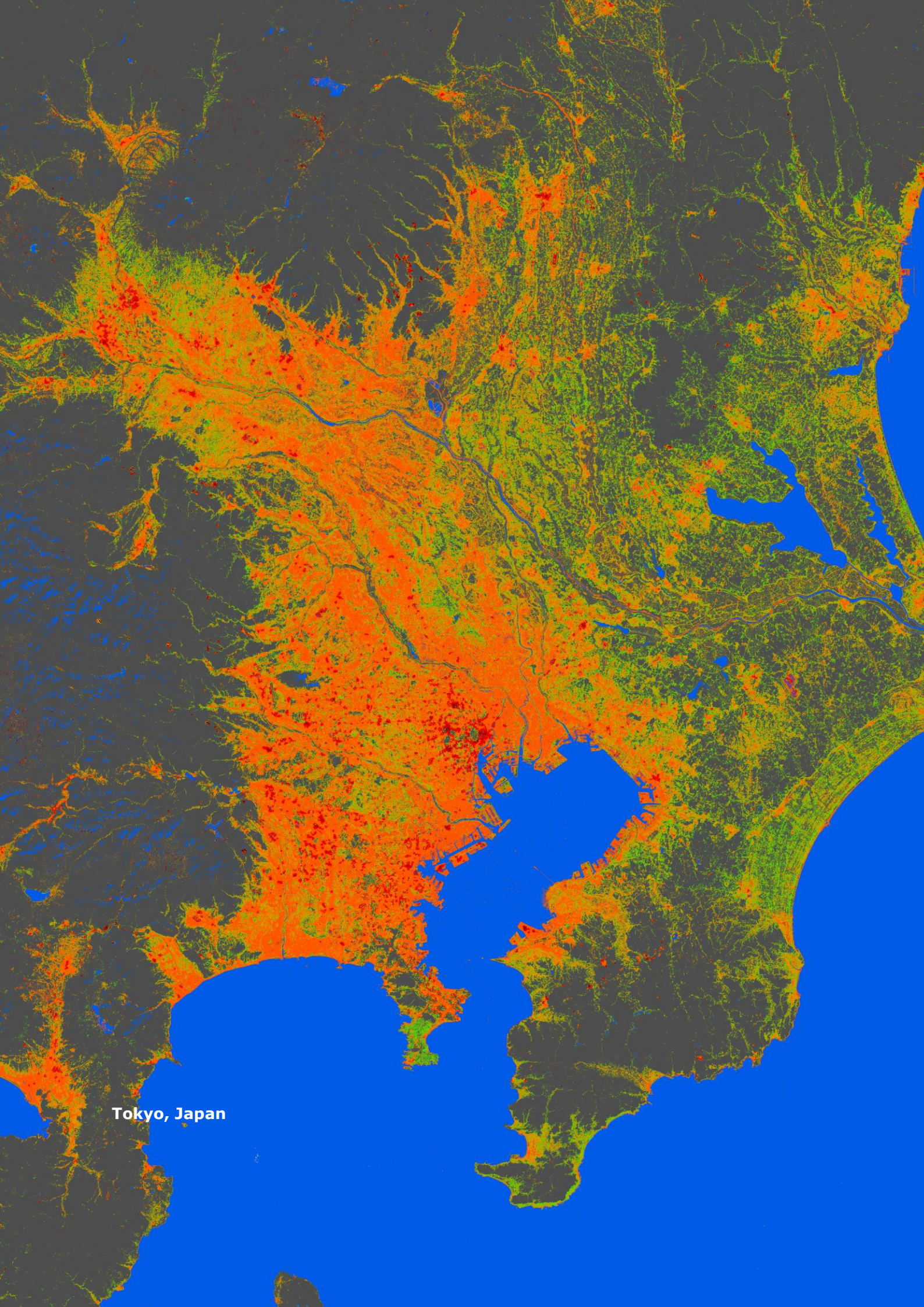
The Atlas profited from the close collaboration and the funding support of the **Economic Analysis Unit of DG REGIO, European Commission**. In particular *Lewis Dijkstra* and *Hugo Poelman* contributed actively to this version of the Atlas.

The generation of the high resolution population data would not have been possible without the access to the data hosted by the ***(CIESIN)*** and the discussions *Robert Chen* and *Kytt MacManus.*

In 2014, Joint Research Centre (JRC), the European Commission's science and knowledge service, organised the 1st Global Human Settlement Workshop, which led to the *Manifesto for a Global Human Settlement Partnership*[1]. The participants of this workshop formed the core group of what is now the **GEO Human Planet Initiative**[2], which includes now more than 180 members from 100 different institutions all around the globe. The discussions with the members helped improving the quality of the Atlas significantly. We would like to thank the GEO and the **GEO Secretariat** for their continuous support.

Some members of the GEO Human Planet Initiative contributed as part of the **Human Planet Atlas Expert Group** to the ranking of the findings presented in this Atlas (in alphabetical order): *Shlomo Angel, New York University Stern Urbanization Project; Sharolyn Anderson, University of South Australia; Benjamin Bechtel, University of Hamburg, Center for Earth System Research and Sustainability; Bob Bishop, International Centre for Earth Simulation Foundation; Robert Chen, Columbia University, Center for International Earth Science Information Network; Andrea Civelli, University of Arkansas; Chandan Deuskar, The World Bank; Lewis Dijkstra, European Commission, DG REGIO; Ryan Engstrom, George Washington University; Francesco Gaetani, United Nations Environment Programme, Regional Office for Latin America and the Caribbean; Ellen Hamilton, The World Bank; Rene Peter Hohmann, Cities Alliance; Patrick Lamson-Hall, New York University Stern Urbanization Project; Carlo Lavalle, European Commission, Joint Research Centre; Stefan Leyk, University of Colorado; Linlin Lu, Chinese Academy Sciences, RADI; Kytt MacManus, Columbia University, Center for International Earth Science Information Network; Gerald Mills, University College Dublin, School of Geography; Mark R. Montgomery, Population Council; Helen Morgan, DEVEX; Giorgos Mountrakis, State University of New York, College of Environmental Science and Forestry; Naledzani Mudau, South African National space Agency; Vincent Y. Seaman, Bill and Melinda Gates Foundation; Linda See, International Institute for Applied Systems Analysis; Richard Sliuzas, University of Twente, Geoinformation Science and Earth Observation (ITC); Paul C. Sutton, University of Denver; Maarten van Schie, PBL, Netherlands Environmental Assessment Agency; Susan Wachter, University of Pennsylvania; Li Zhang, Chinese Academy Sciences, RAD*I.

[1] http://www.earthobservations.org/documents/ghs/ghs_brochure.pdf
[2] http://www.earthobservations.org/activity.php?id=51


Tokyo, Japan

Executive summary

Policy context

The *Atlas of the Human Planet 2016* is the first outcome of the Human Planet Initiative. It aims to support the monitoring of the implementation of the post-2015 international frameworks: the UN Third Conference on Housing and Sustainable Urban Development (Habitat III, 2016), the post-2015 framework on Sustainable Development Goals (SDGs), the UN Framework Convention on Climate Change, and the Sendai Framework for Disaster Risk Reduction 2015-2030 (DRR). The Post-2015 international frameworks include targets to be achieved and measured through indicators that focus on measurable outcomes. These indicators are action oriented, global in nature and universally applicable. The Human Planet Initiative supports the implementation of a platform contributing to the UN Technology Facilitation Mechanism and enabling the test and the collective discussion of alternative options in operationalization of the indicators. The Human Planet Initiative is an international partnership. It started in 2014 with the "Manifesto for a Global Human Settlement Partnership"[3] which evolved to the "Human Planet Initiative" within the frame of the GEO work programme[4].

Key conclusions

The release 2016 of the *Atlas* illustrates the rationale and the first results obtained from the processing of large masses of data collected from three main sources: Earth Observation satellite sensors, national statistical surveys, and crowd sources as voluntary geographic information (VGI). These data have been processed by exploiting novel spatial data analytics tools allowing to handle their complexity, heterogeneity and large volume, and generating information and knowledge about the human presence on the planet Earth from the years 1975 to 2015. For the first time globally-consistent and detailed data of the human environment is available in the public domain. The empirical evidences supporting this release of the *Atlas* have been collected and processed within Global Human Settlement Layer (GHSL) of the European Commission, Joint Research Centre.

The GHSL baseline data released with the *Atlas* provides a framework that allows learning from the last 40 years and to closely monitor the impact of the policies of today and the future. It practically demonstrates how new open data and innovative data processing technologies may support novel global awareness on urbanization trends and dynamics. It provides a new view on global urbanisation processes. The systematic global assessment is a pre-requisite to apply uniform definitions of settlements such as the degree of urbanisation[5] used by Eurostat. Most urban indicators are extremely sensitive to where boundary is drawn, such as air quality, presence of open space or access to public transport. Comparing cities internationally using a collection of national definitions will generate many distortions. Cities defined very tightly will have worse air quality, less open space, but better access to public transport than cities defined more widely. Therefor a uniform definition is needed to make meaningful comparisons and allow cities to learn from each other.

Main findings

While the number of people on the globe is considered well monitored by statistical offices, there is little consistent, open and detailed information on the spatial distribution of population, and hardly any information on the built-up areas with complete, global coverage. For the first time, with the GHSL baseline it is possible to analyse in a consistent, detailed frame the development of built-up areas, population and settlements of the whole planet in the past 40 years.

This *Atlas* using GHSL baseline shows that in the past 40 years built-up areas increased by approximately 2.5 times globally, while population increased by a factor of 1.8. The

[3] GEO 2014 - Manifesto for a Global Human Settlement Partnership http://www.earthobservations.org/ghs.php
[4] The GEO Human Planet Initiative - https://www.earthobservations.org
[5] Dijkstra & Poelman, "A harmonised definition of cities and rural areas: the new degree of urbanisation"

changes in population and built-up areas show big regional differences. The strongest growth is observed in Low Income Countries (LIC). In the past 40 years the population of Africa tripled and the built-up area quadrupled. Instead the population of Europe kept stable while the built-up area doubled.

Today, most of the world's population is living in agglomerations with a density greater than 1,500 people per square kilometre and more than 50,000 total inhabitants. These agglomerations are qualified as *Urban Centres* in the *Atlas*. More than 13,000 individual *Urban Centres* have been reported in the GHSL baseline of the year 2015. *Urban clusters* capture the dense *Urban Centres*, as well as the surrounding suburbs and towns. They are defined as clusters of cells with more than 300 people per square kilometre and at least 5,000 inhabitants. Over the past 40 years, their extent has virtually doubled. *Urban Clusters* increased from 4% of the global land mass in 1975 to 7.6% in 2015, this is approximately half the size of the European Union.

Most of the population and built-up areas increases took place in locations at risk to natural disasters. For example, the world urban population of coastal areas has doubled in the last 40 years from 45 to 88 million people. The different growth trends lead also to an unequal distribution of *Built-up per capita*. *Built-up per capita* in *Urban Clusters* in Northern America is almost ten times that of Asia. National variability is even greater. Similarly, large regional and income inequalities are reported in accessing the electric energy as observed from night light emissions of *Urban Centres*. Moreover, a relative decline of night light emissions can be observed in *Urban Centres* of high income countries, possibly related to the implementation of environmental protection and energy saving policies. Finally, accordingly to the evidences collected by the GHSL and reported in this *Atlas*, our *Urban Centres*, towns and suburbs are getting greener: the average intensity of vegetation associated to built-up areas in the whole *Urban Clusters* of the planet has increased by 38% in the past 25 years.

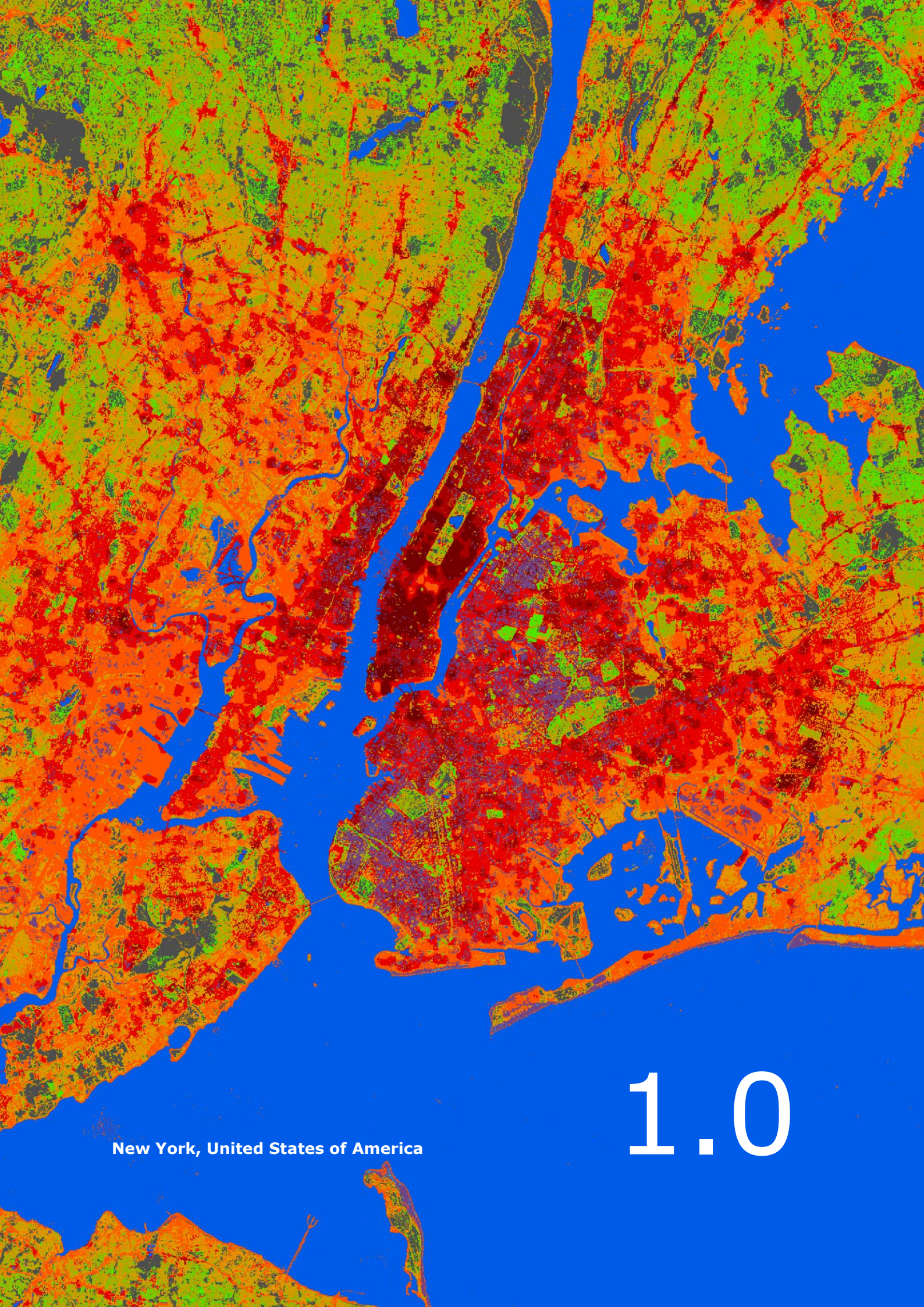
Related and future JRC work

The GHSL is one of the core datasets used in the GEO Human Planet initiative, and is the main baseline used in the first release of the *Atlas of the Human Planet* 2016. The GHSL concept was initialized by the JRC in 2010-2011[6]. GHSL activities are currently supported by the JRC scientific working plan 2016-2019 in the frame of the JRC Directorate E "Space, Security & Migration". The JRC, together with the Directorate-General for Regional and Urban Policy (DG REGIO) and Directorate-General (DG) for Internal Market, Industry, Entrepreneurship and SMEs (DG GROWTH) are working towards a regular and operational monitoring of global built-up and population based on the processing of Sentinel Earth Observation data produced by the European Copernicus space program. At the JRC, the GHSL framework of data and tools supports the Knowledge Centres for Disaster Risk Management, Sustainable Development, Territorial Modelling, and Security & Migration. Moreover, the GHSL is one key test case contributing to the JRC Earth Observation and Social Sensing Big Data Pilot project in the frame of the JRC Text & Data Mining Competence Centre.

Quick guide

The *Atlas of the Human Planet* 2016 is based on evidences collected by the GHSL project of the JRC. GHSL combines satellite and census data to produce high resolution, global open information on built-up area and population. In the current release supporting the *Atlas* 2016, it covers the epochs 1975, 1990, 2000 and 2015. The data sets are used to understand, where and in which built environment people live, how the settlements and the population change over time. This knowledge is used in policy areas including environmental impact assessment, risk assessment, transport, health care services, education, natural disasters and hazards and urban planning.

[6] https://ec.europa.eu/jrc/en/news/mapping-human-settlements-globally-8276


New York, United States of America
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1. Introduction

The *Atlas of the Human Planet 2016* is the first outcome of the Human Planet Initiative. It aims to support the monitoring of the implementation of the post-2015 international frameworks: the UN Third Conference on Housing and Sustainable Urban Development (Habitat III, 2016), the post-2015 framework on Sustainable Development Goals (SDGs), the UN Framework Convention on Climate Change, and the Sendai Framework for Disaster Risk Reduction 2015-2030 (DRR). The Post-2015 international frameworks include targets to be achieved and measured through indicators that focus on measurable outcomes. These indicators are action oriented, global in nature and universally applicable. The Human Planet Initiative supports the implementation of a platform contributing to the UN Technology Facilitation Mechanism and enabling the test and the collective debate of alternative options in operationalization of the indicators. The Human Planet Initiative is an international partnership. It started in 2014 with the "Manifesto for a Global Human Settlement Partnership"[7] which evolved to the "Human Planet Initiative" in the frame of the GEO work programme[8].

The 2016 release of the *Atlas* illustrates the rationale and the first results obtained from the processing of large masses of data collected from three main sources: Earth Observation satellite sensors, national statistical surveys, and crowd sources as voluntary geographic information (VGI). These data have been processed by exploiting novel spatial data analytics tools allowing to handle their complexity, heterogeneity and large volume, and generating information and knowledge about the human presence on the planet Earth from the years 1975 to 2015. For the first time globally-consistent high-detail data of the human environment is available in the public domain. The empirical evidences supporting this release of the *Atlas* have been collected and processed within Global Human Settlement Layer (GHSL) of the European Commission, Joint Research Centre.

The GHSL baseline data released with the *Atlas* provides a framework that allows learning from the last 40 years and to closely monitor the impact of the policies of today and the future. It practically demonstrates how new open data and innovative data processing technologies may develop knowledge on urbanization trends and dynamics. It provides a new view on global urbanisation processes. The systematic global assessment is a pre-requisite to apply uniform definitions of settlements such as the degree of urbanisation[9] used by Eurostat. In fact, most urban indicators such as air quality, presence of open space or access to public transport are extremely sensitive to where boundary is drawn. Comparing cities internationally also requires standardized boundary definitions as national definitions will generate many distortions. Cities defined very tightly will have worse air quality, less open space, but better access to public transport than cities defined more widely.

The GHSL generates data that allow to compare cities in time and space hence providing meaningful comparisons. The GHSL is one of the core datasets used in the GEO Human Planet initiative, and is the main baseline used in the first release of the *Atlas of the Human Planet* 2016. The GHSL concept was initialized by the JRC in 2010-2011. GHSL activities are currently supported by the JRC scientific working plan 2016-2019 in the frame of the JRC Directorate E "Space, Security & Migration". The JRC, together with DG REGIO and DG GROW are working towards a regular and operational monitoring of global built-up and population based on the processing of Sentinel Earth Observation data produced by the European Copernicus space program. At the JRC, the GHSL framework of data and tools supports the Knowledge Centres for Disaster Risk Management, Sustainable Development, Territorial Modelling, and Security & Migration. Moreover, the GHSL is one key test case contributing to the JRC Earth Observation and Social Sensing Big Data Pilot project in the frame of the JRC Text & Data Mining Competence Centre.

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[7] GEO 2014 - Manifesto for a Global Human Settlement Partnership http://www.earthobservations.org/ghs.php
[8] The GEO Human Planet Initiative - https://www.earthobservations.org/
[9] Lewis Dijkstra, Hugo Poelman, "A harmonised definition of cities and rural areas: the new degree of urbanisation"

While the number of people is accounted through national statistical census, there is little consistent, open and detailed information on the global spatial distribution of population. In fact, hardly any fine scale information on the built-up areas and its change over time with complete, global coverage is available. The GHSL baseline allows to analyse in a consistent, detailed frame the development of built-up areas, population and settlements of the whole planet in the past 40 years. GHSL combines satellite and census data to produce high resolution, global open information on built-up area and population. In the current release supporting the *Atlas* 2016, it covers the epochs 1975, 1990, 2000 and 2015. The data sets are used to understand, where and in which built environment people live, how the settlements and the population change over time.

The high level-of-detail or "spatial resolution" of the GHSL baseline data about built-up areas and residential population densities offer real benefits for policy making in a wide range of domains. Compared to more aggregate level information, such as municipal or regional indicators, these two sources can provide far more detailed and up-to-date information.

A number of policy domains depends on knowing where people and buildings are located. For example, transport, health care services, education, natural disasters and hazards and urban planning can all be improved with more detailed spatial information.

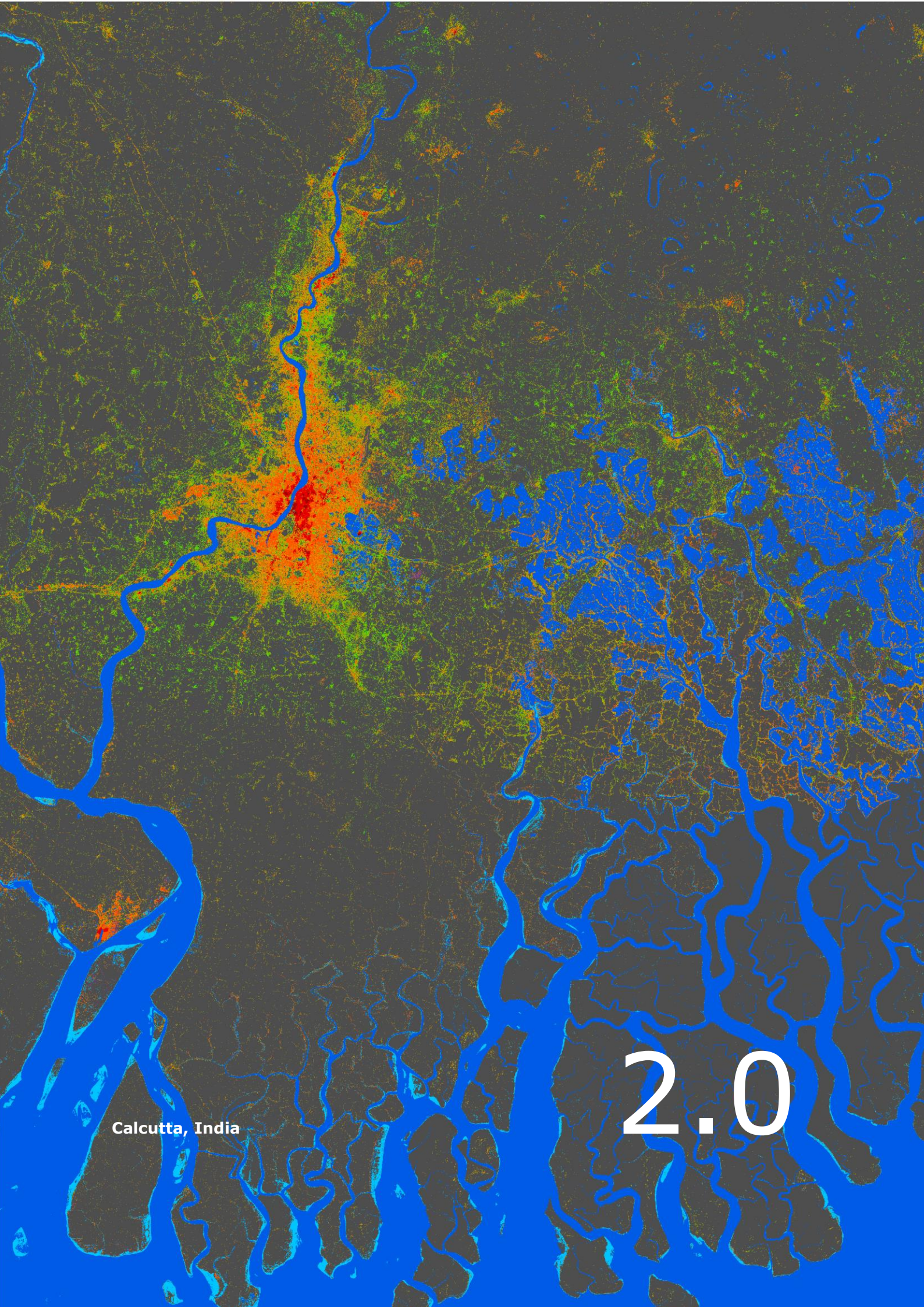
In addition to high spatial resolution data, GHSL provides two more distinct advantages: cross-country comparability and timeliness. As the data source (satellite imagery) and the method of classification (automated using machine learning) do not depend on national borders, countries and cities can compare themselves to understand which cities are faced with a similar situation. Currently, different administrative borders and differences in the methodologies to measure land cover (difference in resolution, in the number and types of classes…) make it very difficult to compare cities in different countries.

The timeliness is another substantial benefit and with the shift to the Sentinel imagery, regular updates will become feasible and more reliable. In rapidly growing cities without the means to update their maps regularly, GHSL can provide more accurate and up-to-date vision of their city. Remote sensing also has the advantage that it captures formal and informal housing, whereas a planning department may only be informed of new dwellings with a construction permit.

As the cost of computing continues to fall and with open source options to analyse spatial information, using geographic information becomes within reach of a growing number of cities. GHSL wants to support this shift by providing customised data extractions on demand. This will allow any city or anyone to obtain information about their city or region free of charge. Ensuring that this information is in the public domain will allow for a greater use.

The *Atlas of the Human Planet 2016* presents a preliminary set of findings based on the newly available GHSL data. It also provides a set of show cases in different application and policy domains. The final section delivers practical instructions on how to access and handle the GHSL open baseline data supporting the *Atlas* are provided.

What is presented here is just a first step toward a general vision, where continuously improved information processing tools and open baseline data will support a more comprehensive and public understanding of our role in the planet Earth, contributing to the collective discussion and evaluation of possible alternative development pathways.



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2. Setting the scene

Before presenting the key findings and the applications of GHSL it is important to develop a common understanding on the concept and the methodology that were used to generate the information in this atlas.

The chapter illustrates why it makes sense to use Earth Observation systems for the study of human settlements and what are the definitions for settlements used in this *Atlas*. The section includes also a review of previous efforts to map settlements at various scales and with different data sets in order to put the GHSL in the scientific context.

The following section introduces the concept of the GHSL. The concept evolved over time and comprehension of this process will prepare the ground for the fundamentals of GHSL, which provide the necessary descriptions and definitions of all the data sets produced by GHSL. The chapter introduces only the essential parts of the concept and in particular the methodology. For an in-depth description the chapter includes a number of scientific references for further reading.

2.1 Why study human settlements using Earth Observation?

Population increase is unprecedented and so it is the growth of human settlements. Population estimates assembled by the United Nations Agencies (United Nations 2015b) report on the nearly tripling of world population in the lifespan of the authors, from the nearly 3 billion in 1960 to the nearly 7.5 billion at the moment of writing. Population growth is accompanied by the physical growth of settlements for which there is no corresponding global figure, only rough estimates (Seto, Güneralp, and Hutyra 2012). In fact, the physical size of villages, towns, cities, megacities remains unaccounted for. Questions such as: **How much of Earth Surface is covered by settlements? How much and how fast are settlements growing? Where are they growing most?** Where are settlements growing on an unsustainable path, remain open questions. That physical size and its growth impacts societal processes at all levels (resilience) and good settlement information are required to guide country development plans, issue legislation aiming at developing risk free and sustainable societies (United Nations, General Assembly 2015). Earth observation is the most promising measurement system to address the assessment of human settlements from local to national and global scale (Martino Pesaresi, Guo Huadong, et al. 2013).

Population are accounted through censuses that are carried out by country statistical departments but not all countries keep up with the updates and most censuses do not account for physical size of settlements. Population censuses address the location, temporal dynamics, age structure, social wellbeing of population among many other characteristics. Censuses provides also information on the use dwellings like the average living space per person or the proportion of rural and urban population as reported by each country. However, **censuses do not report on physical variables that can provide an understanding of the spatial size of towns, villages or cities, or their physical characteristics**. In addition, the delays in carrying out the censuses and delays in reporting the findings leave many countries with no updated figures on population. These shortcomings are often addressed through global statistical models using physical spatial settlement information derived from satellite imagery to estimate current population spatial distribution (Freire Sergio, MacManus, Kytt, et al. 2016).

Settlements increase as a result of population growth within settlements and also as a result of urbanization. Urbanization is intended herein as the socio-economic process that moves people from low density-agricultural based environment to high-density-service sector based economy in large cities and settlements. Urbanization dynamics are complex and vary from continent to continent. The processes may be different but results may be similarly described as an increase of population that migrate to larger settlements in search for better livelihood that all require shelter, working environments, and facilities. That growth expands the physical size of settlements and with it the management challenges of larger functional bodies that require energy, resources, defence to natural hazards.

Human settlements are referred to as urban when of high population densities – as in cities – and as rural when related to low population densities – as in villages or hamlets. The urban-rural dichotomy that is the basis for census statistical accounting worldwide may not be adequate to fully describe urbanization patters and settlement growth today (Morrill 2004). In fact, the increase in settlement physical size as well as in population is not only associated with cities and megacities but also with that of smaller settlements. While the measurement of larger cities and megacities is relatively well documented, the location and growth of smaller settlements is largely unaccounted for and thus limiting our understanding of the new challenges of urbanization (Tony Champion and Graeme Hugo 2003) and the associated demographic processes that are at its core (Montgomery 2008) .

The need for global settlement information goes beyond scientific enquiries and has practical implication related to local and global sustainability. **Information on location**

and size of human settlement are used to model access (to services, market, industrial infrastructure, food, water, land), **exposure** (to natural / man-made hazards, disasters, pollution), and **impact** (of human activity on land and water ecosystems). In fact, global human settlement information are in demand by a number of institutions operating globally including the European Commission Services for Development and Humanitarian Aid[10], the United Nations agencies and programs, the World Bank, as well as the donor countries that require quantitative variables to prioritize their humanitarian and development aid or their national investments.

Crisis management relies on information on the hazard, exposure and vulnerability. The physical size of human settlement is the main information source for physical exposure. In fact, satellite imagery is an important data source used to quantify the building stock (Daniele Ehrlich et al. 2010) and the lifeline that can be harmed by hazard impacts. Satellite imagery can be used to derive exposure at all scales (D. Ehrlich et al. 2013; Daniele Ehrlich and Tenerelli 2013; Martino Pesaresi, Guo Huadong, et al. 2013) and exposure at the global level is mainly derived from human settlement information such as that of GHSL (Martino Pesaresi and Freire 2014).The different phases of crisis management including risk assessment, alerting of disaster and emergency response all require exposure information and all at fine detail that is not available to the degree required. Global alert systems such as the Global Disaster Alert and Coordination System (GDACS)[11] rely on models with exposure and vulnerability as the weak link of the model. **The more precise the information the better will be the outcome of the alert**. Similarly, disaster risk models rely on same exposure variables with the difference that it may need to take into account also the expanding settlements in the coming age.

In the relation between settlement location and geographical setting, **especially slopes and elevation are relevant for the risks associated to a changing climate**. Coastal and delta areas are the most fertile and suitable regions for human economic activities. Water bodies are used for transport, access to fisheries, and river deltas are among the most fertile agricultural lands. Low-lying areas are also the most vulnerable to changing climate and the potential increase in sea level (Intergovernmental Panel on Climate Change 2015). The accurate mapping of settlements location in low lying areas and the emerging hazardous zone is essential to devise mitigation or adaptation strategies. **Gravity associated to settlements in steep slope is the main underlying root cause that is triggered by hydro meteorological hazards**. These include flash floods or landslides in mountains or along steep coastal areas. Similar risks are emerging in a number of fast developing cities of low income countries such as Lima and Caracas (Intergovernmental Panel on Climate Change 2015, chap. 12).

As highlighted during the Habitat III preparatory process, up-to-date information about land use and cover, cadastral systems and vulnerable areas should be incorporated in the planning process, especially at local level. "Open and easily accessible geospatial data can support monitoring in many aspects of development, from health care to natural resource management. They can be particularly effective especially in spatial analyses and outputs that can also be compared worldwide. Considering the challenge of handling large amounts of data (both in terms of know-how and costs), local and regional authorities can work together with national and international institutions and research centres to make the most effective use of open, easily accessible data." (Preparatory Committee for the United Nations Conference on Housing and Sustainable Urban Development (Habitat III) 2016)

Human settlement information are also used for developing indicators for the four post-2015 international frame-works including 1) Sendai framework for Disaster Risk Reduction (DRR) (United Nations 2015a), 2) Sustainable Development Goals (SDG) with particular focus on Goal 11 (make cities and human settlements inclusive, safe, resilient, sustainable), 3) Paris Climate Agreements and 4) the New Urban Agenda (to be

[10] http://ec.europa.eu/europeaid/about-development-and-cooperation-europeaid_en
http://ec.europa.eu/echo/
[11] http://www.gdacs.org/

adopted in Quito, Ecuador in October 2016). In fact, to monitor the implementation of the SDGs, it will be important to improve the availability and access to data and statistics to ensure that no one is left behind in the information gaps.

The lack of consistency in global settlement information produced through census campaigns and released in aggregate form by **UN has promoted the science community to invest in extracting information from the available satellite remote sensing archives and plan to process future incoming imagery**. Satellite image archives provide globally-consistent measurement system of earth surface characteristics; it is updated regularly and frequently and with increased spatial resolution and still provides a synoptic overview that is considered objective.

2.2 Mapping and measuring human settlements from remote sensing

Remote sensing technology and information extraction techniques have improved steadily in the most recent years. The first attempts to map settlements globally relied on coarse scale resolution imagery. The outcomes have been used extensively for mapping mainly cities and megacities. In fact, global human settlements have mostly been mapped from low to moderate resolution (300m - 1000m spatial resolution) (Potere and Schneider 2007) and with estimates that varies significantly (Schneider, Friedl, and Potere 2010) .

Changes in the physical size of settlements have been measured from a combination of coarse and moderate resolution imagery as well as from medium resolution imagery. For example, DMSP/OLS night time lights and SPOT-VGT data were used to detect changes between 1998 and 2008 in India by (Srinivasan et al. 2013) . MODIS 500m resolution images were used by (Mertes et al. 2015) to map urban areas in East Asia from 2000 to 2010.

Landsat imagery have been also very often used to map of the built environment. Angel and his team (Angel et al. 2015) mapped 120 cities over 1990 and 2000. Taubenböck et al. (Taubenböck et al. 2012) conducted a systematic analysis of 27 current mega cities using multi-temporal Landsat data from 1975, 1990, 2000 and TerraSar-X data from 2010.

The availability and the processing of new generation of global medium resolution imagery have provided new opportunities to generate built-up information. The Terrasar-X was also used in the TanDEM-X mission to generate a Global Urban Footprint (GUF) for the years 2011-2013 by (Esch et al. 2013). Global finer scale built-up areas mapping from Landsat was delivered by the Monitoring of Global Land Cover (FROM-GLC) project for the year 2006 as reported in (Peng Gong et al. 2013) (P. Gong and Howarth 1992). In FROM-GLC, only one epoch (circa 2006) was processed, and the impervious surfaces resulted with not satisfactory classification accuracy as presented in (Ban, Gong, and Giri 2015) and (Peng Gong et al. 2013). Successive experimental activity tried to inject in FROM-GLC output the urban or impervious information derived from third-parts, low-resolution satellite-derived information. Finally, a 30m resolution global land cover (GlobeLand30) was produced in 2014 (Yu et al. 2014).

The GHSL builds on past experiences and on different resolution settlement products and reports on processing 40 years of Landsat imagery for mapping the global built-up areas from 1975 to 2014 (M Pesaresi et al. 2016). The section bellow summarises the methods, the results the limitations and the way forward.

2.3 The Global Human Settlement Layer Concept

The GHSL concept was introduced by the JRC in the years 2010-2011 with the aim of providing improved, ready-to-use or pre-calculated baseline data reporting about the human presence on the globe in support to crisis management applications.

A first experiment tested the use of 75-m-resolution ENVISAT ASAR satellite data for large-area assessment of built-up areas[12], followed by other experiments aiming to test the capacity to derive consistent information about the presence of built-up areas from heterogeneous set of metre and sub-metre resolution satellite data input (M Pesaresi et al. 2011). More generally, the GHSL concept was born in the frame of research and development of new remote sensing data processing and automatic image information retrieval technologies in support to global crisis management (GCM) and disaster risk reduction applications (M Pesaresi et al. 2010). In this context, detailed, updated and internationally-comparable spatial information about population, built-up structures and infrastructure was mainly used as baseline necessary for post-crisis/post-disaster damage assessment, consequence assessment of the population needs, and reconstruction monitoring. The GCM user context, data scenarios and operating experience were strongly influencing the data processing paradigm implemented in the GHSL concept and largely contributing to the successful design of a system that was able to deliver the first globally complete map of built-up areas using decametric-resolution satellite sensors.

The GHSL data processing paradigm was based on two main assumptions, inherited from the GCM operating experience: i) the necessity to handle real-world input data scenarios including large data volume, unavoidable data gaps, documentation gaps, data abstraction, model gaps, inconsistencies, and heterogeneous sources integration and ii) the necessity to handle real-world information needs and user requirements scenarios including unavoidable level of disagreement on abstract definitions and information priorities in multi-stakeholder international user communities as well as stringent time constraints. The two assumptions above lead to a pragmatic design of the GHSL information production system pushing in two interlaced development areas:

i) new, more efficient and more robust computational approaches allowing fast, data-driven information extraction, model prototyping and information output in complex, large-volume data scenarios (Martino Pesaresi 2014; M Pesaresi et al. 2016), and
ii) new, less abstract classification schemas as compared to the dominant land use/land cover classification paradigms in remote-sensing-data-derived products (M Pesaresi and Ehrlich 2009) with the objective to improve sematic interoperability and reusability of the information products derived from automatic classification of remotely sensed data.

Spatial data reporting about the presence of population and built-up infrastructure have a large societal benefit. They are necessary for any evidence-based modelling and informed decision making related to i) human and physical exposure to threats as environmental contamination and degradation, natural disasters and conflicts, ii) impact of human activities on ecosystems and iii) human access to resources.

The mature GHSL concept as used in the *Atlas of the Human Planet 2016* aims to support the post-2015 international frameworks: the UN Third Conference on Housing and Sustainable Urban Development (Habitat III, 2016), the post-2015 framework on sustainable development goals (SDGs), the UN Framework Convention on Climate Change, and the Sendai Framework for Disaster Risk Reduction 2015-2030. Post-2015 international frameworks are accompanied by targets and will be further elaborated through indicators that focus on measurable outcomes. These indicators are action oriented, global in nature and universally applicable. From this perspective, the GHSL is a prototype platform allowing to test and discuss collectively alternative of the indicators. For this purpose, the GHSL information production system is based on a modular hierarchical abstraction

[12] https://ec.europa.eu/jrc/en/news/mapping-human-settlements-globally-8276

schema facilitating the knowledge sharing and the conceptual convergence in case of complex, multi-lateral, multi-stakeholder international processes.

From the general point of view, the GHSL information production paradigm is based on the processing and integration of three main data sources: generalized multi-sensor and multi-temporal remote sensing image data streams, population census data and crowd sources as voluntary geographic information. The data processing methods implemented by the GHSL privilege automatic and reproducible methodologies, allowing public scientific control of the results and of the intermediate results. Moreover, allowing the consistent and systematic process of large masses of fine-scale global data with a cost-effective approach.

The rationale behind the automatic data mining and analytics as implemented in the GHSL it is consistent with the aim of moving the human intelligence efforts from the information gathering to the analytics. The decrease of the information production costs thanks to the efficient algorithms designed in the GHSL information production workflow aims to facilitate the information sharing and the multilateral democratization of the information production, and consequently aims to the facilitation of the collective knowledge building.

The GHSL operates in an open and free data access policy including the full data production and dissemination cycle (open input, open processing methods, open outputs, open sharing platforms), with the mission of improving the public and scientific control of the evidences supporting the monitoring of the post-2015 international frameworks, improve the integration and the quality of global open and public baseline data describing human settlements, facilitate multi-lateral convergence on facts and figures assessing the human presence in the planet, and maximize the access to data and statistics to ensure that no one is left behind in the information gaps.

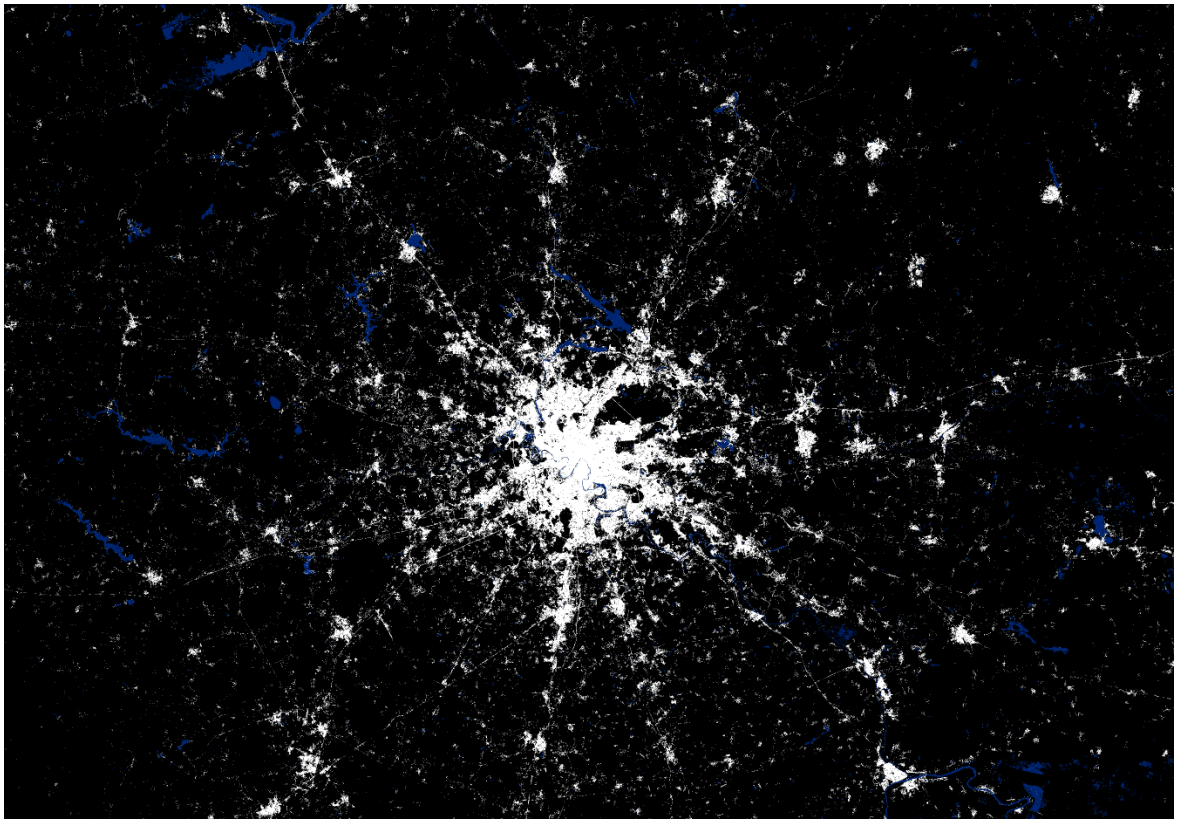


Image 1 GHSL built-up 2015 – Moscow, Russia Fed.

2.4 Fundamentals of GHSL

The GHSL consists of three main information components hierarchically placed at three different levels of abstraction: Global Human Settlement built-up areas (GHS-BU), the GHS population grids (GHS-POP) and the GHS urban/rural classification model (GHS-SMOD).

At the base of the hierarchy - including the most spatially accurate and the least abstract information level - we have a layer collecting concrete evidences about the human presence on the planetary surface as seen from global Earth Observation systems. In the GHSL paradigm, the fundamental link between Earth Observation sensor data and the human presence is the observable presence of built-up structures or buildings. From the GHSL perspective, the "building" makes the physical part of the human settlement fabric or spatial extension that is observable and measurable using the available global sensors. At this basic level the GHSL reports about *built-up areas (GHS-BU)*, as *areas (spatial units) where buildings can be found* {Pesaresi_al_2013}. The concept of "buildings" formalized by the GHSL are *enclosed constructions above ground which are intended or used for the shelter of humans, animals, things or for the production of economic goods and that refer to any structure constructed or erected on its site {ref:* Pesaresi_al_2013}. This abstraction is very similar to the standard topographic definition of the "building" class as compiled in the INSPIRE directive[13], except for the fact that the condition of the *permanency of the structure* it is not in the GHSL definition. This fact allows to include also refugee camps, informal settlements, slums and other temporary settlements and shelters in the notion of *built-up area* in the GHSL concept.

The intermediate abstraction information layer of the GHSL is the population grid or GHS-POP that is produced in an in-between spatial resolution. This information layer is derived from the combination of global collections of national population census data and global built-up areas as extracted from Earth Observation data analytics (GHS-BU). In the approach taken by the GHSL, the population data collected by national censuses with heterogeneous criteria and heterogeneous update time are harmonized in the space and time domains in to the GHS-POP grids, by systematic and consistent application of the same set of data interpolation and spatial disaggregation methods to the best available global spatial baseline data {Freire_al_2016}.

The top abstraction information layer of the GHSL it is the urban/rural classification model (GHS-SMOD). It is provided with the least spatial detail (1 km) by combining the two less-abstract and more-spatially-detailed built-up and population grids, GHS-BU and GHS-POP, respectively. The GHS-SMOD model implemented by the GHSL it is consistent with the "Degree of urbanisation" (DEGURBA) model adopted by EUROSTAT[14]. It discriminates 3 settlement class abstractions: 1) Cities, 2) Towns and suburbs and 3) Rural areas. The discrimination is based on the population density in the square kilometre grid[15], total settlement population and other spatial generalization parameters.

In the GHSL paradigm, the base layer GHS-BU it is designed to be the most stable against different visions and approaches, while GHS-SMOD is the most abstract and as such exposed to conceptual changes and alternative problem settings proposed by the different stakeholders involved in the post-2015 international framework processes. The modular hierarchical abstraction schema used in the GHSL design allows to protect the investment made in the global, fine-scale information gathering from perturbations on the abstract classification schema that may be introduced by different decision-makers involved in the process and potentially producing different problem setting and abstractions. On the other side, the modular hierarchical abstraction schema facilitates the test of alternative abstract

[13] INSPIRE Infrastructure for Spatial Information in Europe D2.8.III.2 Data Specification on Buildings – Draft Technical Guidelines http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_BU_v3.0rc3.pdf
[14] http://ec.europa.eu/eurostat/web/degree-of-urbanisation/overview
[15] densely, intermediate density and thinly populated areas

models on the same agreed information baseline, facilitating the discussion and the comparison of the results also between international stakeholders not necessary sharing the same high abstraction definitions.

The following section helps the reader to understand fundamental concepts of GHSL and its data. The first subparagraph deals with extraction of information from satellite imagery (2.4.1) and built-up definition.

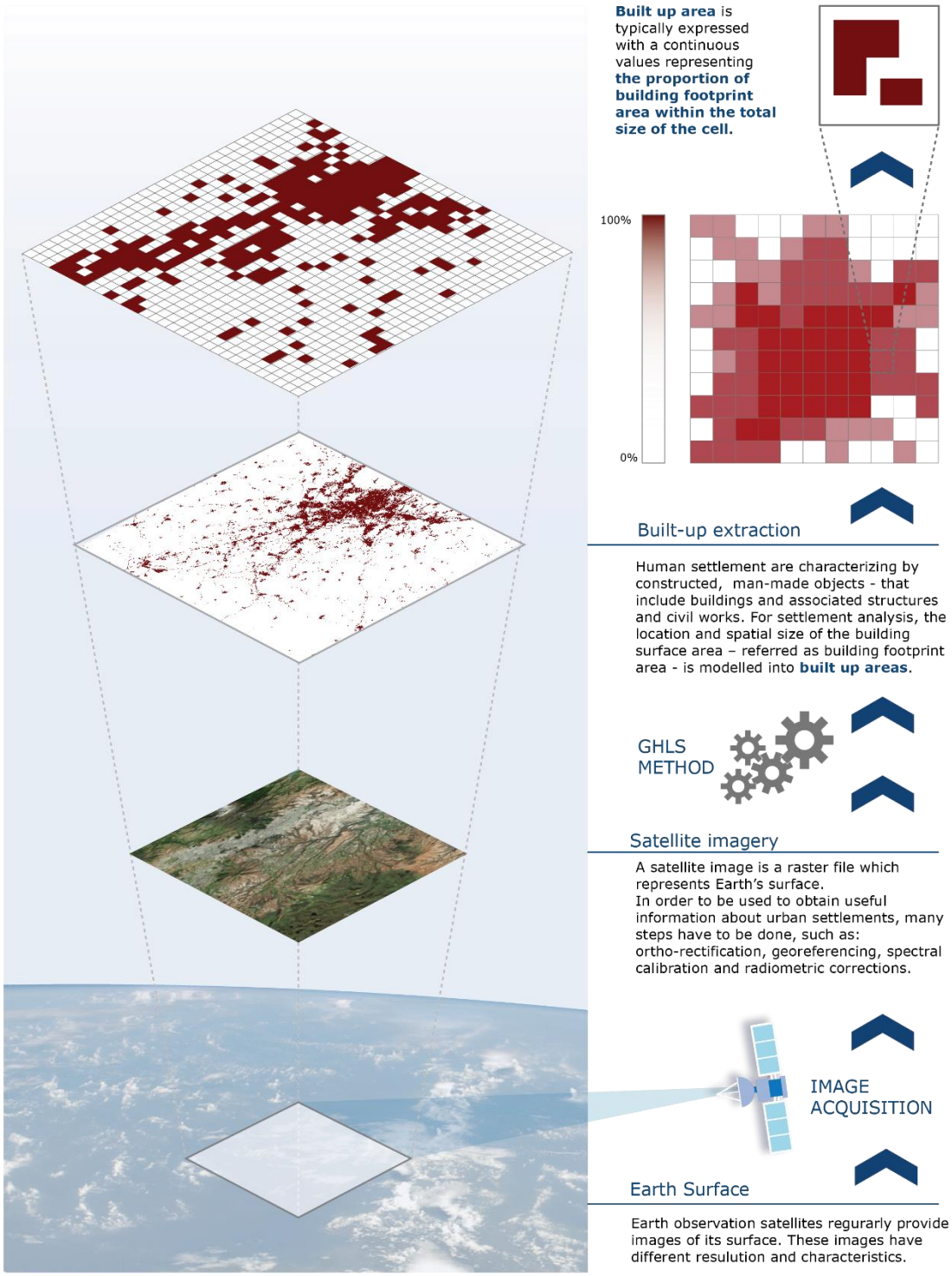
The second paragraph explore the process allows to combine built-up grids with census data to produce the population grids (2.4.2).

The third paragraph (2.4.3) illustrates the key elements and rules of the settlement model, derived from the New Degree of Urbanization (Lewis Dijkstra and Hugo Poelman 2014): specifically, the rules for defining *Urban Centres*, *Urban Clusters* and rural settlements are illustrated.

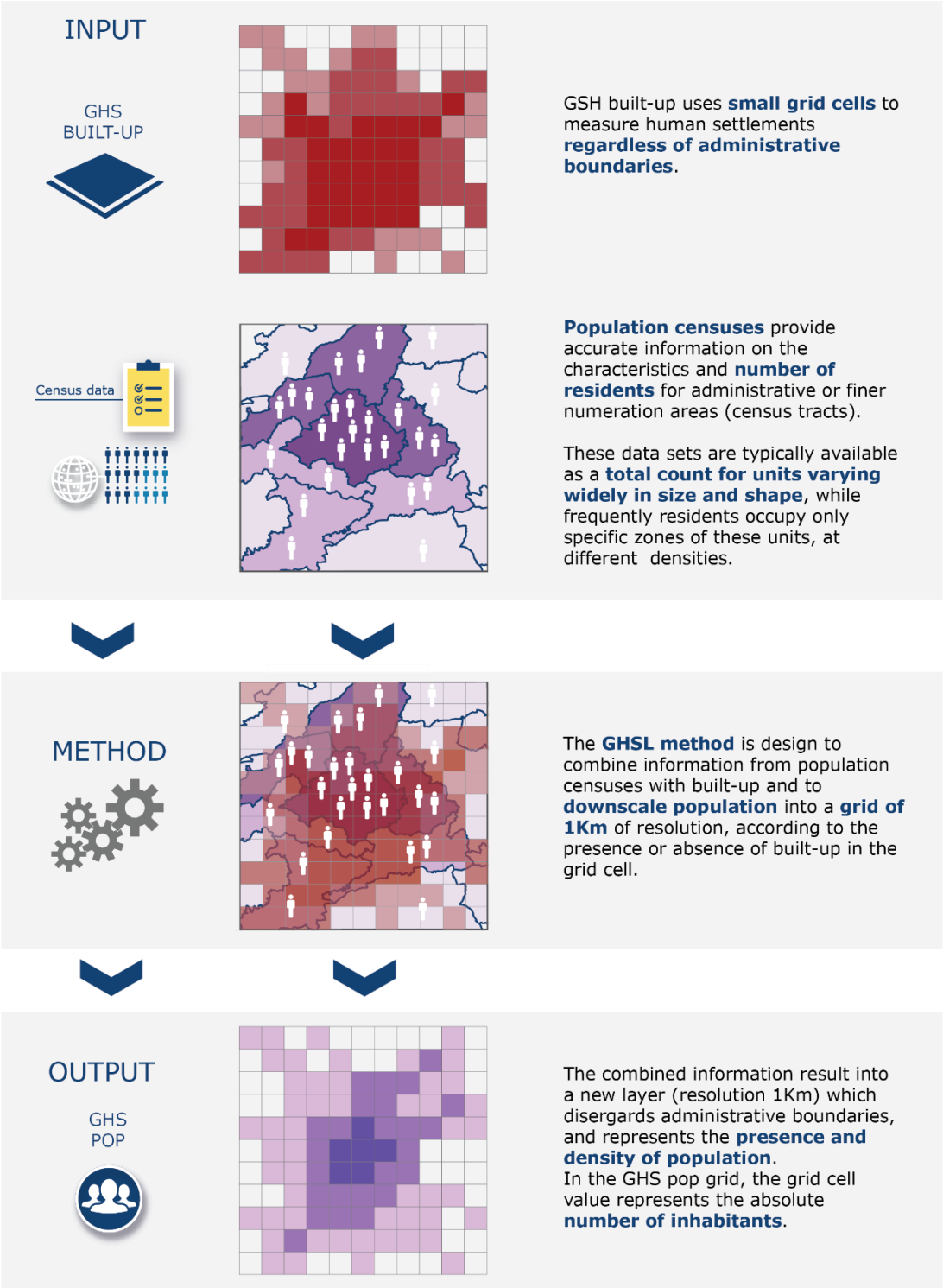
The forth paragraphs show with simple images, and example of three GHSL datasets (GHS Built-up, GHS POP and S-MOD) for the city of Madrid, Spain (2.4.4).

Image 2 © artefacti, Fotolia.com

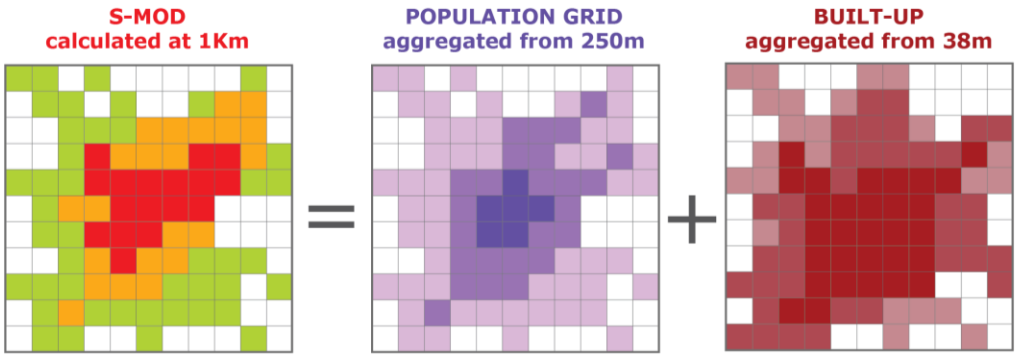
2.4.1 From Earth's surface to built-up area

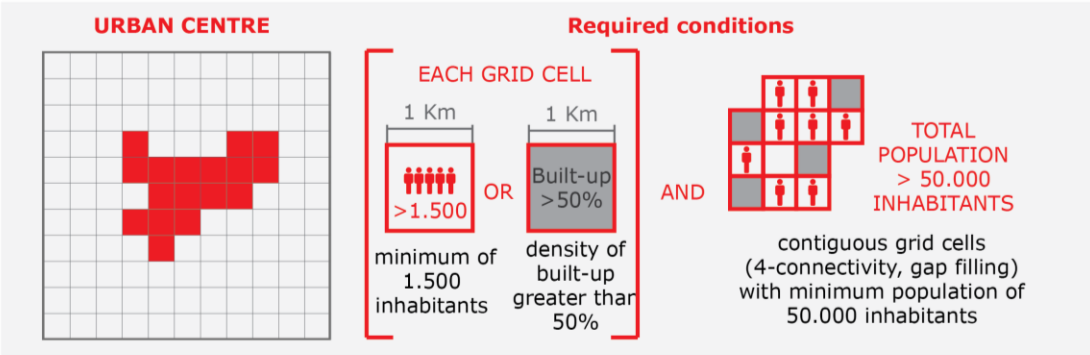


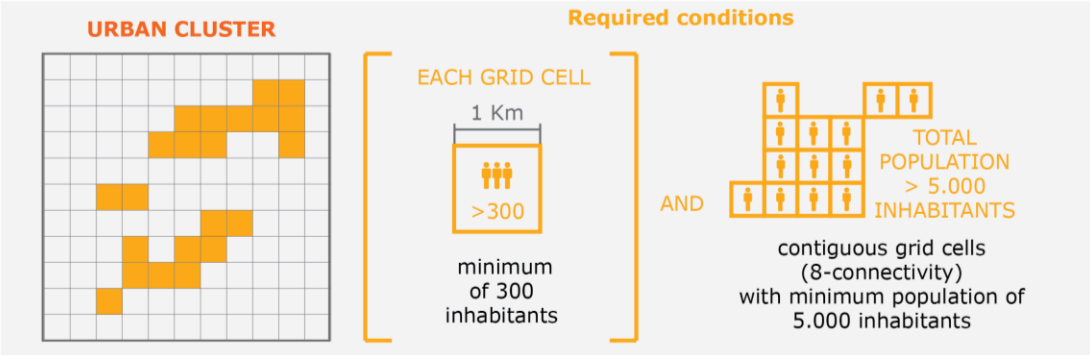
2.4.2 From Built-up area to population grid

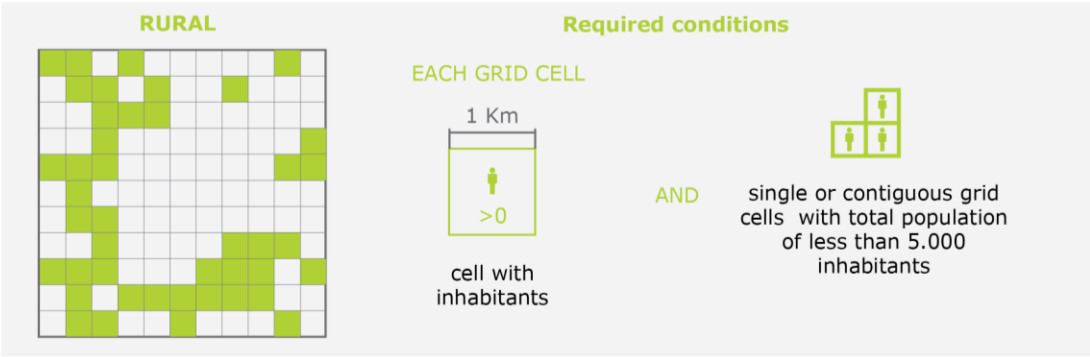


2.4.3 The GHSL Settlement Model

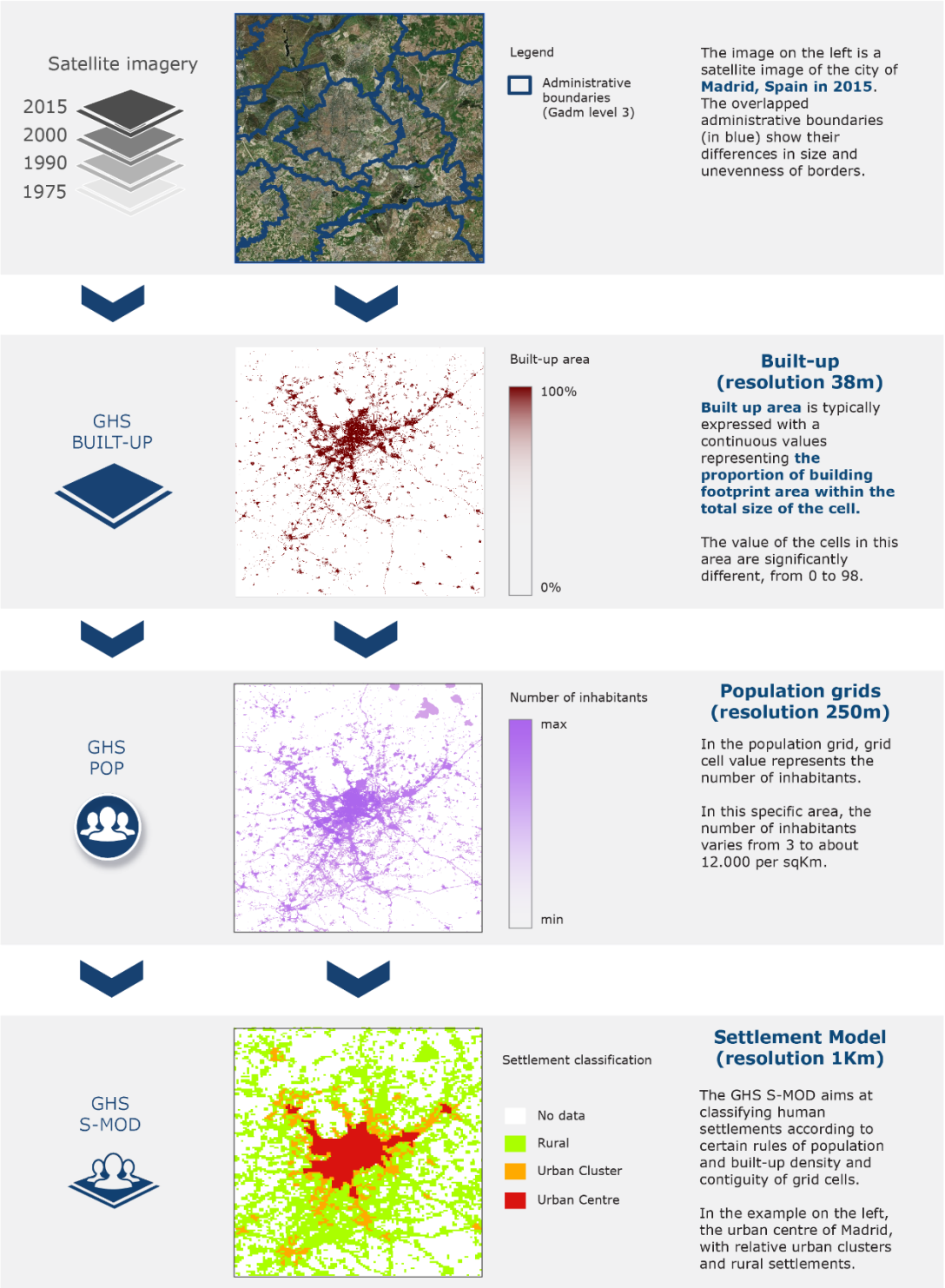








2.4.4 An example from the city of Madrid, Spain



2.5 The *Atlas*

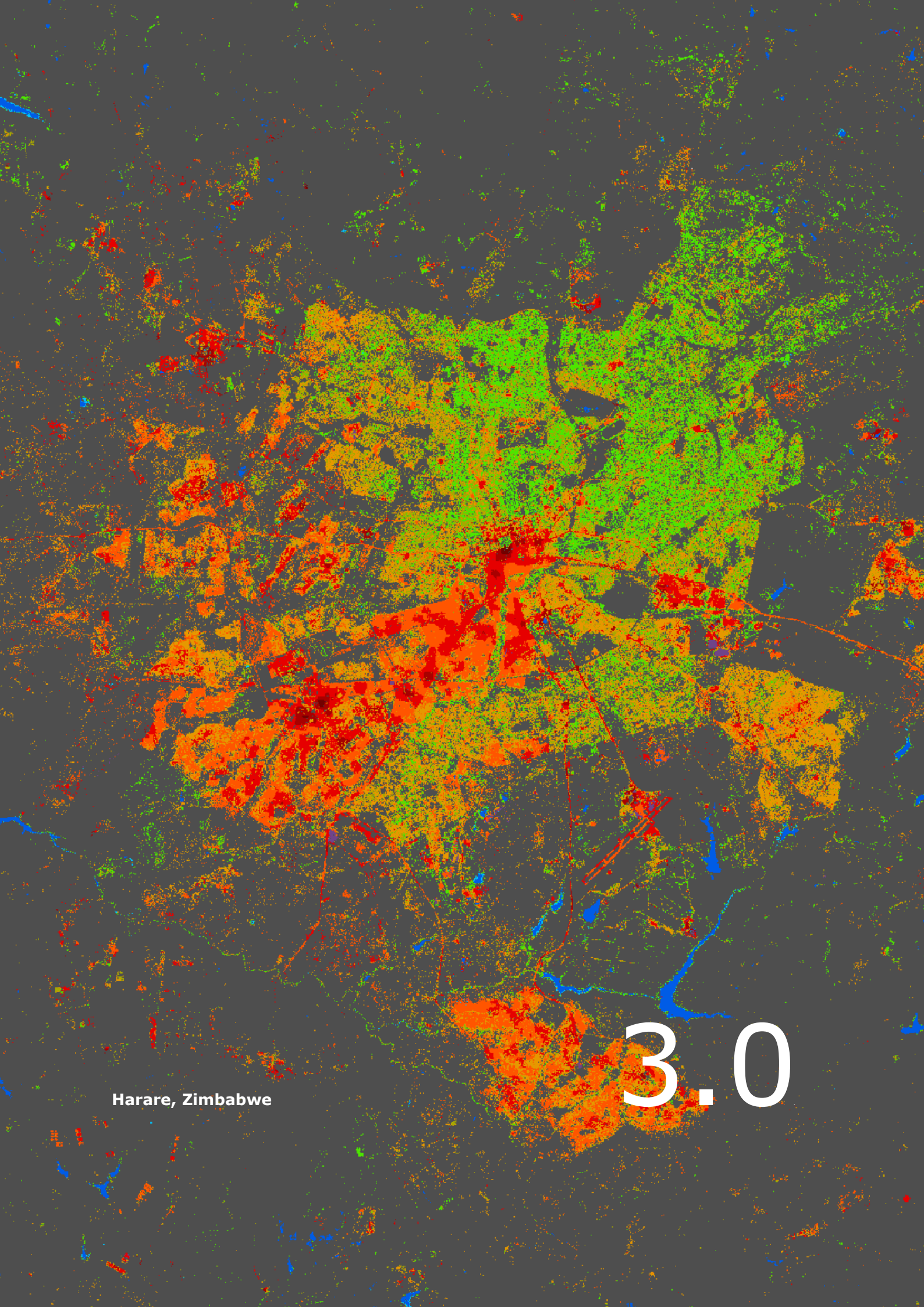
This *Atlas* has been authored and edited by a group of experts at JRC, but the GHSL team includes several expertise, such as: remote sensing, demography, statistics, informatics engineering, data managing, risk and disaster management, planning and urban sciences, among others.

The preparation of the Human Planet *Atlas* included: a) preparatory stage for the preparation of datasets; b) investigation of the database, data mining and analysis; c) elaboration of the findings and drafting of the chapters; d) consultation with the members of the Panel of Experts to validate, verify and rank the priorities about the findings; e) final editing.

The GHSL data production is one of the outcomes of the GHSL Framework, as illustrated in the introduction and in the previous paragraphs. GHS data are usually released as georeferenced raster files, but in order to be mined and analysed they have been also exported as tables at two main levels**: *Urban Centres* (more than 13,000 worldwide**); ***Urban Clusters* (more than 300,000 worldwide)**. Each settlement is identified by a unique code number in its dataset. Since each *Urban Centre* and cluster has been located in a specific country, data have been also aggregated at country, income group and regional level. The information has been analysed by a team of experts, and shared with the panel of experts, that commented, reviewed, validated, verified, and ranked the key findings. The second part of the *Atlas* illustrates the most relevant findings about urbanisation status and dynamics emerged during this process.

The final editing of the *Atlas* involved the whole GHSL Team and lasted several months: contributions from partners about GHSL applications have been collected in the third part of the document.

Image 3 Global mosaic of GHSL tiles


Harare, Zimbabwe
3.0

3. Urbanisation Status and Dynamics

This chapter presents the key findings on the amount of built-up and population at global, and regional/continental levels. It also presents examples on the role of income classes on the distribution of the two variables.

Urbanization statistics are based on the extraction of built information from satellite imagery collected over time. Forty-year collection of satellite imagery are turned into four global built up layers centred on the years 1975, 1990, 2000 and 2014. In addition, the global built up is used to downscale census based population data available at administrative boundaries to produce gridded global population data over four epochs. The statistics on urbanization described herein include both the physical increase in built up areas, as well as the increase in population.

The first graph illustrates the total global population and the global amount of built-up. The two graphs are split per continent. The total population and global built up in time are then included in a scatterplot. More in depth analysis illustrates the increment of built-up at continental level, also by comparing increase rate across continents and against the global average. Finally, maps track the dynamics of built-up and population growth disaggregated by country work that is also presented in detail in (chapter 3.1), global urbanisation trends and regional differences (chapter 3.2) and city level analysis (chapter 3.4.13.4).

The GHSL datasets can be combined with other geospatial information layers to produce additional knowledge. This chapter showcases the combination of GHSL with elevation data for disaster risk assessments (chapter 3.5), an assessment of urban green (chapter 3.6) and the analysis of night-lights in urban areas to reveal economic differences of countries and regions (chapter 3.7). The groupings of the countries, that by continent and that by income classes, are based on the definitions of the United Nations Population Division (see Annexes 2 and 3 for details).

Image 4 © Dudarev Mikhail , Fotolia.com

3.1 Global and regional analysis of built-up and population

The core baseline products of the GHSL addressing urbanisation are the global multi-temporal built-up and global population layers for the four epochs. The statistics are produced by combining gridded built-up and the population at the country level.

The gridded built up and population are thus summarized based on the country administrative borders.

The regional statistics – mostly based on continental grouping of countries - are based on the sum of the statistics at the country level for a given continent. The global figures are summaries of the statistics computed for all the countries of the world. This section depicts first global, then regional statistics, and finally country statistics.

Image 5 © rudi1976, Fotolia.com

3.1.1 Built-up and population by continent in 2015

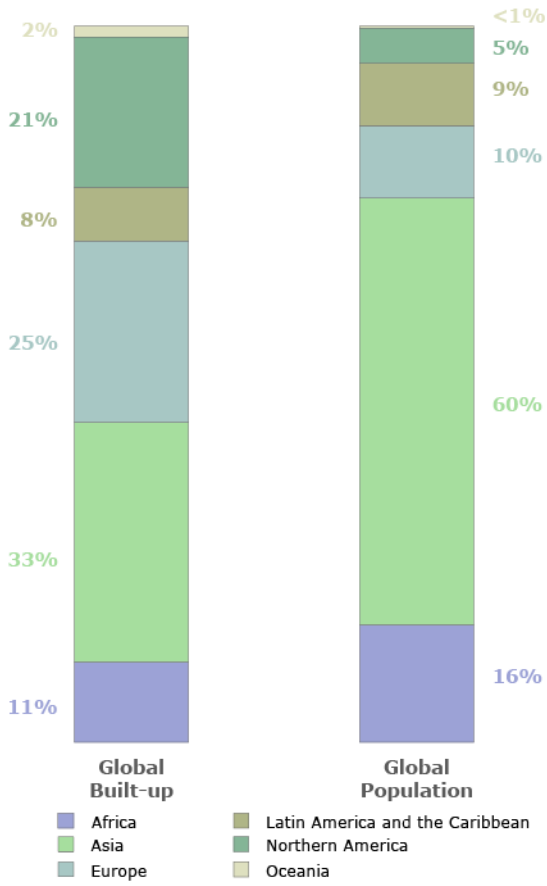


Chart 1 Global distribution of built-up and population in 2015 by continent

Today Asia is the continent which hosts most of global built-up and population. More than 1/3 of global built-up and nearly 2/3 of population are accounted in Asia. The other continents, instead present clear unbalance between built-up and population distribution. With 200 thousand square kilometres and nearly 740 million people **Europe accounts for 25% of global built-up and 10% of world population**. Similarly, **Northern America hosts more than 20% of global built-up and 5% of global population** (hosting 360 million people,).

Africa and Latin America and the Caribbean show the opposite trend. Africa hosts 16% of global population (1.2 billion people) and 11% of global built-up (86 thousand square kilometres). **Latin America and the Caribbean account for 9% of global population** (equivalent to 634 million people) and 8% of global built-up, (60 thousand square kilometres).

Historical trends of built up differ significantly across continents. In Africa, only 25% of today's built up was already constructed in 1975; while in Asia, only 30% was constructed in 1975. Europe and North America built-up growth is less impressive; 50% of the built up was already detected in 1975. The global statistics account for 40% of today's global built up detected in 1975 (Chart 2).

Image 6 © jhonathan97, fotolia.com

3.1.2 Global Built-up and Population trends (1975, 1990, 2000, 2015)

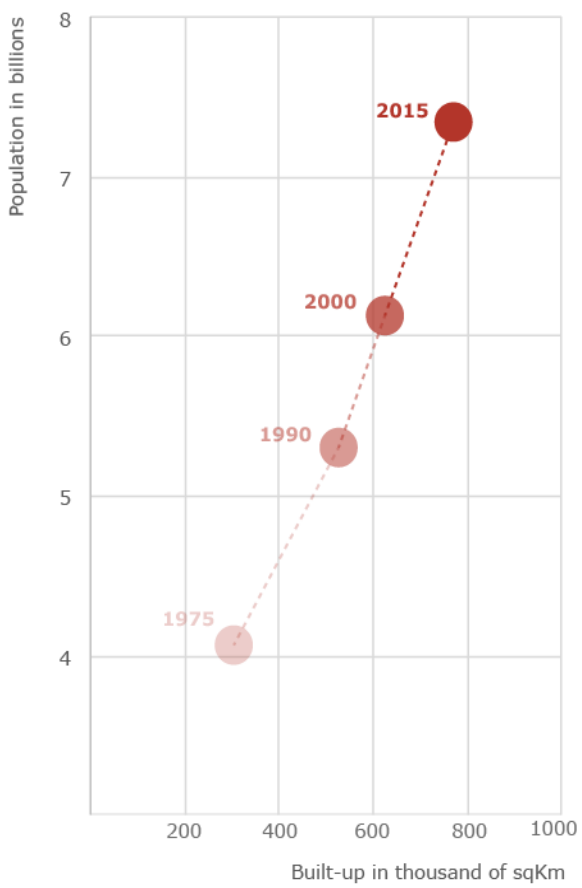


Chart 2 Global Built-up and Population trends (1975, 1990, 2000, 2015)

Global built-up surfaces have more than doubled in forty years and population has nearly doubled. Today global population exceeds 7.32 billion and the surface of built-up exceeds 774 thousand square kilometres.

If the built up areas of the world would be aggregated side by side in one single spatial unit with no open spaces, the resulting areas would resemble the size of Oman in 1975, France in 1990, South Sudan in 2000 and Turkey in 2015.

Instead the average annual growth rate of built-up and population decreases. Built-up has grown by 18% between 1990 and 2000 and by 23% between 2000 and 2015. Just in the last fifteen years more than 27 thousand kilometres of new built-up areas were constructed worldwide, a surface that is comparable to that of Cyprus and Israel combined.

At the current built-up growth rate, 1.1 million square kilometres, would be added between 2015 and 2040 to the planet. That is equivalent to an area of the size of Ethiopia.

Global Population has increased by 38% between 1990 and 2015. Over just the last fifteen years, the globe has added 1.2 billion new inhabitants.

The extent of built-up area and the size of global population poses today serious a number of challenges to global sustainable development. In fact, size and growth trends are addressed by the international community in a number of United Nations framework agreements that may provide guidance on how best to manage that growth. At regional level those trends may even be more striking and require even more urgent action to avoid the construction of risk and the reversal of the development path.

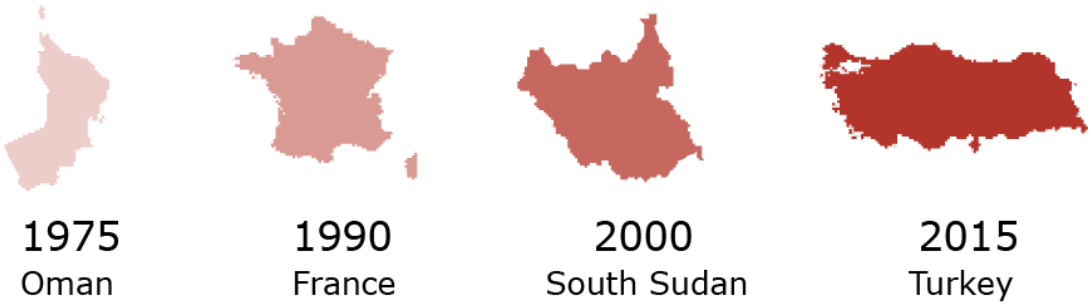


Image 7 Evolution of global built-up surfaces compared to country sizes (1975, 1990, 2000, 2015)

3.1.3 Built-up and Population trends per Continent (1975, 1990, 2000, 2015)

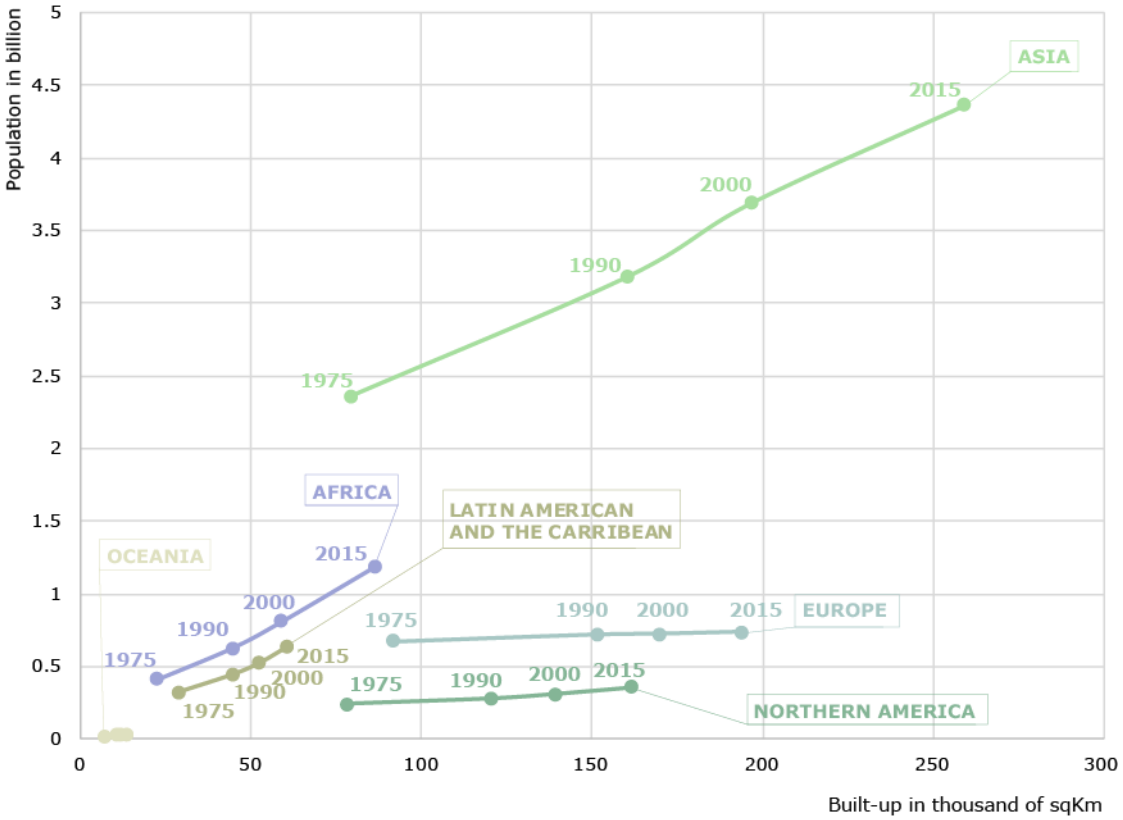


Chart 3 Evolution of Global Built-up and Population per Continent (1975, 1990, 2000, 2015)

Population and built up data collected over time can visualized together to indicate population/built-up trajectories. When plotted per continent over the 1975-2015 time frame these trajectories show evident differences.

A first group of continents (Europe and Northern America), account for a continuous increase of built-up areas, at a rate of 50% between 1975 and 2015. Population increase is far below, under 10% in Europe and slightly above 30% in Northern America.

The second group of continents includes **Asia that shows a unique pattern**. It is by far the most populated and as of the year 2000 it is also the continent accounting for most built-up. **Asia hosts nearly 4.5 billion people** and more than 250km^2 of built-up a surface that is comparable to that of Ecuador.

The third group of continents includes Africa, and Latin America and the Caribbean. The two continents showed comparable figures until 1990. Since 1990 population growth rate in Africa has been higher than the one in Asia: 52 against 35% between 1975 and 1990, 29 against 16% between 1990 and 2000 and most of all more than double the one of Asia in the last fifteen years, 46 against 18%. Also built-up in Africa increases fast, in the last forty years it nearly quadrupled, and between 2000 and 2015 it increased by more than 45%. Asia instead remains the continent where the highest absolute population increase takes place

In Latin America and the Caribbean population increases in line with global growth rate of increase, by 20% in the last fifteen years and by 18% between 1990 and 2000. Built-up in this continent has grown since 1975 at a rate below global average. The last group includes Oceania, where both built-up and population have nearly doubled in forty years.

At global level built-up has grown faster than population; only in Africa population increases as fast as the built-up areas in the last fifteen years. (Chart 4)

3.1.4 Continental Built-up increase

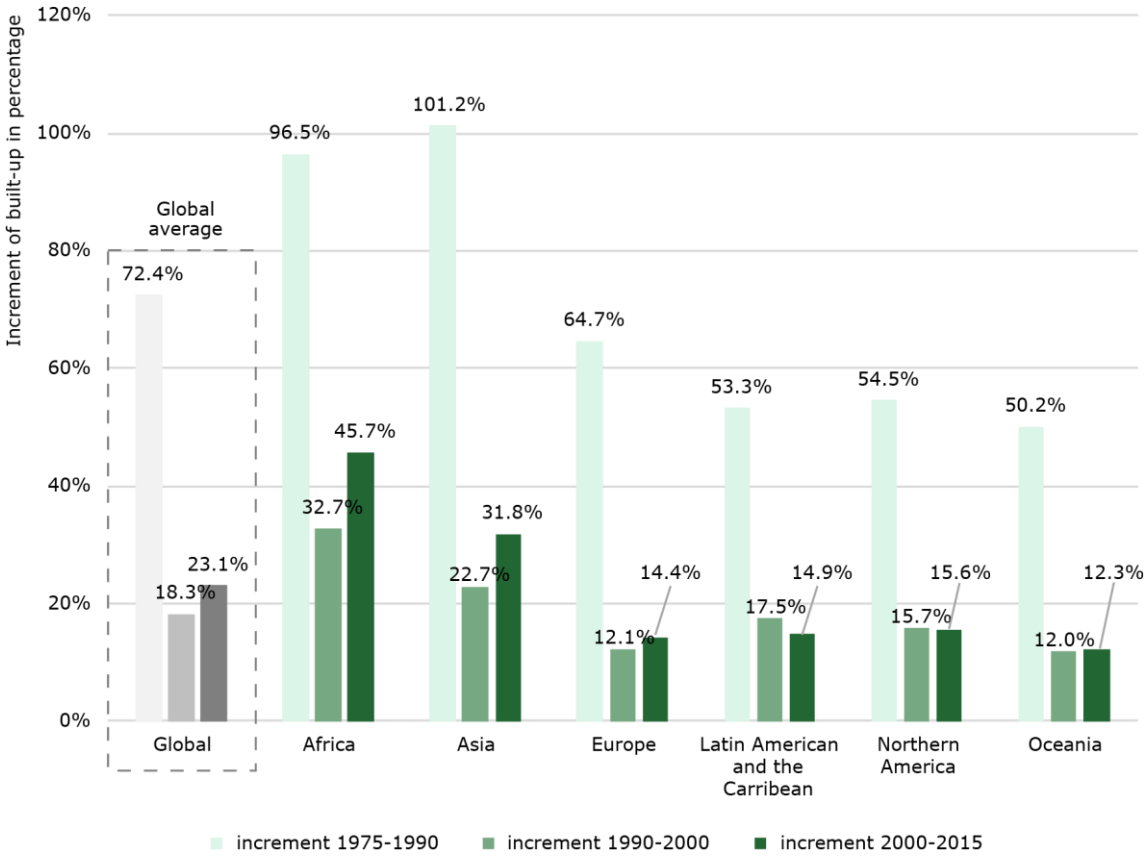


Chart 4 Increase in Regional Built-up by continent (1975, 1990, 2000, 2015)

Over the past 40 years global built-up has more than doubled. Africa and Asia have been the drivers of global built-up growth with growth rates always above 20%. Since 1990 in the globe the growth rate of built-up surfaces increases except in Northern America. The most considerable changes occurred **in Africa between 1975 and 2015 where it has nearly quadrupled and Asia where built-up areas have more than tripled**. Between 2000 and 2015 built-up in Africa nearly doubled, and more than 27 thousand square kilometres were newly built.

The increase in global built-up in Africa is equivalent to the size of the seven biggest *Urban Centres* in the world toady including Los Angeles, Tokyo, Jakarta, Guangzhou, New York, Chicago and Johannesburg. The built-up surfaces in Asia have increased by 30%, a growth that is twice the one of Africa. Theoretically to accommodate the new built-up in Asia during the last fifteen years it was possible to build two times cities such as: Los Angeles, Tokyo, Jakarta, Guangzhou//Dongguan, New York, Chicago, Johannesburg-Pretoria, Dallas, Miami, Osaka that are the cities in the world with the highest values of built-up.

Built-up growth rate in Europe is below global average and since 1975 that increment is equivalent in size to the built-up of New York and Tokyo combined.

According to income classes built-up areas have more than quadrupled in 40 years in LIC, more than tripled in LMC and nearly tripled in UMC, in HIC they more than doubled**. Over the last 25 years, built-up areas in LIC have more than doubled**.

3.1.5 National built-up and population increase (1990-2015)

Built-up and population statistics are generated also at country level. Countries can be clustered in groups according to the rates of population and built up increase as presented below: a) both built-up and population increase above global average; b) built-up growth above global average, population growth below global average; c) built-up growth below global average, population growth above global average; d) both built-up and population growth below global average.

a) **In 74 countries both built-up areas and population increased faster than global average** (global averages: built-up = 46% and population = 40%), more than half are in Africa of which half are LIC and include: Malawi, Niger, Tanzania, Chad, Senegal, Somalia and Ethiopia.

b) **In 29 countries the growth of built-up areas was not coupled with the growth of population above global average**, including: Spain where built-up increased by 47% while population by 18%, Ireland (60% and 32% respectively), Sri Lanka (52% and 20% respectively), Portugal (57% and 5% respectively) and Thailand (60% and 20% respectively) among others.

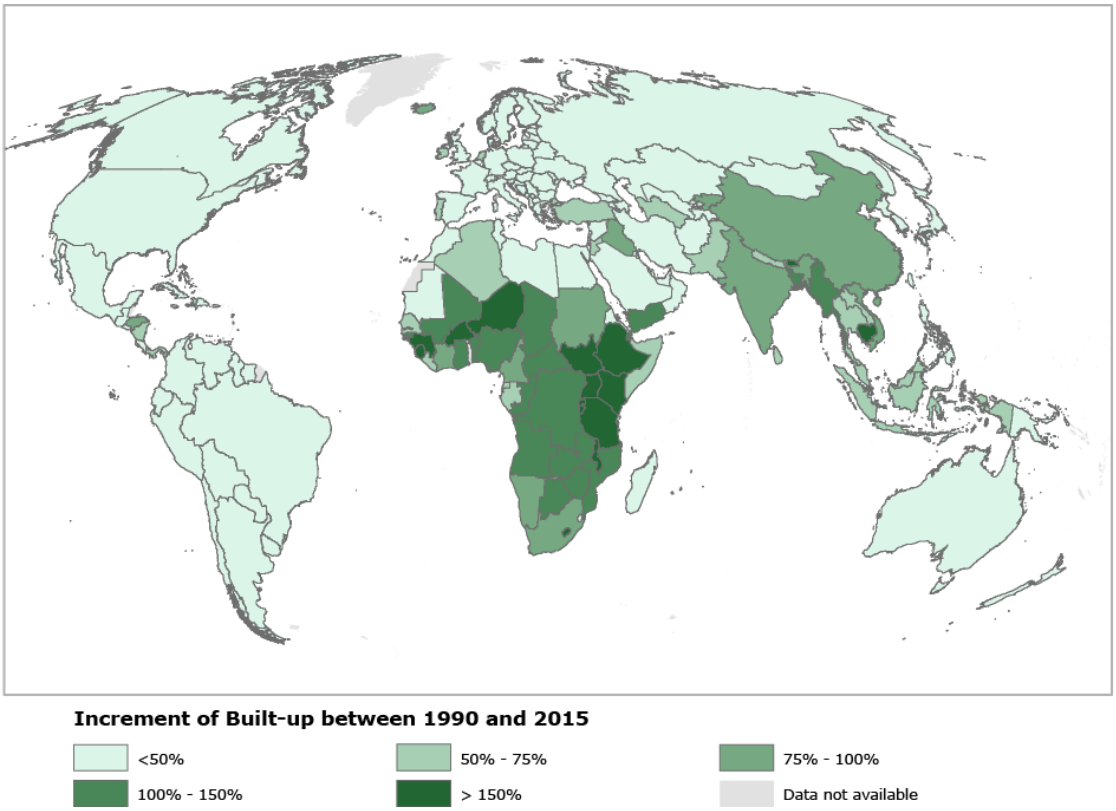
c) **Between 1990 and 2015 there are other 52 countries in which population growth above global average was not accompanied by a corresponding growth of built-up areas above global average**. This phenomenon has been mostly accounted in Latin America and the Caribbean where, for example, in French Guyana population more than doubled while built-up has increased by 20% only. Other countries including Paraguay, Ecuador, Venezuela and Bolivia account for population increase between 55% and 60% while built-up increased between 20% and 30%. In other 12 countries in the globe population has doubled while built-up increased between 11% and 43%, these counties include Qatar, Bahrain, Oman and Lebanon among others.

d) **The last grouping includes 82 countries where the increase of both built-up and population have been below global average**. 40 of these countries are in Europe and more than half are HIC and include: Italy, Austria, Norway, and Poland among others. More than 15 countries where the same pattern is observed are in Latin America and the Caribbean. In these countries population increase on average between 10% and 38% while built-up between 2% and 37%, these countries include Argentina (33% and 25% respectively), Uruguay (10% and 26% respectively), Chile (37% and 33% respectively). In Northern America, both the United States of America and Canada present both growth rates below global average. In the United States population increased at a rate of 27% equivalent to nearly 70 million people in 25 years, while built-up increased by 34% equivalent to 38 thousand square kilometres of new built-up areas. Population and built-up in Canada both increased by 30% and account for 8 million people and 2.5 thousand square kilometres of new built-up surfaces. In 22 countries population has decreased, many of these are in Eastern Europe or Central Asia.

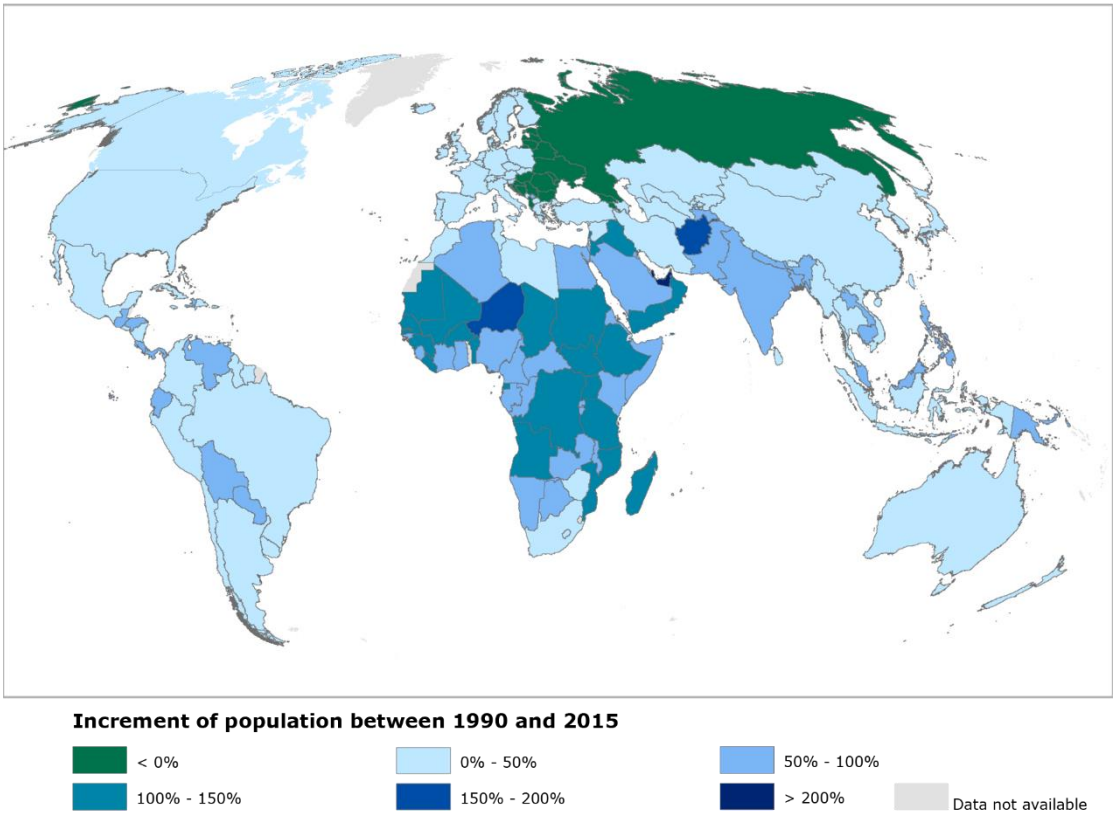
In section 3.1 it has been reported that globally built-up surfaces have increased faster than global population. However, around 100 countries show the opposite trend whereas increase in population is higher than the one in built-up. This phenomenon is not necessarily correlated to income classes as 20%of countries are UMC, 30% HIC, 17% are LIC and 14% are LMC.

Table 1 Continental split of countries where both built-up and population have doubled between 1990 and 2015

Africa	Angola, Benin, Botswana, Burkina Faso, Burundi, Central African Republic, Chad, Congo, Djibouti, Ethiopia, Ghana, Guinea, Guinea-Bissau, Kenya, Malawi, Mali, Mozambique, Nigeria, Rwanda, Sierra Leone, South Sudan, Swaziland, Tanzania, The D.R Congo, Uganda, Zambia, Zimbabwe, Niger
Asia	Yemen



Map 1 Increment of built-up between 1990 and 2015



Map 2 Increment of population between 1990 and 2015

3.1.6 Global built-up in 2015 by income class

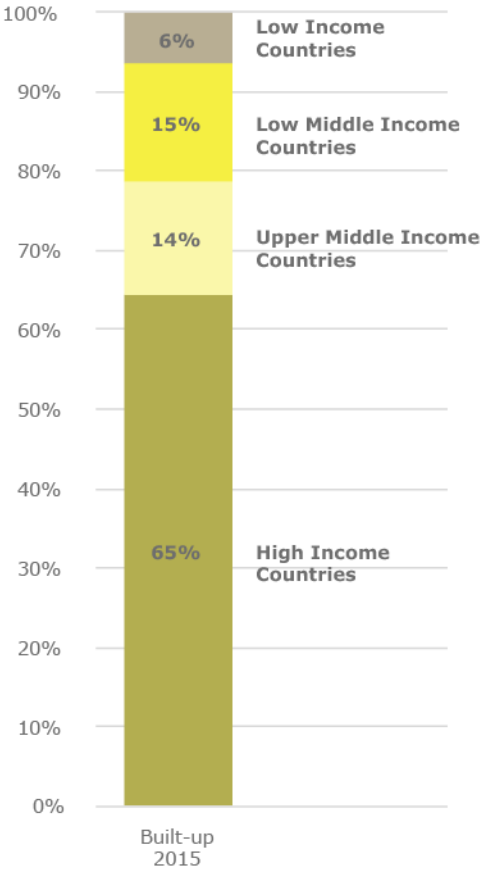


Chart 5 Global distribution of built-up in 2015 by income class

A clear pattern of the distribution of built up area per country can be associated to the level of income and class disaggregation. **In 2015 65% of global built-up is accounted in HIC, just 6% in LIC and around 15% in both UMC and LMC**. Nearly half the built-up in HIC was already constructed in 1975, while less than 1/4 in the LIC existed in 1975 (Chart 6)

The share of built-up in HIC is not equally distributed across continents, in fact 65% is concentrated in Europe and Northern America[16]. 40% of built-up in UMC is accounted in Latin America and the Caribbean, while 30% in Asia and 20% in Africa. More than 60% the built-up areas in LMC are accounted in Asia while more than 85% the one in LIC are concentrated in Africa.

Image 8 © justasc, fotolia.com

[16] For the complete data, please refer to the GHSL datasets as per Annex 4

3.1.7 Global Trends of Built-up and Population per Income Class (1975, 1990, 2000, 2015)

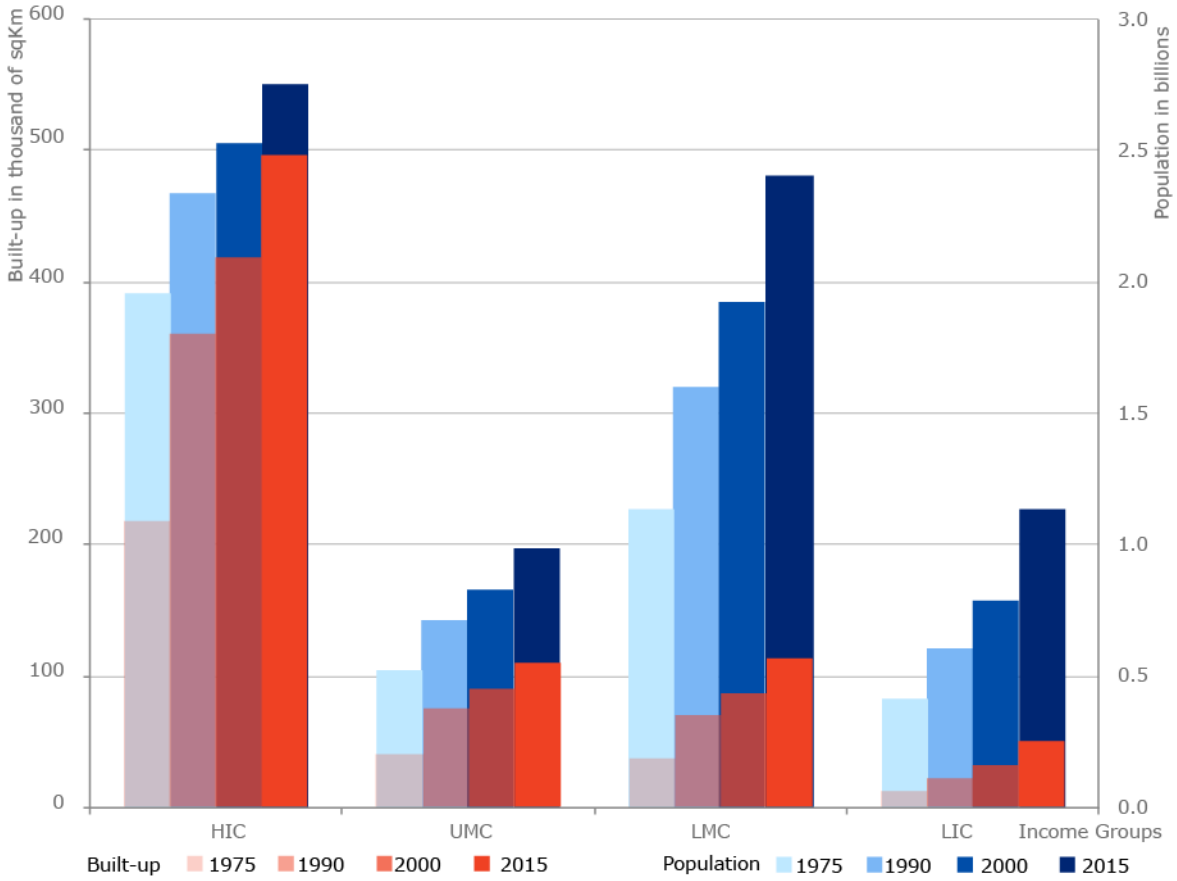


Chart 6 Built-up and Population per Income Class (1975, 1990, 2000, 2015)

HIC[17] host today the majority of global built-up and population. Instead built-up growth increases the most in LIC: in the last 40 years LIC built-up has increased by 300%. However, **the built-up gap between high and low income continues to increase**. Population in LIC is growing the fastest. In the last 40 years it increased by 176%, moving from 410 million people in 1975 to 1.13 billion in 2015.

In 1990 the amount of built-up in HIC was more than 15 times the one in LIC, in 2015 it is 10 times. Todays' population in HIC is 2.4 times the one in LIC, it was more than 4 times in 1975.

In both UMC and LMCs the built-up exceeds one hundred thousand square kilometres, instead high disparities in population are to be reported. While built-up is in both income classes around 15% of the global one, population in UMC is close to the 1 billion mark (13% of global population), while in LMC it is more than double and tops 2.4 billion (33%).

In terms of continental distribution of population in income classes: nearly 60% of population accounted in HIC is concentrated in Asia (mostly on China); 40% of UMC population is in Latin America and the Caribbean; 85% of LMC population is in Asia (especially in India), and all the population in LIC is split 70% in Africa and 29% in Asia.

[17] For the complete list of countries included in the HIC, see Annex 2 Income classes

3.1.8 *Built-up per capita*

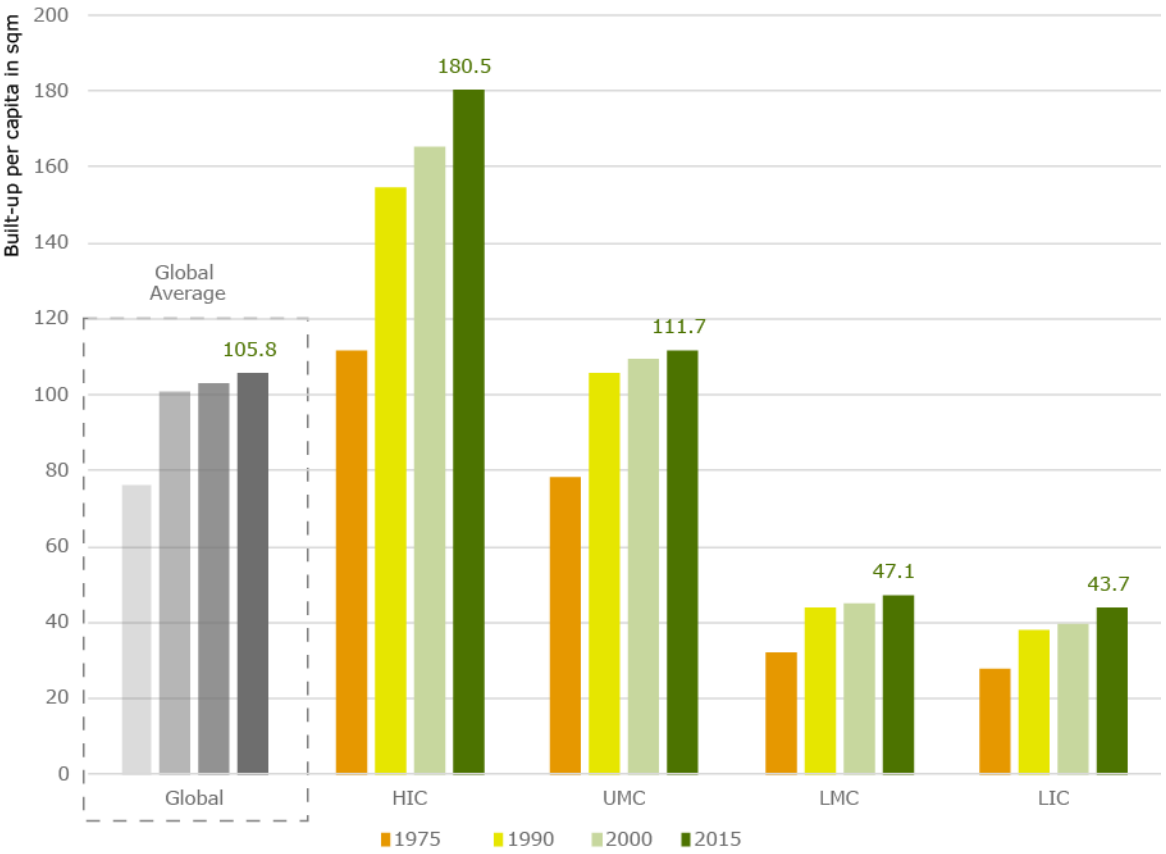


Chart 7 *Built-up per capita* per income group (1975, 1990, 2000, 2015)

The GHSL allows also to measure *Built-up per capita* that might become one important indicator to monitor quality of life. The *Built-up per capita* measures the space occupied by housing, public buildings, infrastructures and civil works. Its increment over time represents land consumption and its ratio to population growth rate is useful to measure land use efficiency and the SDG Goal indicator 11.3.1.[18]

Globally Built-up per capita grows constantly from 1975 to 2015. This can mean that **every urban newcomer produces more built-up than in the past**.

Cities in developing countries tend to have lowest *Built-up per capita* values than developed countries. The proportion of built-up and population in the different income groups is even clearer if looking at the *Built-up per capita* registered over time.

In 1975 the *Built-up per capita* in HIC was about 110m^2 – already higher than the 2015 global average, and it has been growing so far, reaching the value of 180 m^2 in 2015, the highest among the income groups. **In 2015 *Built-up per capita* in HIC is four times the one in LMCs**.

LIC have exceeds 40m^2 of *Built-up per capita* in 2015, with an increment of about 10m^2 from 1975.

[18] For a more detailed description of this indicators see 4.2

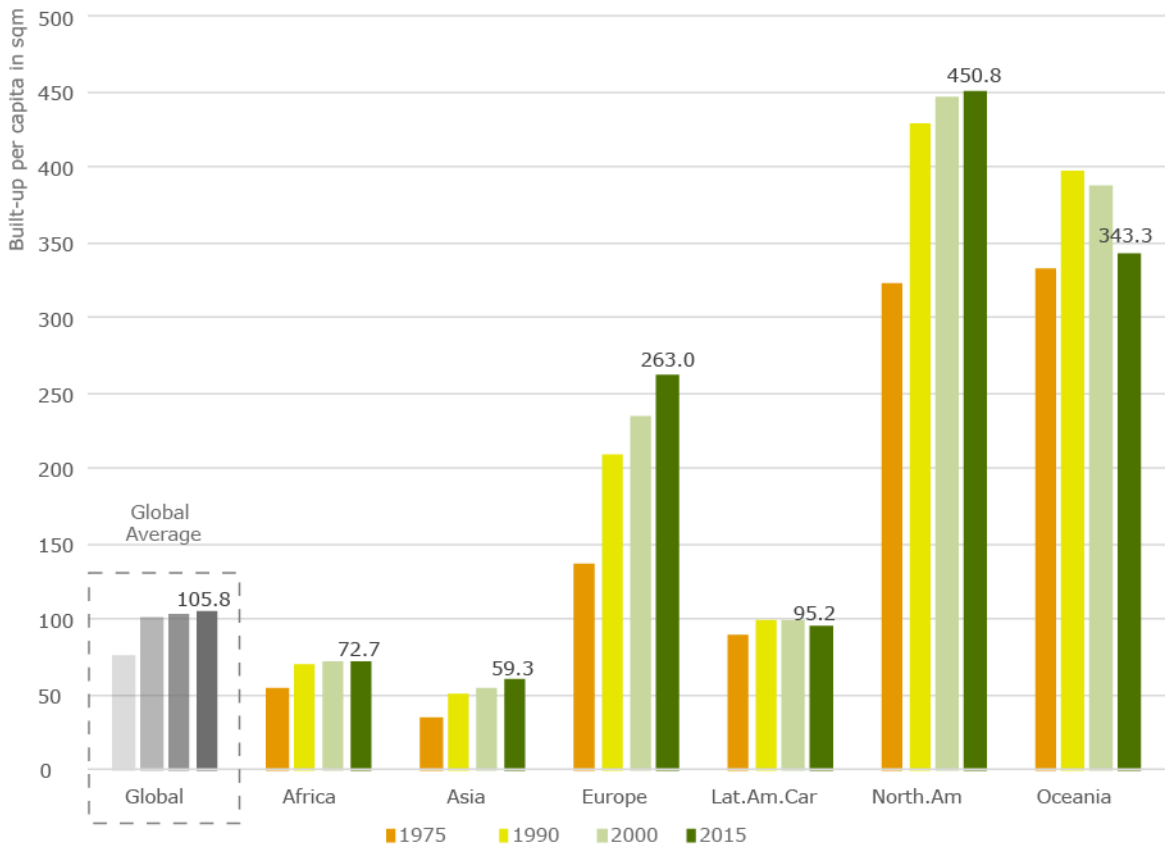


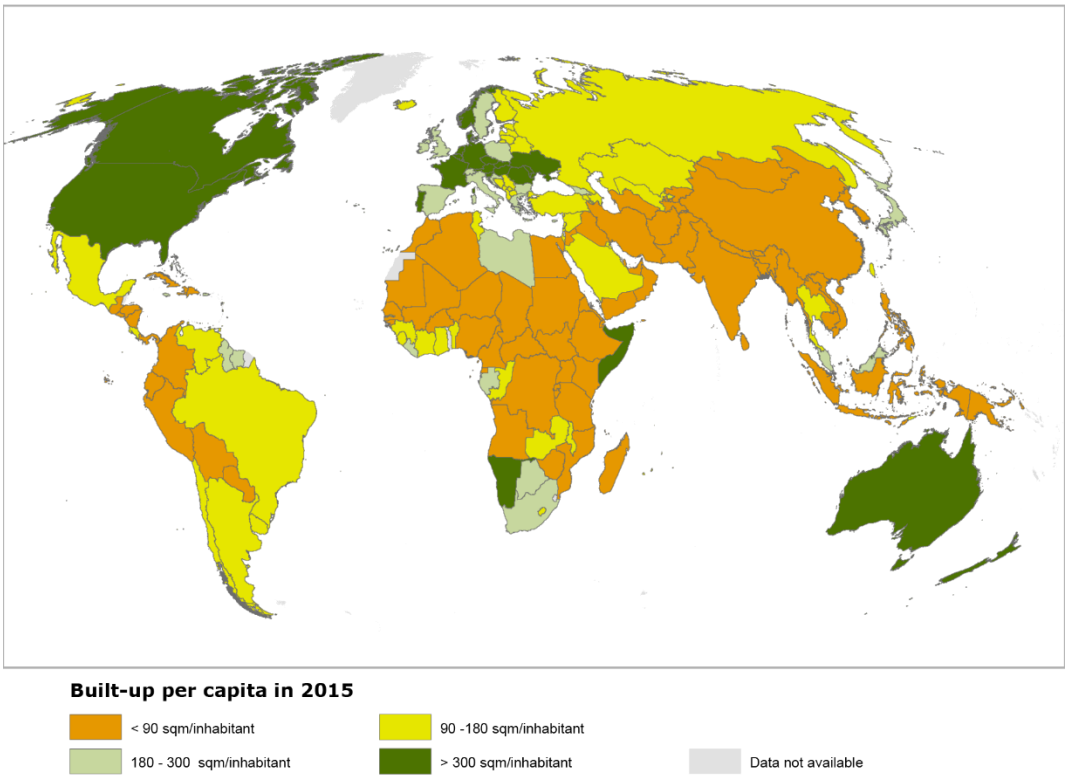
Chart 8 *Built-up per capita* per continent (1975, 1990, 2000, 2015)

The *Built-up per capita* by continent shows that **Northern America and Oceania** (despite a little decrement from 2000 to 2015) have the **highest *Built-up per capita***. While in 1975 the two regions had similar values, in 2015 Northern America reached 450m^2 and Oceania 343m^2

As per income groups, *Built-up per capita* is increasing in all regions, except in Latin America and the Caribbean in which a slight decrease is registered in the last 15 years. Then the continents can be grouped in two: Europe, Northern America and Oceania, with *Built-up per capita* value extremely higher than the global average, and a second group composed by Africa, Asia, and Latin America and the Caribbean with values slightly below the global average. Asia shows half of global average.

In **Northern America** *Built-up per capita* has always increased in the last 40 years (from 332m^2 in 1975 to 450m^2 in 2015): it is now more than **seven times the *Built-up per capita* in Asia in 2015** (59m^2), almost **two times the one in Europe**, and **four times the global average**. Also in Europe *Built-up per capita* has increased in the last 40 years (from about 140m^2 to 263m^2).

Africa, Asia, and Latin America and the Caribbean *Built-up per capita* values remain above the global average and have slightly increased in the last 40 years. ***Built-up per capita* in Asia is remarkably lower than in any other regions, and four times smaller than Europe**.



Map 3 *Built-up per capita* in 2015

The Map 3 shows world countries analysed using GHSL data grouped per classes of *Built-up per capita* value in 2015.

Countries have been grouped in four classes: the first two are below the global average - 105.8 m^2 (in orange countries with *Built-up per capita* less than half of global average); the third and the forth reported values above the global average (in green the countries with more than 300m^2).

The map illustrates differences within each continent, especially in Africa and Europe.

While **most of European countries reported values above – and highly above - the global average**, others, such as some Balkan countries, have values lower than it.

Also **Asian countries** have different *Built-up per capita* values: **most of the countries report to have low values** - as illustrated in the previous section - with some exceptions, as Malaysia and Japan.

***Built-up per capita* values in African countries differ**: South Africa, Botswana, Libya, Gabon, Liberia, are higher than the global average. Namibia, and Somalia even more than 300m^2, while at continental level the average is 72m^2.

3.2 Global and Regional Urbanisation trends

This section analyses global urbanisation[19] based on the people centred definition of urban areas as per "Degree of urbanisation" (DEGURBA) model adopted by EUROSTAT[20].The description of urbanisation extent and dynamics is based on global and national trends of population and built-up in urban areas as defined in 2.4.3 The GHSL Settlement Model.

The world in 2015 is on average more urbanised than it was 25 years ago. Degrees of urbanisation vary considerably across continent, income class and countries. While the **most urbanised countries are in Asia** and especially in the south east region, Africa is the continent where urbanisation has grown fastest since 1990. This section summarizes urbanization trends at country level. It also describes the world cities that cover the majority of a country built-up surface and finally cities with the fastest growth rate.

In addition, analysis of population concentration in the *Urban Centres* of today shows evidence of a shifting geography; with the inhabitants of *Urban Centres* in Asia account for up to 1/3 of global population and the share of global population living in European and Northern American centres that continue to decline.

Image 9 © aquatarkus, fotolia.com

[19] Calculated as the ratio between Urban Cluster population and National population in percentage
[20] http://ec.europa.eu/eurostat/web/degree-of-urbanisation/overview

3.2.1 Global Urban Population in 2015

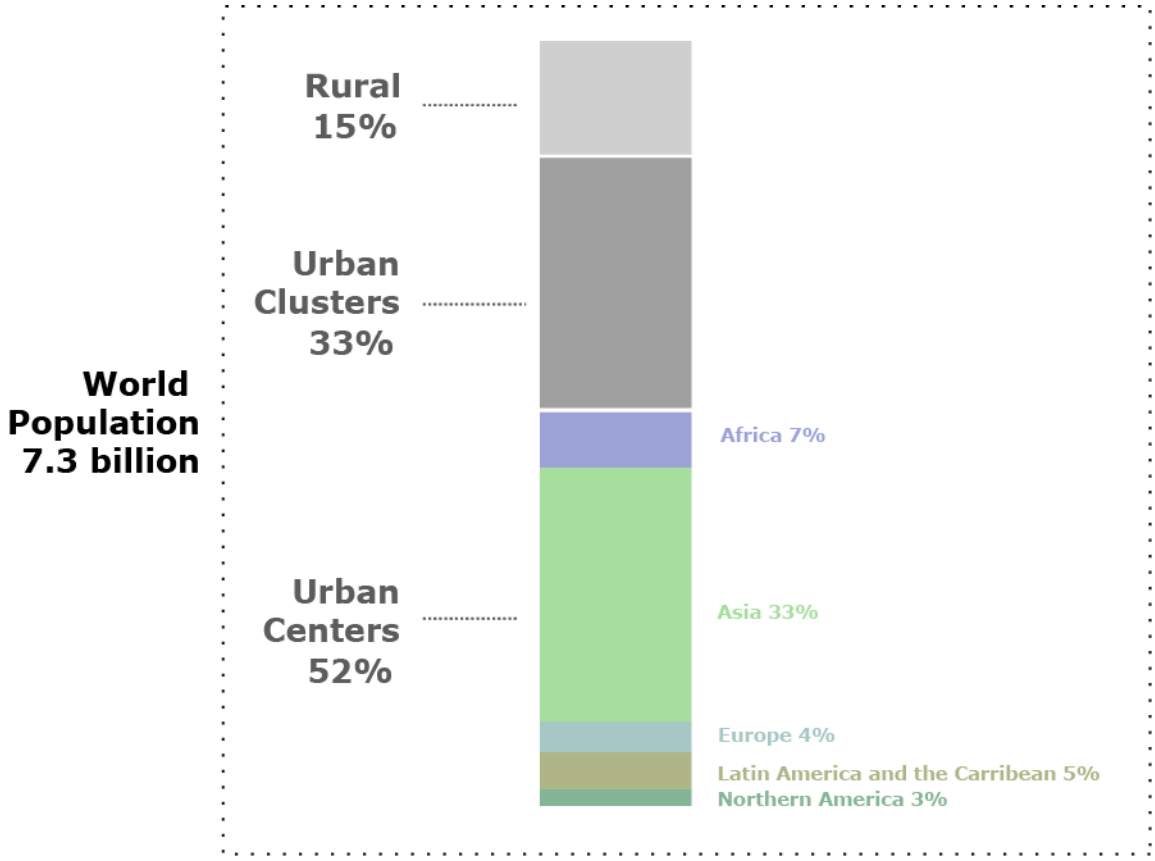
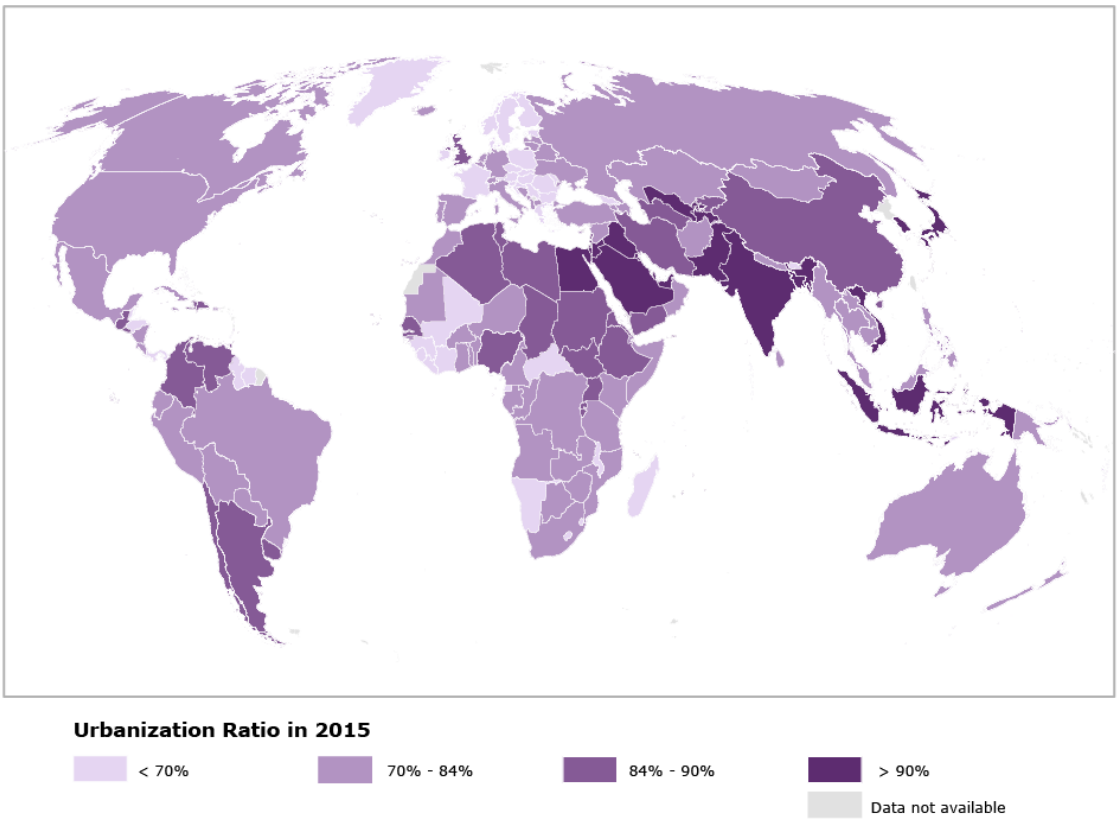


Chart 9 – Distribution of global population in *Urban Centres*, *Urban Clusters* and rural settlements in 2015

It is estimated that more than 6.1 billion people live in urban areas today. Global population distribution reports 85% of global inhabitants to live in cities, in either *Urban Clusters* and *Urban Centres*. The distribution of global urban population is largely included by *Urban Centres* that today account for 52% of global population. *Urban Clusters* instead host additional 2.4 billion people, equivalent to 1/3 of global population. At global level more than half the population live in *Urban Centres,* 1.4 billion in Asia, 430 million in Africa, 250 million in Europe, nearly 100 million in Northern America and 166 million in Latin America and the Caribbean. Rural population accounts today for 15% of the global population.

In 2015 more than 50% of global population live in *Urban Centres* which are the densest urban settings. More surprisingly 2.5 billion people (1/3 of the 3.8 billion) living in *Urban Centres* are concentrated in Asia. *Urban Centres* population in Africa (532 million) is of the same order of magnitude of the one of Northern America and Europe together (462 million).

3.2.2 Degree of Urbanisation in 2015 per country



Map 4 Urbanization Ratio in 2015

Global urbanisation a key dynamic of contemporary human development. GHSL data processed according to EUROSTAT Model has detected 3.1 billion people living in urban areas in 1975. **In 2015 GHSL maps over 110 thousand *Urban Clusters* home to 6.1 billion people worldwide.** GHSL data processed with OECD-REGIO model revealed that in 1975 the majority of global population (80%) lived in urban areas, forty years later, global *urbanisation ratio* tops 85%. This planetary phenomenon is particularly relevant in both absolute and relative terms. In 137 countries of the world urbanisation over the last 25 years has increased. In 2015 there are 25 countries where urban residents are at least 90% of the national population, the majority of which in Asia.

Urbanisation is a widespread phenomenon. In fact, in only 10 countries (the majority of which are islands) *urbanisation ratio* stays below 50%, among those Bhutan (31%) and Namibia (41%). **In most countries the majority of population lives in urban areas, and in 119 countries urban population is between 70% and 90%.** Countries in South Eastern Asia and in Western Asia have the highest concentration of national population in *Urban Clusters*. In Eastern Europe in the majority of countries *urbanisation ratio* is below 85% (the global average) and often below 70%. In countries in North East Africa *urbanisation ratio* is often above global figure.

Table 2 Countries per urbanisation ratio (small islands excluded)

Urbanisation below 50%	Bhutan, Greenland, Namibia, Swaziland
Urbanisation above 90%	Argentina, Bahrain, Egypt, Kuwait, Bangladesh, United Arab Emirates, Qatar, Malta, Aruba, Korea, Israel, Japan, Vietnam, Jordan, Saudi Arabia, Iraq, India, Pakistan, Uzbekistan, Indonesia, Tajikistan, South Sudan, Lebanon

3.2.3 Degree of urbanisation in 2015 per continent

Chart 10 Urbanization ration in 2015 per continent

In 2015 worldwide 85 out of 100 inhabitants are settled in urban areas. This global figure is composed by quite strong continental patterns. Asia is the most urbanised Continent with nearly 90 out of 100 people living in *Urban Clusters*. **Latin America and the Caribbean and Africa have similar *urbanisation ratio*, in fact 82 in 100 people live in cities**. Both, **Europe and Northern America account for 73 in 100 inhabitants settled in *Urban Clusters***. In these latter two continents rural population is the highest at global level, more than 25% of continental population is settled in rural areas.

Bhutan is the least urbanised country in Asia, where only 32 in 100 inhabitants are accounted in urban areas, the second least urbanised country in Asia (excluding islands) is Georgia where already 70 in 100 inhabitants are settled in cities. In Asia 17 countries account for more than 90% of their national population in cities and in Bahrain, Kuwait, Bangladesh, United Arab Emirates and Qatar urban population is above 96%.
In Europe only Malta, the United Kingdom and the Netherlands account for a degree of urbanisation above the global figure, and in half the countries less than 70 in 100 inhabitants are settled in *Urban Clusters*. Urbanisation in Europe is the lowest in Slovenia (53%), Ireland and Slovakia (55%).
Considering income classes, the most urbanised countries are LMCs where 89 in 100 are settled in *Urban Clusters*. Urbanisation in both UMC and HIC is 83%. Least urbanised countries are those in the low income class, where up to 80 in 100 people are settled in *Urban Clusters*.

3.2.4 Change in urbanisation between 1990-2015 by continent

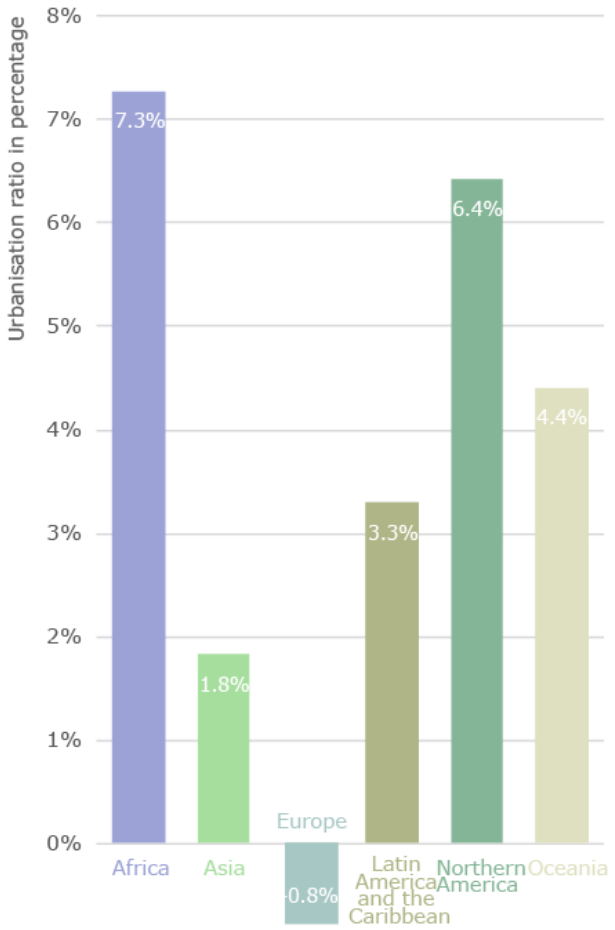


Chart 11 Regional Change in Urbanisation Ratio between 1990 and 2015

In 1990 there were globally 82 in 100 people living in *Urban Clusters*. Today 25 years later there are nearly 85. Urbanisation has increased globally at a rate of 2.8%, by 1.5% only between 2000 and 2015.

Changes in *urbanisation ratio* are uneven across continents. Africa is the fastest urbanising continent, at a rate more than double global average and above 7%. *Urbanisation ratio* in 25 years in Africa changed from 76 to 81 in 100 inhabitants settled in cities. Between 1990 and 2015 urban population increased by 485 million.

Urbanisation grows fast also in Northern America, where today 73% of population is accounted in *Urban Cluster*, it was 69% in 1990, equivalent to a 6% increase. *Urbanisation growth rate* is above global average also in Oceania and Latin America and the Caribbean.

In Asia urbanisation grows at a rate of nearly 2% and the share of urban population moved from 87% in 1990 to 89% in 2015. It is important to mention that urbanisation in Asia was 87% already in 1990.

Europe shows a unique global trend where urbanisation decreases. The rate of urban population decline is nearly 1% and *urbanisation ratio* moved from 74 to 73%.

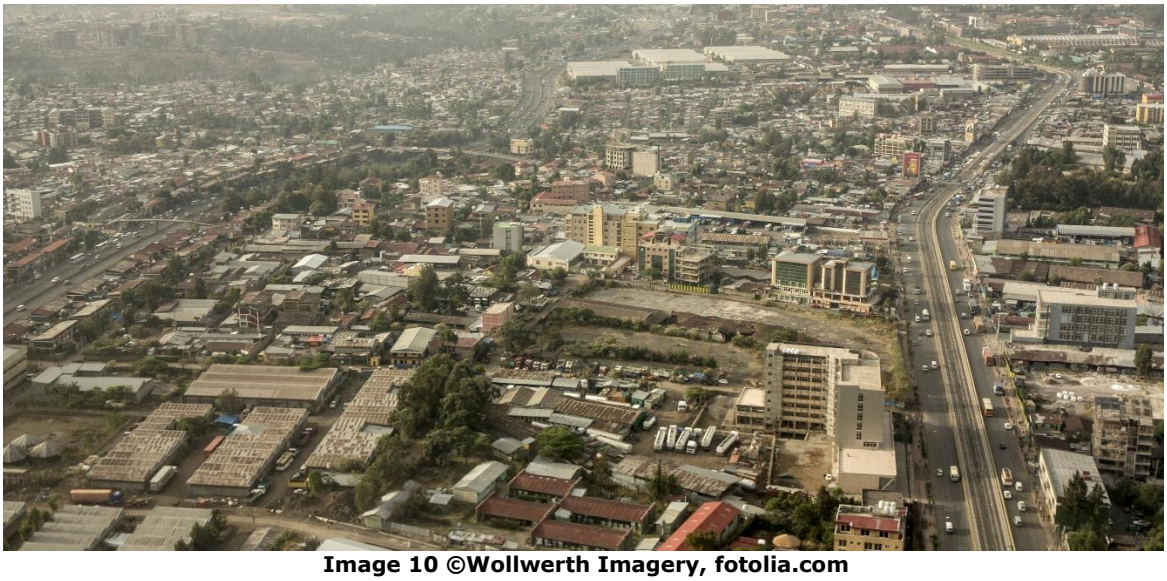


Image 10 ©Wollwerth Imagery, fotolia.com

3.2.5 Evolution in the Surface of Human Settlements 1975-2015

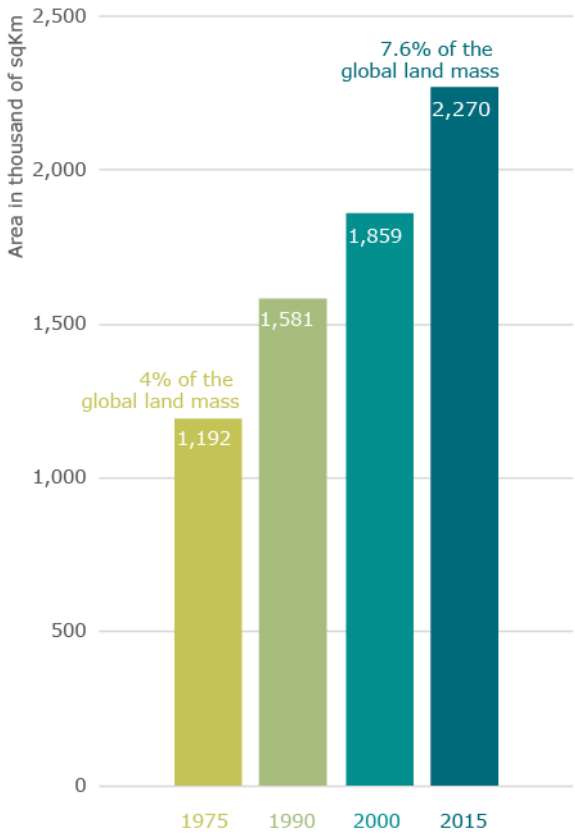


Chart 12 Area Covered by *urban clusters*

The physical surface of human settlements, (i.e. the area of cities), is one of the most interesting parameters as it is used to quantify the human presence on the Earth. In the *Atlas of the Human Planet* 2016 this indicator is calculated as share of global land mass[21] occupied by *Urban Clusters*.

The surface of *Urban Clusters* has nearly doubled in 40 years. *Urban Clusters* in 1975 occupied 4% of global land mass. In 2015 that share increased to 7.6%. The expansion of the area of cities in 1975 is equivalent to the surface of Niger, and in 2015 to half one of the surface of Europe-28. Countries with the highest absolute amount of urban areas include China, India and the United States with respectively 470, 256 and 195 thousand square kilometres; that are equivalent to the surface of Spain, Ecuador and Senegal. *Urban Cluster* surfaces in the last forty years in China have nearly doubled, have more than doubled in India and have increased by 1.5 times in the United States. In more than 30 countries the surface of urban areas has more than doubled between 1990 and 2015. In 10 countries, the respective cities cover more than half of the country surface. These countries include: Gibraltar, Bahrain and Macao, Singapore and other islands. In 58 countries urban areas cover less than 1% of the surface of the country among others: Finland, Venezuela, Somalia, Russia, Oman, Australia Mongolia, Namibia and Mauritania.
The surface of *Urban Centres* has more than doubled between 1990 and 2015 in 47 countries of which half are LIC and six are HIC.

Table 3 Countries where changes in the surface of urban areas has been the highest between 1990 and 2015 (excluding islands)

Urban Areas have more than tripled	Burundi, Malawi and Niger, and Qatar
Urban Areas have more than doubled	Afghanistan, Angola, BangladeshBenin, Bhutan, Burkina Faso, Cambodia, Chad, Côte d'Ivoire, Democratic Republic of the Congo, Ethiopia, Gambia, Ghana, Guinea, Honduras, Iraq, Mali, Mozambique, Myanmar, Nigeria, Oman, Pakistan, Rwanda, Senegal, Sierra Leone, South Sudan, Tanzania, Togo, Uganda, Venezuela, Yemen

[21] Land mass is the total surface of continental land excluding inland water bodies.

3.2.6 *Urbanisation growth rate* 1990-2015

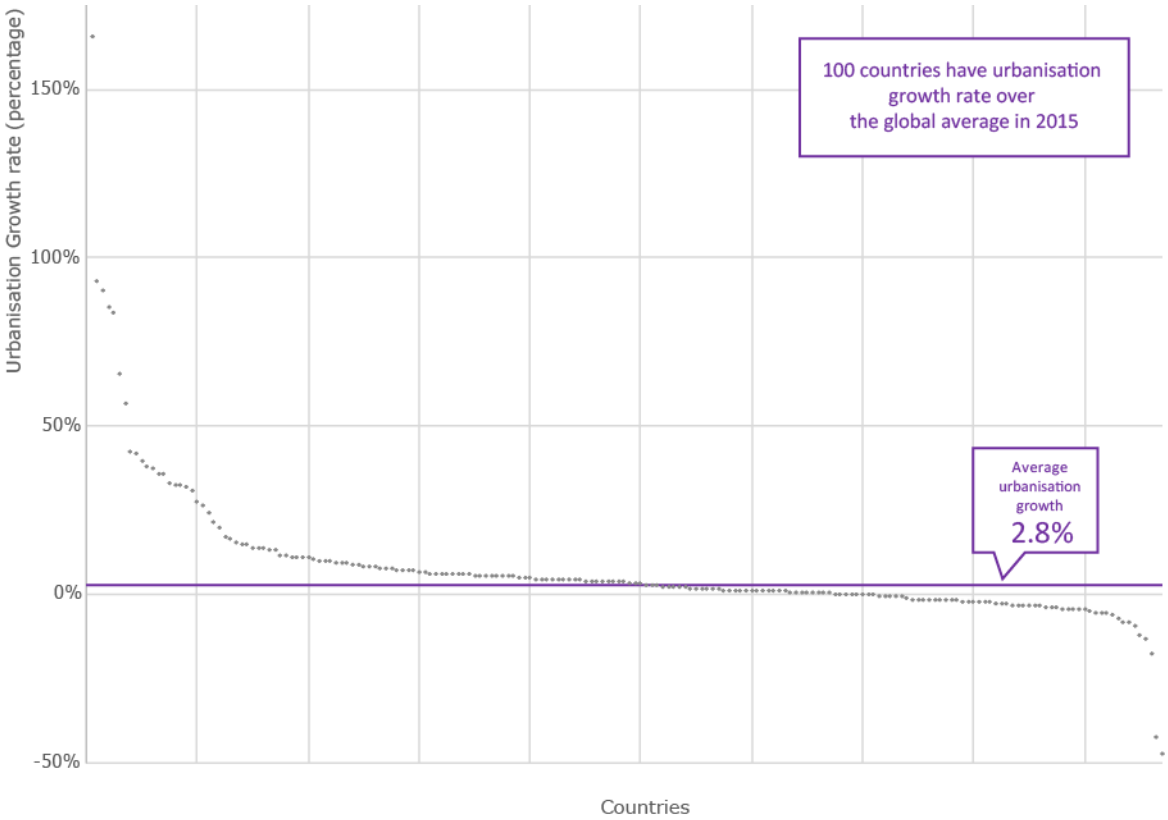


Chart 13 *Urbanisation growth rate* 1990-2015

Urbanisation over the past 25 years has increased globally at a rate of 2.8%. Urbanisation has increased 10 times faster than global average in 19 countries. The chart also shows that decline in urbanisation ratio are possible. In the past 25 years it occurred in 57 countries. Urbanisation has decreased by up to more than 10% in Georgia, Congo and Estonia.

Constant *urbanisation ratio* is accounted in Germany, Lesotho, Tunisia, Vietnam, Malta, and the Netherlands.

Considering income classes, HIC increase in *urbanisation growth rate* has been below global average, at a rate of 2% and it has been driven by Equatorial Guinea (38%), Oman (13%), Luxembourg (11%) excluding islands and only pointing out growth rates above 10%. At least 19 HIC shows a decline in urbanisation, most of these countries are in Europe.

The *urbanisation growth rates* increase fast in LIC and UMC. UMC urbanise at the fastest global rate of nearly 6%, while LIC at 5%. In 25 years the share of urban population in LIC moved from 77 to 80% and in UMC from 78 to 83%.

3.2.7 Levels of *Urbanisation Ratio* in 2015 and *Urbanisation growth rate* 1990-2015

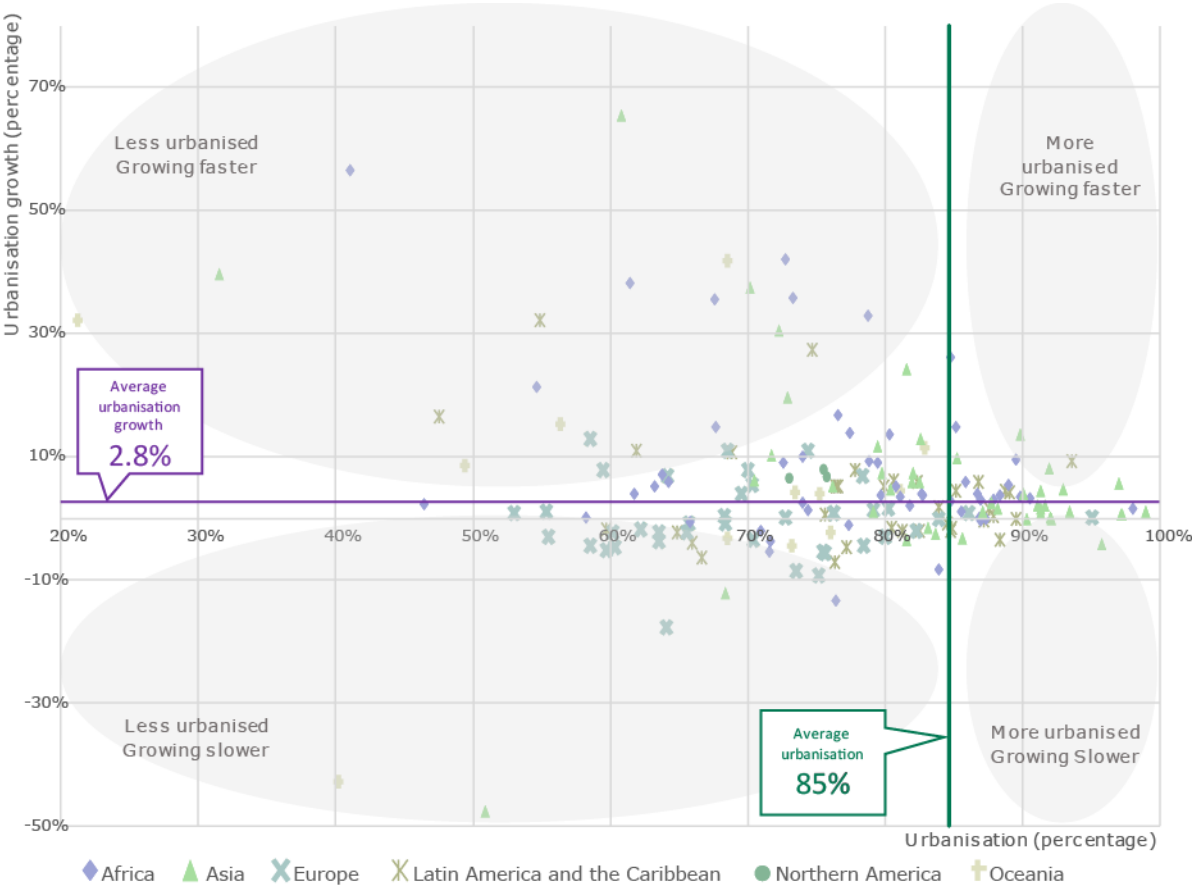


Chart 14 National urbanisation ratios and urbanisation growth in 2015

The combination between *urbanisation ratio* and the *urbanization growth rate* between 1990 and 2015 propose a global analysis of urbanisation status and dynamics at country level. First it emerges that there are 24 countries (11 in Africa, 7 in Asia and 6 in Latin America and the Caribbean) where urbanisation is above global average and the increase in urbanisation over the last 25 years occurred at a rate higher than global average. In those countries, the majority of which are LIC and in Africa, urban areas are clearly the key ground and the drivers of societal development. In 31 other countries urbanisation in 2015 is above global average but the rate of growth of urbanisation has been below average between 1990 and today. More than half of these countries are in Asia, where urbanisation in 1990 was already higher than the global average of 2015. Countries where *urbanisation ratio* is above global average but *urbanization growth rate* is below average are mostly accounted in HIC including Japan, the United Kingdom, Qatar, Kuwait and Bahrain. **The most interesting category of countries is the one where 2015 urbanisation ratio is below global average but where *urbanisation growth rate* between 1990 and 2015 has been above global average**. This phenomenon is accounted in 76 countries, 1/3 of which in Africa and 16 in Asia. The distribution in income class is also very clear: 1/3 are LIC and other 13 are LMCs. Among the 25 countries that are in Africa, 21 are LIC or LMCs, and *Urbanisation growth rate* can be as high as above 80% in Malawi, 50% in Namibia, 40% in Tanzania. Among the highest u*rbanisation growth rate* outside Africa, the following countries are particularly relevant, among others: nearly 40% in Bhutan, above 35% in Mongolia, above 30% in Cambodia and nearly 25% in Afghanistan. Finally, 63 countries are both less urbanised and urbanising less than global average; nearly half are in Europe and HIC, and include Germany, Spain, Poland and the Russian Federation.

3.2.8 *Urban Clusters* and national population growth

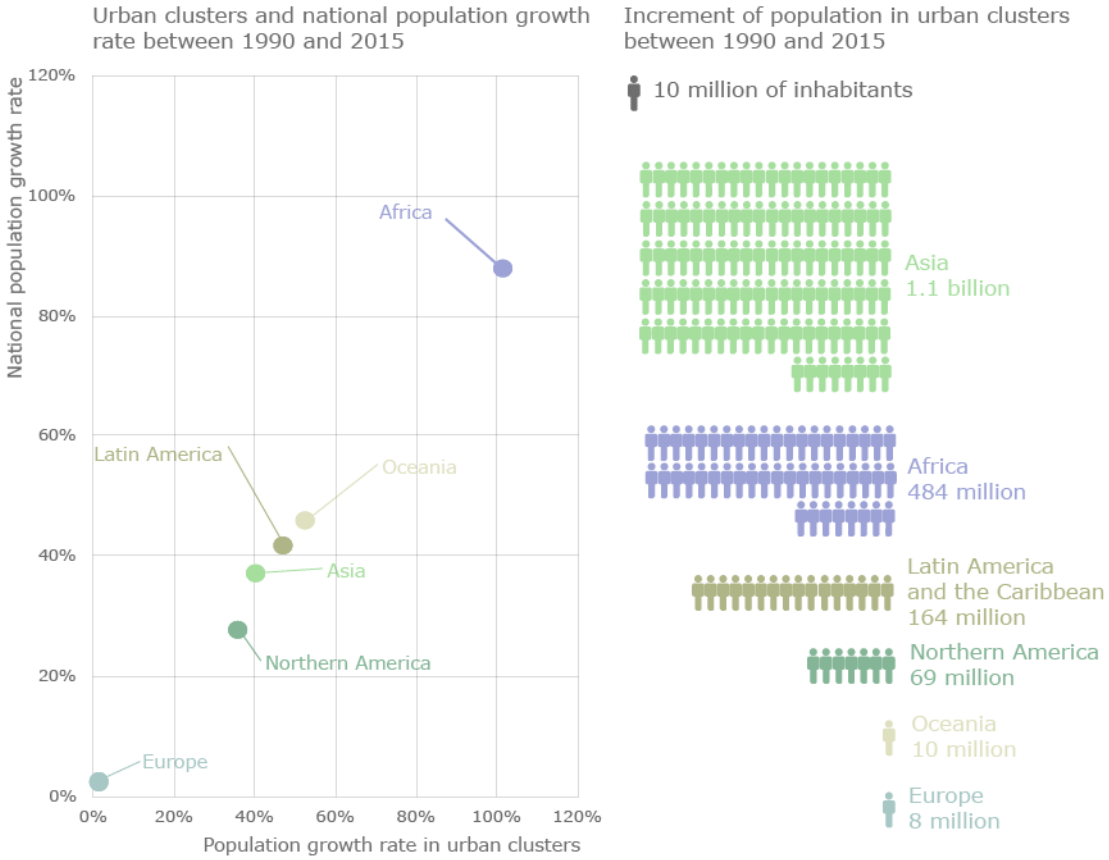


Chart 15 *Urban Clusters* and national population growth rate between 1990 and 2015

Urban population has increased globally by 42% between 1990 and 2015. In 2015, urban areas around the globe account 1.8 billion more inhabitants than in 1990, nearly 90% of these new inhabitants are concentrated in Asia or in Africa. Moreover, in the last fifteen years, urban population increased by 1.1 billion (22% increase). Since 1990 the fastest increase in urban and national population occurred in Africa, where urban population has doubled to reach 484 million. In absolute figures, urban population increased the most in Asia, where 1.1 billion new inhabitants were accounted between 1990 and 2015. The increase in urban population in Africa and Asia accounts alone for ¼ of today's global population in the last 25 years.

Population growth over the last 25 years has not been equally distributed between cities and non-urban areas. Urban population has increased faster than national population globally except that in Europe. **In Africa urban population has doubled in 25 years while national population increased by 88%.** In Northern America urban population increased by 36% equivalent to nearly 70 million people when national population increased by 27%.

Urban population growth in Europe could be ideally located in a new settlement of 8 million people, less than the *Urban Cluster* of London, in Oceania in one megacity like the *Urban Cluster* of Rio de Janeiro, in Northern America in nearly seven *Urban Clusters* like Santiago de Chile. In Africa and Asia, the above comparison is no longer suitable. **To account for the new urban population Africa would require nearly five new Giga-cities and Asia nearly eleven new Giga-cities.** In spatial terms each Giga-city hosts more than 100 million inhabitants can be as wide as 55 thousand square kilometres; to accommodate urban population growth in Africa such Giga-city could be as wide as Guyana, and to accommodate the one in Asia as wide as Madagascar.

3.2.9 Population in *Urban Centres* 1975-2015

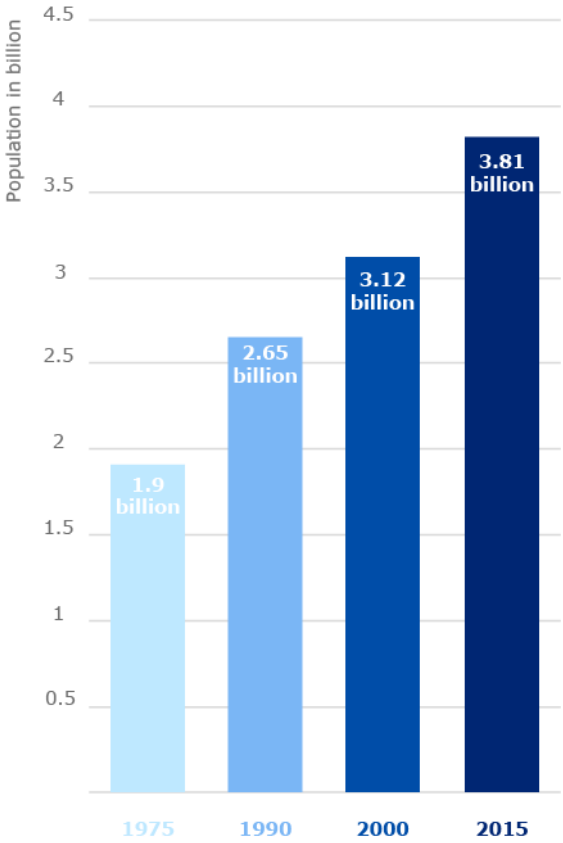


Chart 16 Global Urban Centre Population 1975-2015

Urban Centres alone host more than half global population in 2015 (see 3.2.1). Population living in *Urban Centres* has doubled over the past 40 years, in Africa and in LIC it has tripled.

In 1975 *Urban Centres* already hosted 1.9 billion people. By the year 1990 50% of global population, 2.65 billion people were accounted in *Urban Centres*. The share of global population living in *Urban Centres* has moved from 47% in 1975 to 50% in 1990, to 51% in 2000 and to today's 52%. In Asia, Africa and Latin America *Urban Centres* host an increasing share of global population. Centres in Africa hosted 4% of global population in 1975, they host more than 7% today, in Latin America and the Caribbean such figure was 4.3% forty years ago and it is now 4.8%, more considerable changes occurred in *Urban Centres* in Asia where today 1/3 of global is accounted, and it was already more than ¼ in 1975 (already mentioned 3.2.1). Centres in Europe and in Northern America host a decreasing share of global population even if population in such centres continues to increase. Europe accounted for nearly 7% of global population in 1975 while today it accounts for 4%, in Northern America the transition has been from 2.8% to 2.3% in 2015.

Considering income classes *Urban Centres* population is well split in 1/3 in HIC little more than 1/3 in LMC, and 13% in UMC and LIC. Currently, HIC host nearly 1.3 billion inhabitants in *Urban Centres*. These shares have evolved over the last 40 years.

Image 11 © eyetronic, fotolia.com

3.2.10 Growth Rate of *Urban Centre* Population in Europe

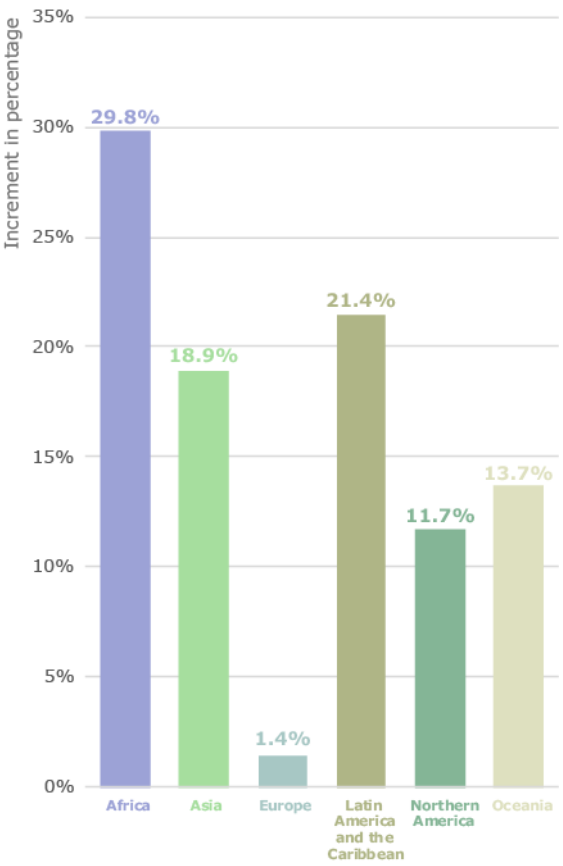


Chart 17 Increment of population in *urban centres* between 1990 and 2000 by continent

Population in *Urban Centres* in the world has increased by 44% over the last 25 years. Such increment is subject to strong continental differences and high fluctuation in sub intervals. In fact, in 25 years (1990-2015) *Urban Centres* population has nearly doubled in Africa, it increased by nearly 50% in Asia, Latin America and the Caribbean and Oceania, it increased by nearly 30% in Northern America and by just 4% in Europe.

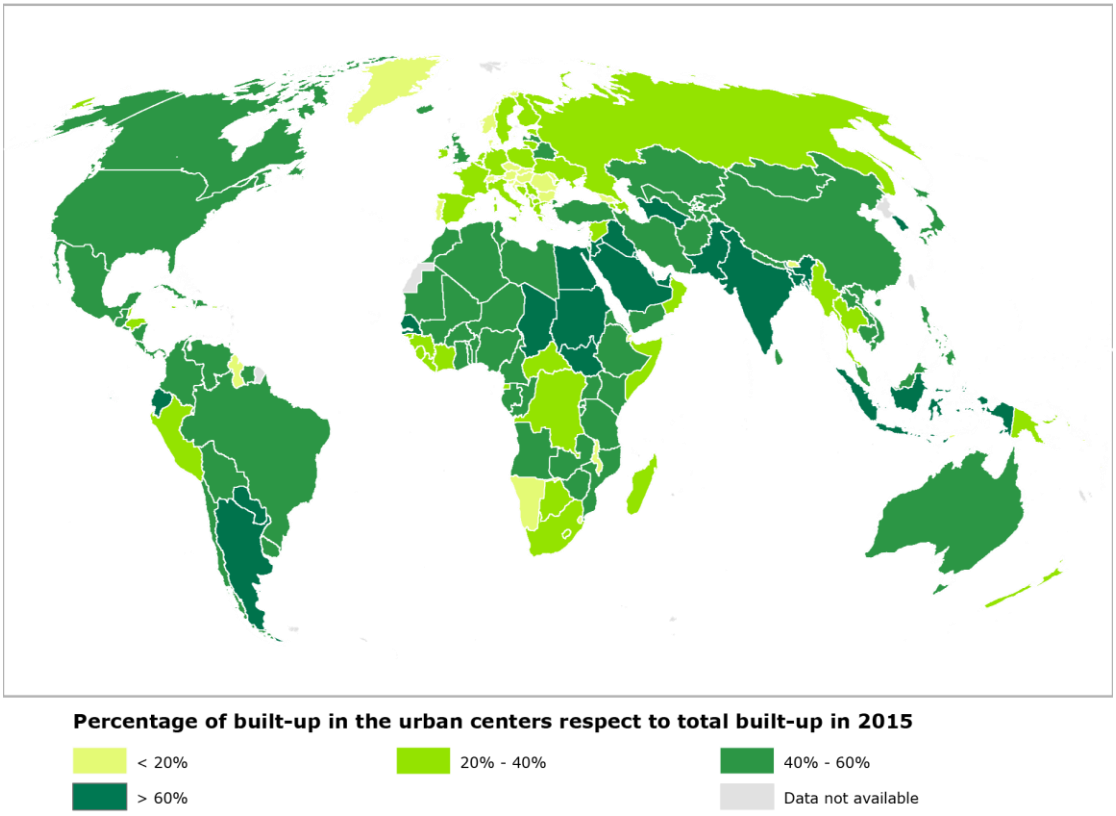
Between 1990 and 2000 *Urban Centres* population increased globally by 18% equivalent to nearly 476 million people (Chart 17). More than half this growth was concentrated in Asia (above 320 million people), Africa (more than 80 million). The highest growth rate occurred in Africa where population in *Urban Centres* increased by nearly 30% and in Latin America and the Caribbean by 21%.

Considerably different trajectories were instead observed in Europe where population in *Urban Centres* increased by only 1.4% equivalent to not even 4 million people in these 10 years. To give an example, for each new-born in Europe, there were 80 new-borns in Asia, 20 in Africa and 11 in Northern America

Between 2000 and 2015 the global average increase of population amounted to 5.8 million people per year *Urban Centres* hosted worldwide nearly 700 million new inhabitants. Global split followed the trajectories of the previous interval (1000-2000) and more than 85% of such population is concentrated in Asia (more than 420 million people) and in Africa (more than 172 million). Globally, population has increased and a faster rate compared to the previous observed period. In Africa population increase tops nearly 50% in 15 years while in Europe it remains nearly 1/10 the global average. For each new inhabitant in Europe there are still approximately 20 in Africa, 50 in Asia or 81 in the globe.

Income classes reflect the general global tendency of faster growth of urban population in LIC, in fact over the last 25 years LIC population in *Urban Centres* has nearly doubled, it increased by around 50% in both LMCs and UMC, in HIC it increased by 25%. In the period 1990-2000 LIC population in *Urban Centres* increased by nearly 1/3 while in HIC by slightly more than 10%.

3.2.11 Built-up in *Urban Centres* compared to national built-up in 2015



Map 5 Percentage of built-up in *Urban Centres with* respect to the total built-up in 2015

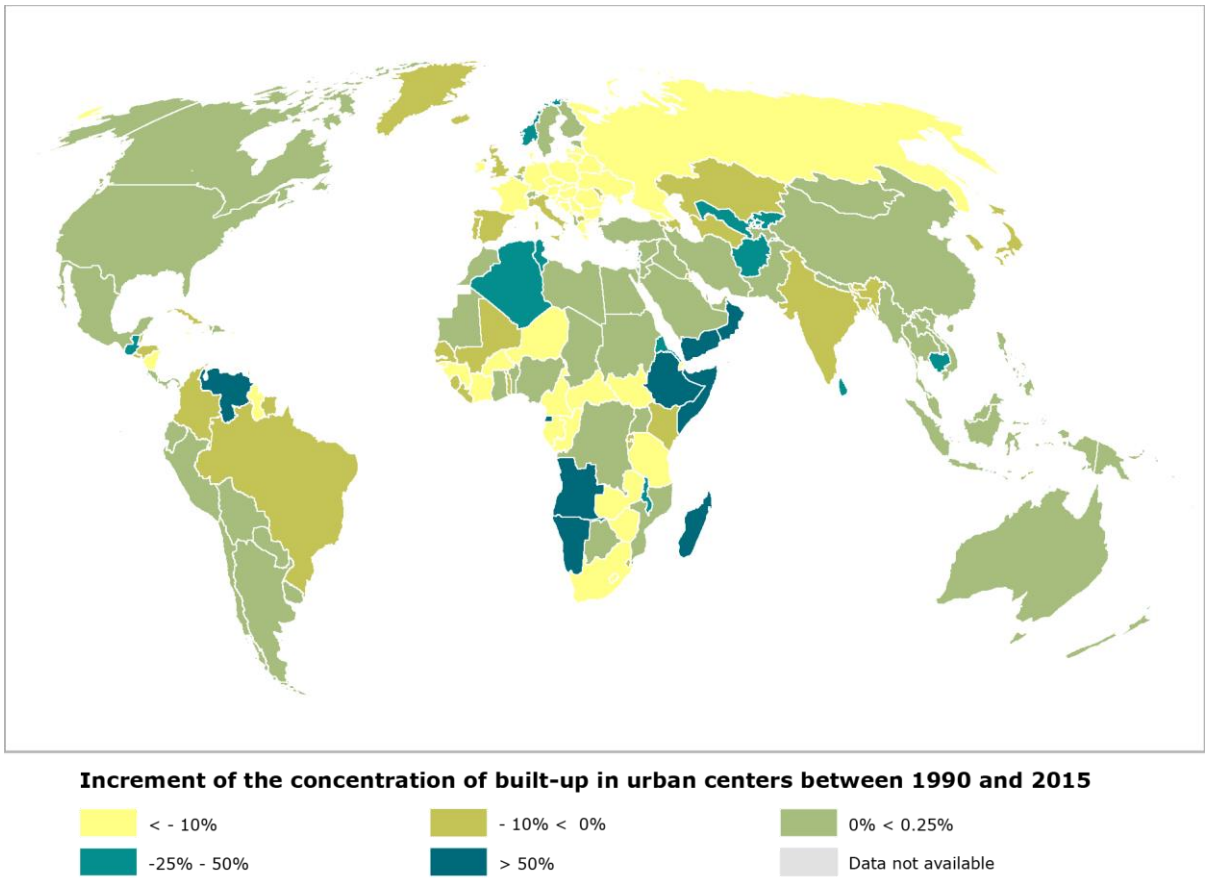
Agglomeration is the share of built-up surfaces in *Urban Centres* over the total built-up in the country. High degrees of agglomeration are related to high concentration of built-up in dense urban settings. Globally 40% of built up is accounted within *Urban Centres*. In 9 countries more than 70% of built-up is accounted in *Urban Centres*, while in other 45 countries at least half the national built-up is agglomerated in centres. Among the countries with highest agglomeration the HIC in the Middle East, and other countries in South Asia that are also higly urbanised such as India, Pakistan, Bangladesh and Indonesia.

Low levels of agglomeration are accounted in countries in Eastern Europe including Slovakia, Romania, Bulgaria and Moldova among others. Agglomeration figures appear to be quite independent from income classes as HIC and LIC average is close to 41% while UMC and LMCs concides with global figure (40%).

Table 4 Countries with high share of agglomeration in 2015 (excluding small islands)

Agglomeration above 70%	Bahrain, Bangladesh, Egypt, Kuwait, Paraguay, Qatar, Saudi Arabia, United Arab Emirates
Agglomeration between 50% and 70%	Angola, Argentina, Brazil, Chad, China, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Eritrea, Gambia, India, Indonesia, Iran, Iraq, Japan, Jordan, Kenya, Lao People's Democratic Republic, Mali, Malta, Mexico, Mongolia, Nigeria, Pakistan, Panama, Philippines, Senegal, South Sudan, Sri Lanka, Sudan, Tajikistan, Togo, Tunisia, Turkmenistan, Uganda, United Kingdom, Venezuela, Vietnam

3.2.12 Increase of built-up in *Urban Centres* per country between 1990-2015



Map 6 Increment of the concentration of built-up in *urban centres* respect to the total built-up in 2015

Changes in agglomeration[22] describe the trajectories of built-up concentration in dense *Urban Centres* versus the sprawl to *Urban Clusters* or rural areas within countries. High decrease in agglomeration might be associated to suburuabnisation or fast growth of rural and *Urban Cluster* built-up, while sharp increase can be associated to a dynamic growth of *Urban Centres* within the country. On average over the last 25 years agglomeration of built-up in *Urban Centres* has increased by 3%. Accordingly, between 1990 and 2015 the constructions in the globe tend to concentrate slightly more in *Urban Centres* than elsewhere. Most relevant changes in built-up agglomeration, above 70%, occur among others in: Ethiopia and Luxembourg and Venezuela. In other 35 countries agglomeration increase by more than 10%. Stable agglomeration within +/- 1% is accounted in 16 countries which include among others: Belgium, Indonesia, Moldova and Kuwait.

In other 71 countries, mostly in Europe, a decrease in agglomeration has been accounted, up to 35% as in the case of Slovakia. Decrease above 10% occurrd in central Europe, while more limited decrease up to 10% occurred among others in Spain, Italy and the United Kingdom. Limited decrease in agglomeration has also been accounted in Norther America. In India and Brasil agglomeration has decreased up to 10%. In half HIC agglomeration has decreased while in 30% of LIC agglomeration has increased at rates of at least 10%.

[22] concentration of built-up in *urban centres* respect to the total built-up

3.3 Population Concentrations in the World

By Lewis Dijkstra and Hugo Poelman, European Commission DG REGIO

The biggest obstacle to comparing cities and settlements in the past was the big differences in the areas of municipalities. Some cities were spread over multiple small municipalities, while others were included in such a large municipality that the density of the municipality was distinctly un-urban.

The GHS population grid allows us to overcome this obstacle. By dividing the world in a grid of cells with the mostly same size (there is some distortion closer to the poles). The population grid is a relatively abstract tool. It ignores borders and geography. The grid does not show where one country stops and the next country starts.

Nevertheless, many people can identify the main cities in their country on these grids. It can also reveal concentrations of population in a place that people would not have thought of because it does not have a single name, boundary or government.

New methods can be developed that combine cells based on density and contiguity. This can create powerful new insights about levels of urbanisation using more comparable definitions (European Commission, Regional and Urban Policy 2016)

For this *Atlas*, however, we did not aggregate cells based on density or contiguity. We only aggregated the cells to cells of 10 x 10 km. Subsequently we created a data visualisation to highlight the concentrations of population in the world. The grid cells with less than 50,000 inhabitants are not shown. The other cells are shown as colour coded vertical bars. The colour corresponds to population classes, while the height of the bar is reflecting the total population. The map of the world is slightly tilted to create a three-dimensional effect.

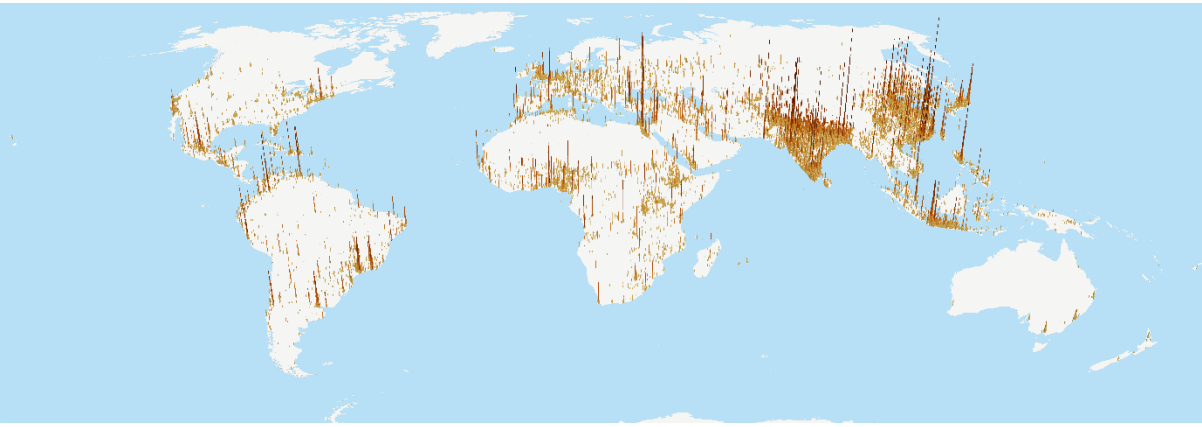


Figure 1 Population grid in 3D - World

On the global map, the incredible high population concentrations in India and China is instantly apparent. In addition, the high concentrations are relatively close to each other compared to most other countries, where the biggest concentration is often only in one location with all other concentrations with a substantially lower density and at a distance from the main concentration. In North America, Australia and New Zealand these cities tend to have much lower density levels and are spaced further apart.

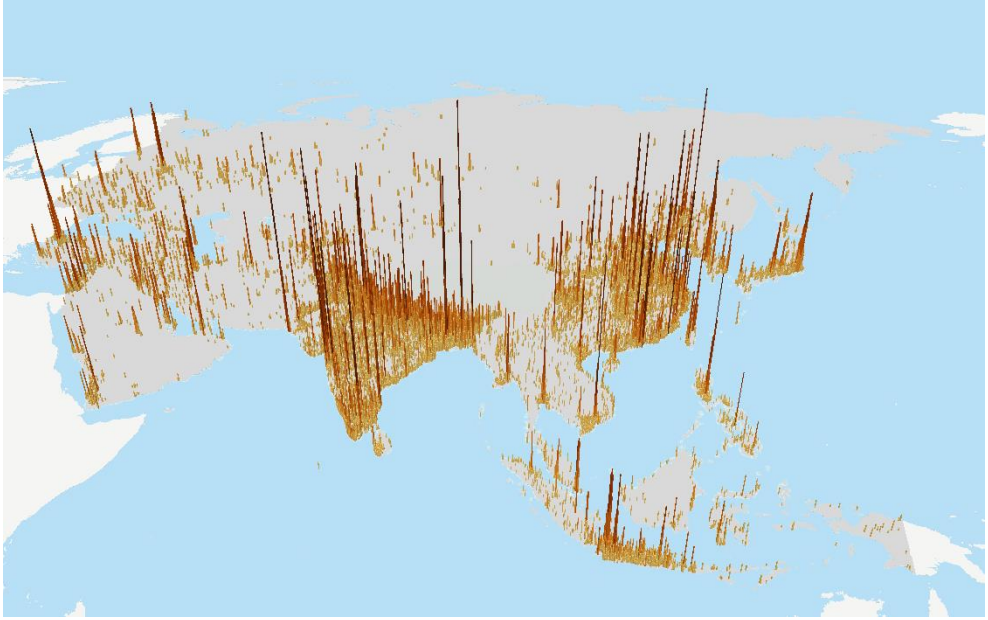


Figure 2 Population grid in 3D - Asia

The map of Asia, Belorussia, Moldova, Russia and Ukraine shows the big concentrations in Indonesia, Philippines and Japan as well as in India and China. On the mainland of Southeast Asia, the cities of Singapore, Bangkok, Hanoi and Ho Chi Minh City are clearly visible. Further to the west, the cities of Istanbul, Moscow and Saint Petersburg can be identified.

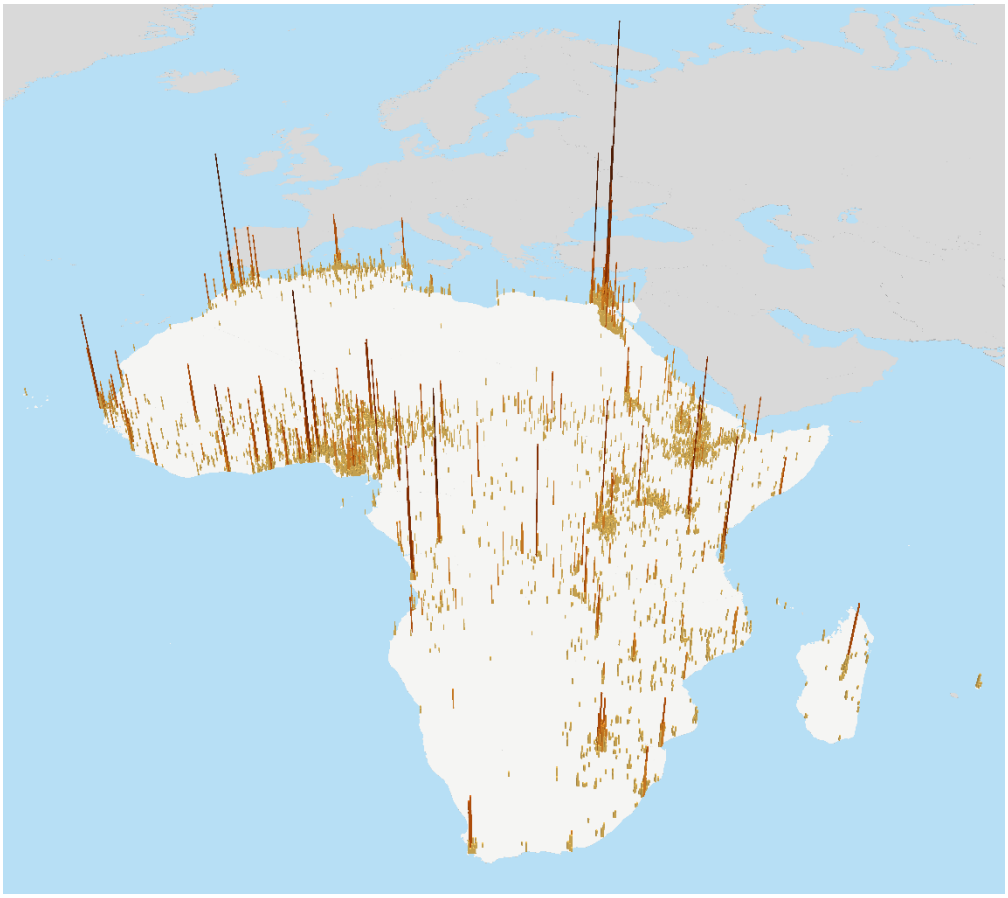


Figure 3 Population grid in 3D - Africa

The map of Africa reveals a couple of areas with very high concentrations. The Nile valley around Cairo stands out. Most of the big concentrations can be found on the coast, such as Accra, Casablanca, Lagos, Luanda and Dakar.

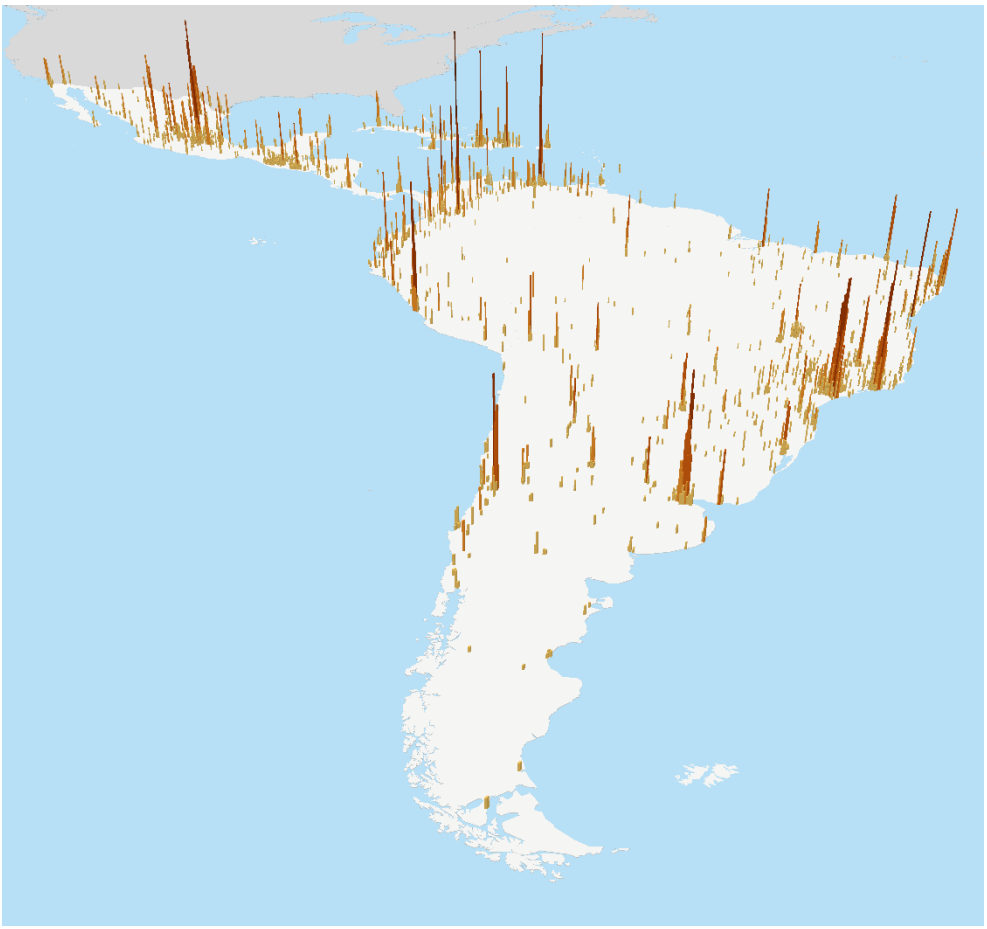


Figure 4 Population grid in 3D - Latin America and the Caribbean

The map of Latin America shows virtually all the big concentrations close to the coast and the relative absence of large cities in the interior. In the North, Mexico City stands out. The cities Caracas, Bogota, Buenos Aires, Lima, São Paulo all reach high density levels.

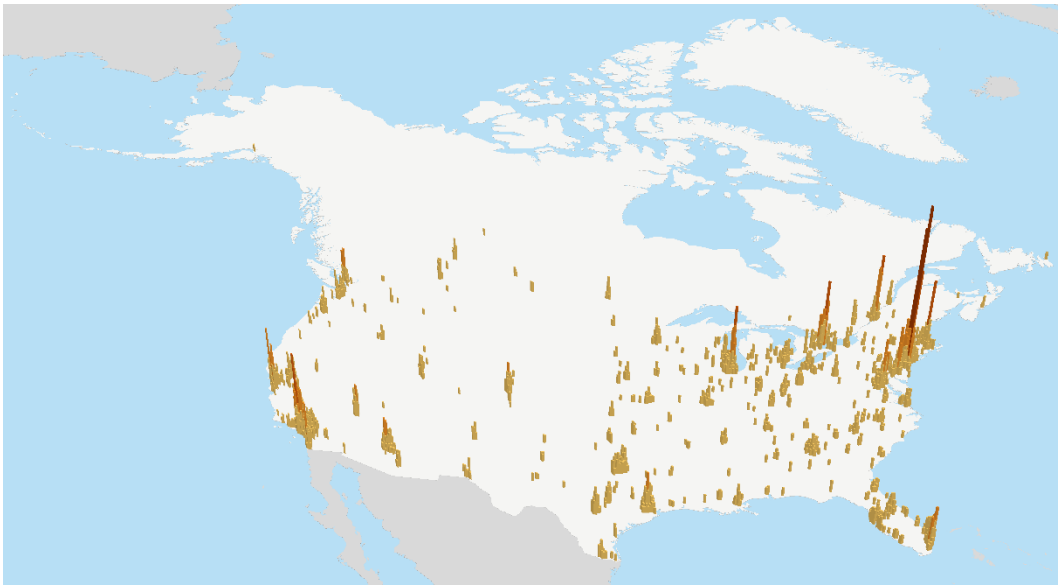


Figure 5 Population grid in 3D - Northern America

The map of North America offers a big contrast. Only a few of the grid cells around New York City reach a high density. Other cities, such as Boston, Washington D.C., Montreal, Toronto, Los Angeles, San Francisco stand out in part due to their density but also because so few of the grid cells reach 50,000 inhabitants. Most of the cities stand quite isolated.

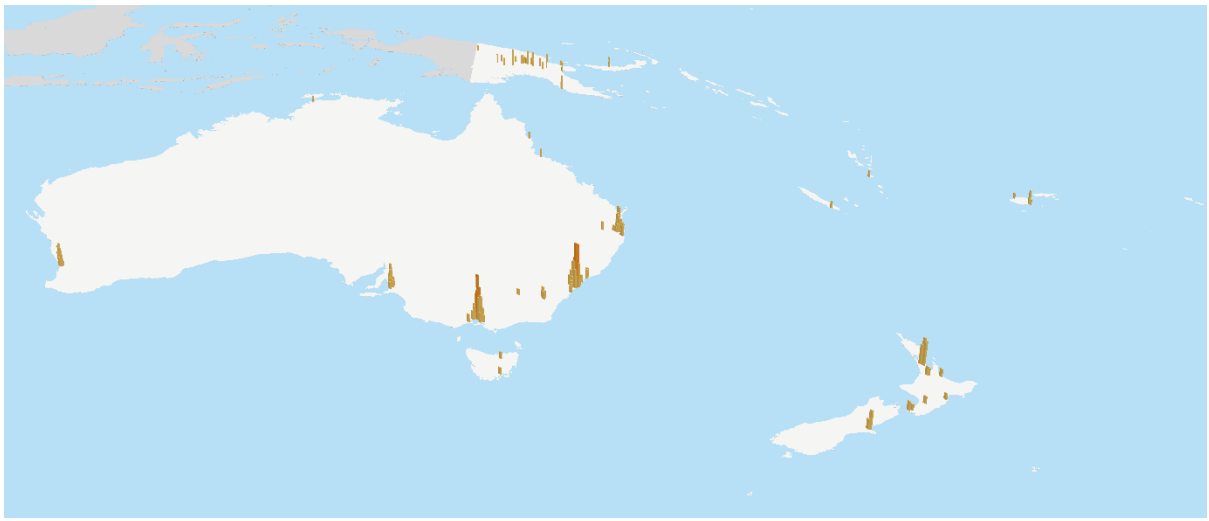


Figure 6 Population grid in 3D - Oceania

The map of Oceania is even more extreme with a large land mass and only a few cells with more than 50,000 inhabitants. In Australia, the cities Adelaide, Brisbane, Melbourne, Perth and Sydney all consists of multiple cells of 10 x 10km. The other settlements mostly consist of only one cell with a fairly low density. Also in New Zealand, the main cities can be easily spotted but have lower densities and smaller populations than Melbourne and Sydney.

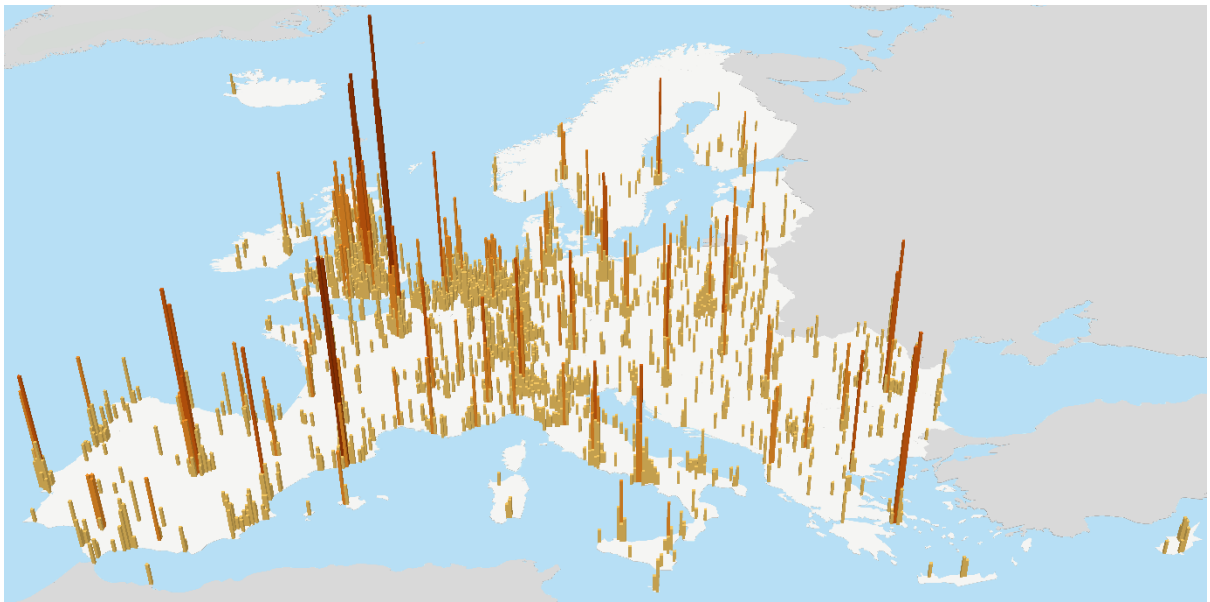


Figure 7 Population grid in 3D - Europe

The map of Europe the three cities with the densest cells are Barcelona, London and Paris. In most countries, the capital stands out as the biggest and densest population concentration. In some countries, such as Iceland and Malta, the capital is the only settlement to show up on this map. Overall, the impression is of a much denser cluster of cities with moderate size and densities, especially compared to North America.

The first chapter of the State of European Cities Report, 2016 compares population size, density and distances between cities in various parts of the world. European cities have

double the density of North American cities, but half the density of the cities in Asia and Africa.

The goal of this visualisation was to spark interest and allow people to engage with the population grids as an alternative and informative way to grasp differences in urban structure. These grids are but a first step towards a global people-based definition of cities and settlements as called for the new urban agenda. Nevertheless, this new and freely available source of information can help to identify where cities are and help with the monitoring of their performance.

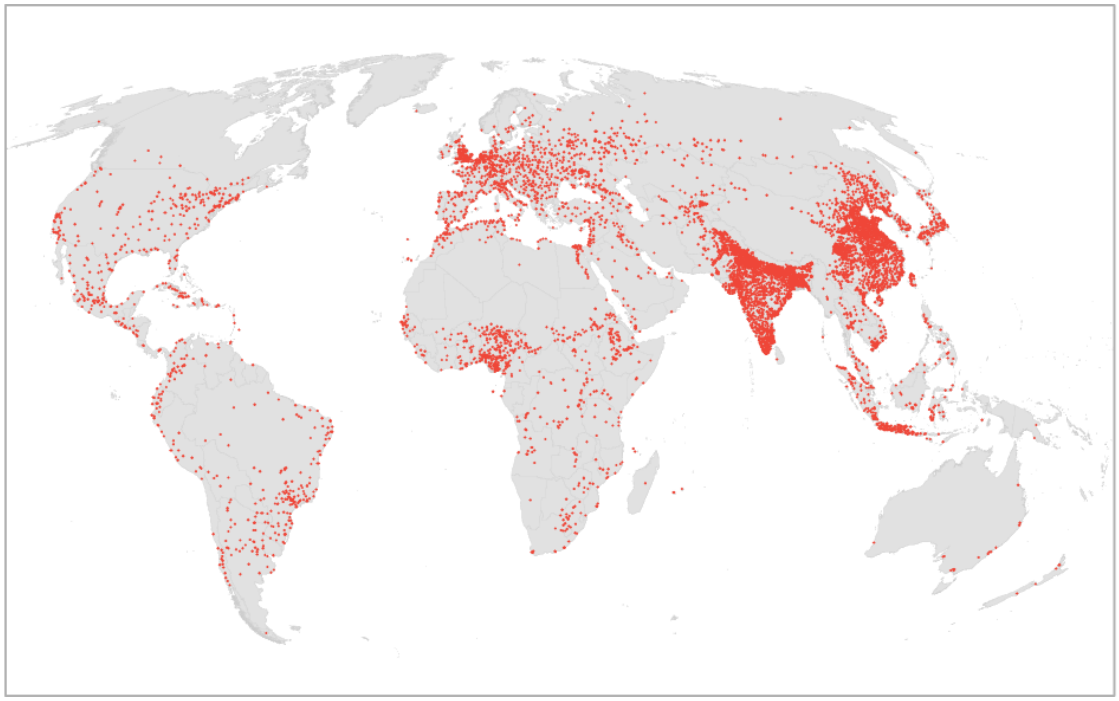
Image 12 © Prachanart, fotolia.com

3.4 City analysis

Cities are the most vivid representation of human presence on Earth. Despite the fact that a globally-shared agreement on what a city is has not yet been reached, most of the city definitions deal with population and built-up density.

In the settlement model defined using the GHSL (2.4.3 The GHSL Settlement Model), both *Urban Centres* and *Urban Clusters* are considered "urban" and then "cities", even though they reflect different characteristics of density.

According to the S-MOD, an *Urban Centre* is an agglomeration of contiguous grid cells of 1km^2 with density of a least 1,500 inhabitants per km^2 or built-up of at least 50%, and a minimum population of 50,000.



Map 7 *Urban Centres* in 2015

In 2015 *Urban Centres* are the human settlements in which the majority of the world population live. The Map 7 shows their location in the world.

The GSH S-MOD maps over 13,000 *Urban Centres* in 2015. The country with higher number of *Urban Centres* is India (more than 3,700), followed by China (more than 2200). **In 2015 almost 9,000 *Urban Centres* are in Asia** (65% of the total number), about 2,300 in Africa, and around 1,000 respectively in Europe and Latin America and the Caribbean.

3.4.1 Megacities

Map 8 – Location of the 32 *Urban Centres* with more than 10 million of inhabitants in 2015

A megacity is an urban settlement hosting more than 10 million of people. **In 2015 the GHSL mapped 32 *Urban Centres*** that reached this population. **In 1975 there were only 13:** in the last 40 years their number has more than doubled. In particular, the number of megacities in 1990 doubled by the year 2000, from 16 in 1990, to 32 in 2000, additional 11 cities achieved the megacity rank just in the last 10 years.

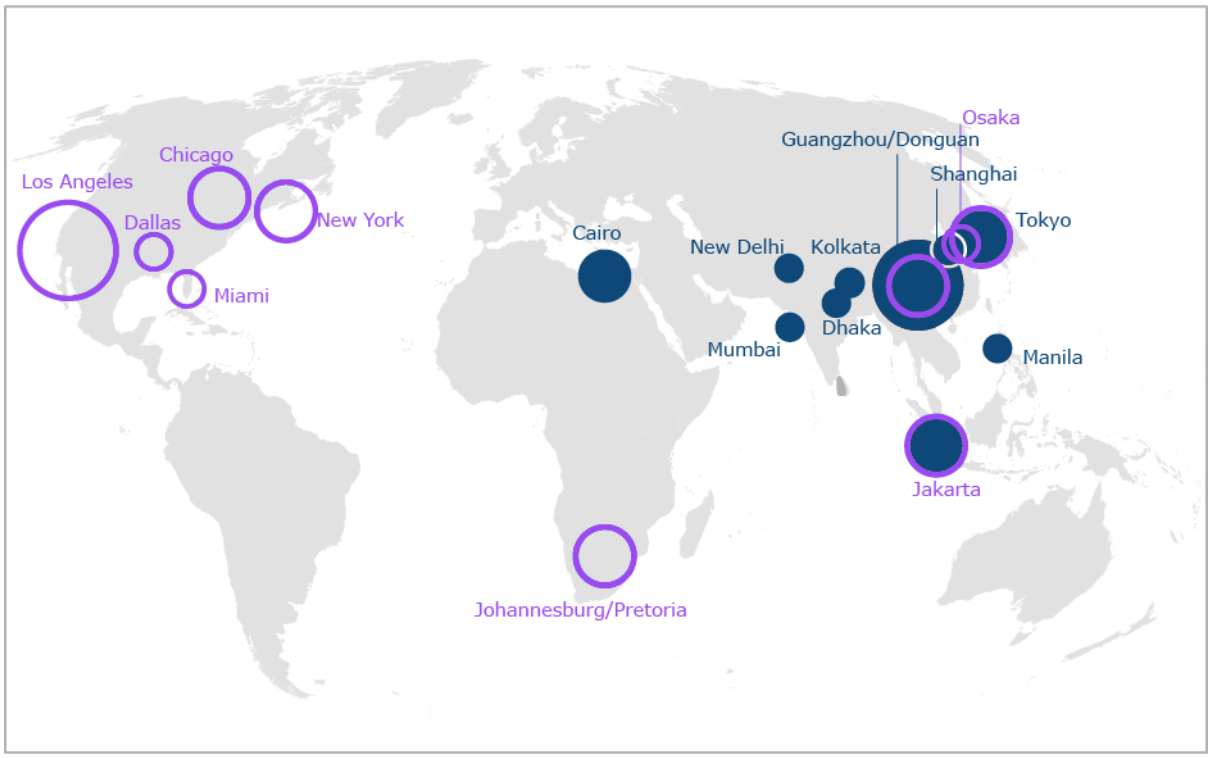
In 2015 *Urban Centre* megacities **collectively host more than 610 million people**, and account for 8.4% of the global population and 7% of global built up. The location of these 32 *Urban Centres* are shown in Map 10. **Most of them are in Asia** (22 over 32) and 12 respectively in HIC and LMC.

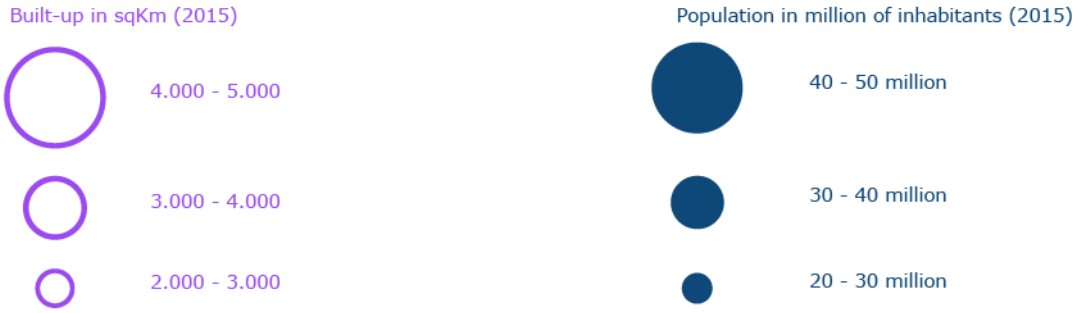
These cities are Guangzhou, Cairo, Jakarta, Tokyo, Delhi, Calcutta, Dhaka, Shanghai, Mumbai, Manila, Seoul, Mexico City, Sao Paulo, Beijing, Osaka, New York, Bangkok, Moscow, Buenos Aires, Istanbul, Los Angeles, Karachi, Tehran, Changzhou, Ho Chi Minh City, Johannesburg, Lagos, Shantou, Lahore, Bangalore, Paris, Chennai (ranked by population). Resident population vary a lot among them: from Guangzhou with more than 46 million, to Chennai with little more than 10 million of inhabitants.

Among them, the one with the biggest amount of built up is Los Angeles, followed by Tokyo and Jakarta. Los Angeles is also the one with the highest value of *built-up per capita* (333m^2), followed by Johannesburg (272m^2), while **Dhaka has the lowest *built-up per capita*, only 20m^2.** 21 megacities have *built-up per capita* above the global average (105.8m^2) while the average *built-up per capita* in the 32 megacities is 94m^2 and therefore below global average.

In 1975 in Changzhou, Lahore, Dongguan, Dhaka, Chennai, Bangkok and Shanghai there was less than ¼ of today's built-up; in Changzhou still 15 years ago, in 2000 there was just half of today's built-up. In Bangalore and Ho Chi Min, population in 2000 was below 60% the one of today. The largest *Urban Centre* is Dongguan which covers an area wider than 8 thousand square kilometres hosting 46 million people, and it is bigger than the Caspian Sea. The smallest megacity instead is Karachi which covers an area of 715 square kilometres, so it is less than 1/10 of Dongguan and it hosts more than 13 million people. The equivalent urban area per capita in Karachi is 54m^2 per capita while on global average it is more than 360m^2.

3.4.2 TOP10 *Urban Centres* by population and built-up in 2015





Built-up (sqKm)		Population	
1 Los Angeles	4,734	1 Guangzhou/Donguan	46,038,426
2 Tokyo	3,874	2 Cairo	37,839,851
3 Jakarta	3,867	3 Jakarta	36,398,769
4 Guangzhou/Donguan	3,666	4 Tokyo	33,744,544
5 New York	3,540	5 New Delhi	27,634,561
6 Chicago	3,523	6 Kolkata	26,865,342
7 Johannesbourg/Pretoria	3,170	7 Dhaka	24,833,278
8 Dallas	2,469	8 Shanghai	24,669,234
9 Miami	2,427	9 Mumbai	23,413,134
10 Osaka	2,357	10 Manila	22,448,173

Map 9 TOP10 *Urban Centres* by population and built-up in 2015

In the top ten *Urban Centres* by population in all cities population exceeds 20 million inhabitants (Map 9). Some of the top ten *Urban Centres* by built-up are not megacities (Chicago, Dallas, Miami). 9 of the 10 *Urban Centres* by population are in Asia while 1 is in Africa. Top ten *Urban Centres* by built-up are located in USA (5 over 10),

South Africa, Malaysia, China and Japan. All those cities have more than 2,000km^2 and they go from Osaka (2,357km^2) up to Los Angeles (4,734km^2).

On the right side of Map 9, the table shows the first 10 *Urban Centres* ordered by population: the difference among them is huge, as more than **46 million of people are accounted in *Urban Centre* of Guangzhou (China)** – the first in the ranking - and 22million, less than half in Manila (Philippines), the tenth.

Overall the map shows a clear polarisation in the continental split of the top 10 cities per population and per built-up. In fact, the majority of the top 10 cities per built-up areas are located in Northern America, the ones per population are mostly in Asia. Furthermore, most of the top 10 per built up are in HIC while the ones per population in lower income classes.

3.4.3 TOP 10 *Urban Clusters* per Population in 2015

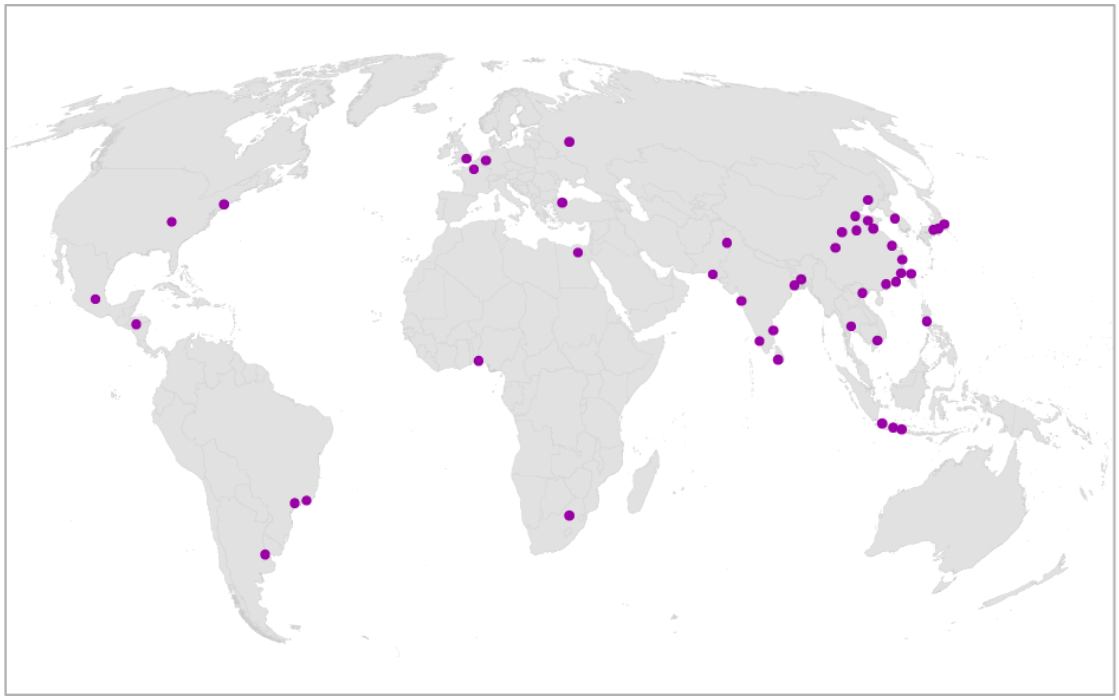
In addition to the *Urban Centres*, the Settlement Model applied within the GHSL identifies another kind of urban settlement: *the Urban Clusters* (see 2.4.3 The GHSL Settlement Model). *Urban Clusters* are clusters of contiguous grid cells of 1km^2 with a density of at least 300 inhabitants per km^2 and a minimum population of 5,000.

In 1975, there were only 25 *Urban Clusters* which population was 10 million or more accounting for 650 million people (16% of the global population). **By 2015, the number of *Urban Clusters* with more than 10 million of inhabitants had increased to 50** (Map 10), of which 22 in LIC and LMC.

Nowadays these urban settlements are home of 1.2 billion people, representing 17.6% of the world population and 17% of global built up. 37 of them are located in Asia, 3 in Africa, 2 in Northern America and 4 respectively in Europe and Latin America and the Caribbean.

China is the country with the highest number of *Urban Clusters* with more than 10 million inhabitants (12), followed by India with 6 *Urban Clusters*.

Image 13 © victor217, fotolia.com



Map 10 Location of 50 *Urban Clusters* with more than 10 million of inhabitants in 2015

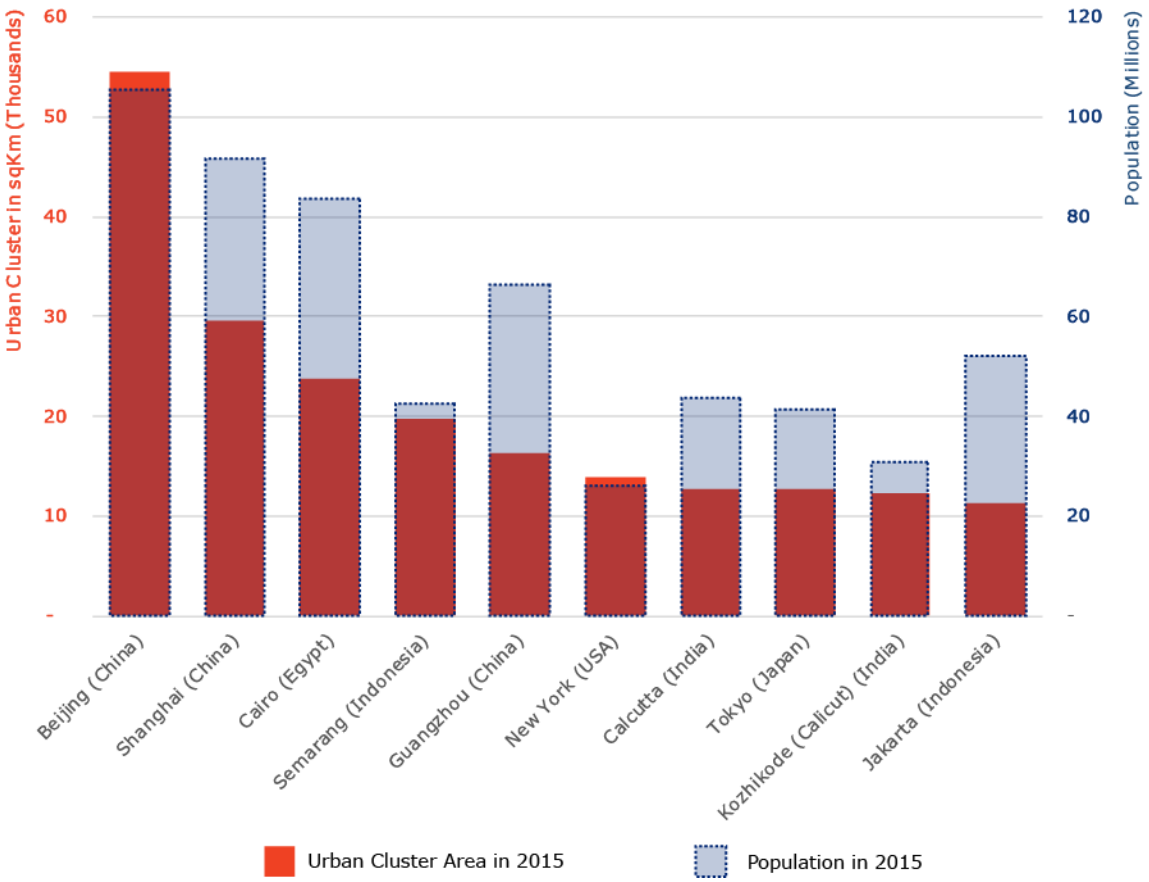


Chart 18 Population and Area of the TOP 10 *Urban Clusters* in 2015 ranked by area

Chart 18 shows both population and area of the largest *Urban Clusters* in 2015 (highest value of occupied area). **Beijing is the largest and most populated *Urban Cluster* in**

the world in 2015, with more than 100 million people it is the first and only giga-city[23] on Earth and *Built-up per capita* of 144 m^2.

Looking at this value, it can be observed that there is not direct proportion between population and land area: New York, Calcutta, Tokyo, Calicut, and Jakarta have similar areas (around 13,000km^2) but very different population (between 20 and 50 million), and this can be related to many factors, such as presence of big unbuilt and unpopulated zones inside the city areas, because of urban fabric features and textures, building typologies, or planning regulations.

This is reflected also in the *Built-up per capita*, since for example New York has the highest b*uilt-up per capita* and Calcutta the lowest among the top10.

Since the ranking by area does not coincide with the ranking by population, in some cases smaller *Urban Clusters* have more inhabitants than bigger ones, and this is clear observing the Chart 18 Population and Area of the TOP 10 *Urban Clusters* in 2015 ranked by area

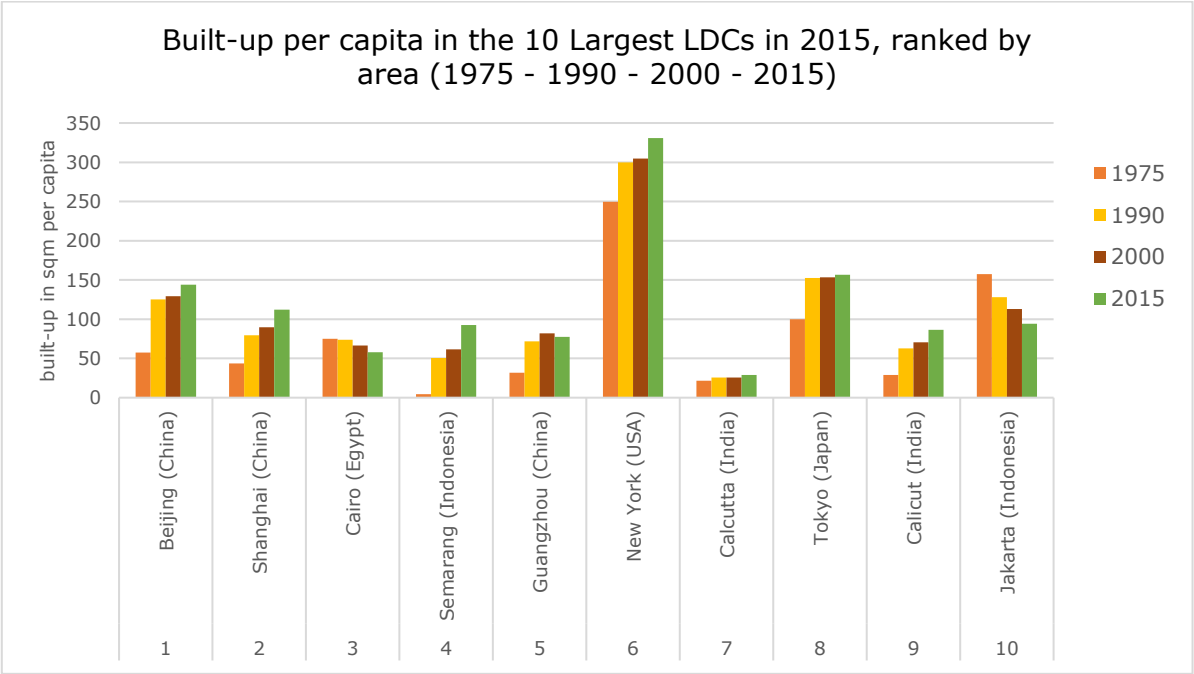


Chart 19 - *Built-up per capita* in the Top10 Largest urban clusters in 2015 ranked by area (1975 - 1990 - 2000 - 2015)

In the Chart 19 the values of the *built-up per capita* in the 10 largest *Urban Clusters* are reported for the years 1975, 1990, 2000, 2015.

Among the selected, Cairo and Jakarta are the only ones in which the *built-up per capita* has decreased between 1975 and 2015, while New York has by far the highest *built-up per capita* (more than 300m^2) and Calcutta the lowest (less than 30 m^2).

In half of these cities *built-up per capita* is lower than the world average in *Urban Clusters* (92m^2 per capita). The sum of the inhabitants living in these 10 large *Urban Clusters* represents 8% of the world population.

[23] In this Atlas, a giga-city is defined as a human settlement whit more than 100,000,000 of inhabitants.

3.5 Mapping exposure with GHSL for disaster risk reduction

The findings presented in the previous chapters are based on the analysis of the core GHSL data, namely built-up, population and settlements. However, it is possible to combine the information of GHSL also with any other spatial data set. This combination potential augments the value of the data significantly and broadens the application domain considerably.

The Sendai Framework for Disaster Risk Reduction[24] calls for a better understanding of disaster risk. Disaster risk management should be based on an understanding of disaster risk in all its dimensions including exposure of persons and assets as well as the technical means and policy options to reduce risk The GHSL built-up and population are currently the finest scale globally consistent global exposure data sets.

This will be illustrated in the following sections where GHSL population data is used as global exposure data. It is combined with open and free (almost) global elevation data from the Shuttle Radar Topography Mission (SRTM) to derive information about population in low lying coastal zones and hence at risk of flooding due to tsunamis, storm surges or sea level rise induced by climate change. A number of populated low-lying coastal areas are well protected by engineering civil works, others are not and thus more vulnerable and urban growth occurs increasingly in coastal areas. In a climate change scenario both will require investments to maintain these low-lying coastal areas safe and that is an issue of concern at global level

GHSL is also combined with slope information generated from the SRTM data. The analysis aimed to estimate the amount of global population living on steep slopes, which amplify the risk of natural hazards including that of landslides and flash floods.

Image 14 © aquatarkus © xuanhuongho, fotolia.com

[24] http:/ /www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf

3.5.1 Global Urban Population at sea level or below (1975-2015)

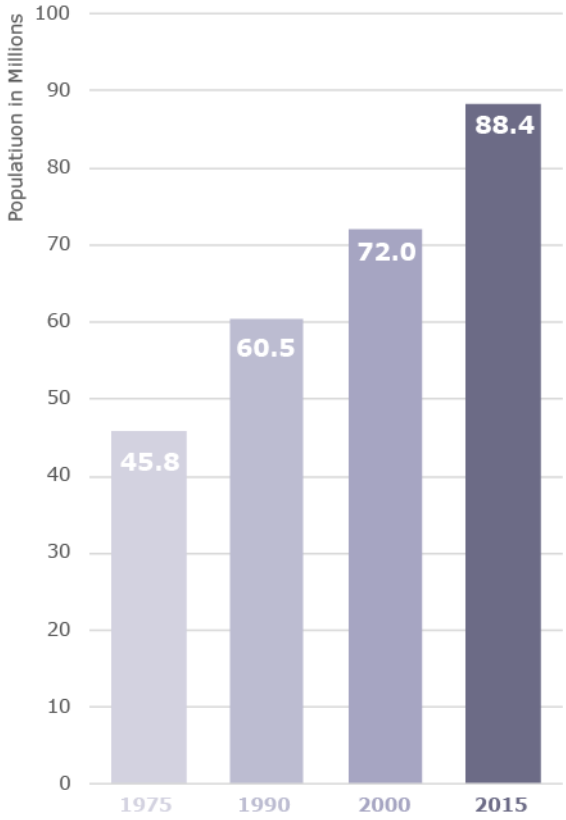


Chart 20 Urban population living at sea level or below

The world urban population living at sea level or below[25] continued to increase and it has doubled in the last 40 years from 45 to 88 million people, similarly to the average population growth rate. Only 1.4% of global urban population lives in urban areas that are potentially exposed to tsunamis, storm surges and sea level rise.

The distribution of built-up and population in this risk area of elevation below or equal to sea level is uneven across income groups. The fastest increase of population in these risk areas is concentrated in LIC, while the majority of built-up in HIC. Up to 9% of global urban population live in *Urban Clusters* in elevation class zero or below. This figure has more than tripled in forty years from nearly 2 to more than 6 million; only in the last fifteen years population increased by more than 1.5 million. In Lagos (Nigeria) more than half a million people are accounted today at sea level or below, more than 450 thousand in Dhaka (Bangladesh) and nearly 200 thousand in Port Harcourt (Nigeria).

The top10 cities per population in elevation class zero or below host in 2015 nearly 27 million people, 30% more than in 2000, more than 6 million more in 15 years. On average, these 10 cities host 10% of their urban population in this elevation class. This share raises to almost 50% in Amsterdam (where 3 million people are concerned), nearly 15% in Guangzhou (9.5 million) and 10% in Nagoya (1.2 million). More than 7 thousand square kilometres of built up are detected by GHSL in potential risk areas at or below sea level. The Netherlands account more than 1.3 thousand square kilometres, equivalent to more than ¼ of the global figure.

Table 5 Cities with the highest value of population living below the sea level

CITY	TOTAL POPULATION	POPULATION EXPOSED [%]
GUANGZHOU (CHINA)	66,403,832	14.4%
CAIRO (EGYPT)	83,824,701	6.0%
AMSTERDAM (NETHERLANDS)	6,786,158	47.3%
MUMBAY (INDIA)	24,481,393	6.9%
SHANGHAI (CHINA)	90,175,014	1.6%
CALICUT (INDIA)	31,063,096	4.5%
CALCUTTA (INDIA)	43,818,444	2.9%
NAGOYA (JAPAN)	11,964,329	10.1%
HO CHI MINH CITY (VIET NAM)	15,475,872	7.3%
TOKYO (JAPAN)	41,559,430	2.3%

[25] Due to the unavailability of SRTM data at latitudes greater than 60 degrees North or South the USA, Canada, Norway, Greenland, Iceland, Sweden, Finland and Russia are excluded from the analysis

3.5.2 Global Urban Population on steep slopes (1975-2015)

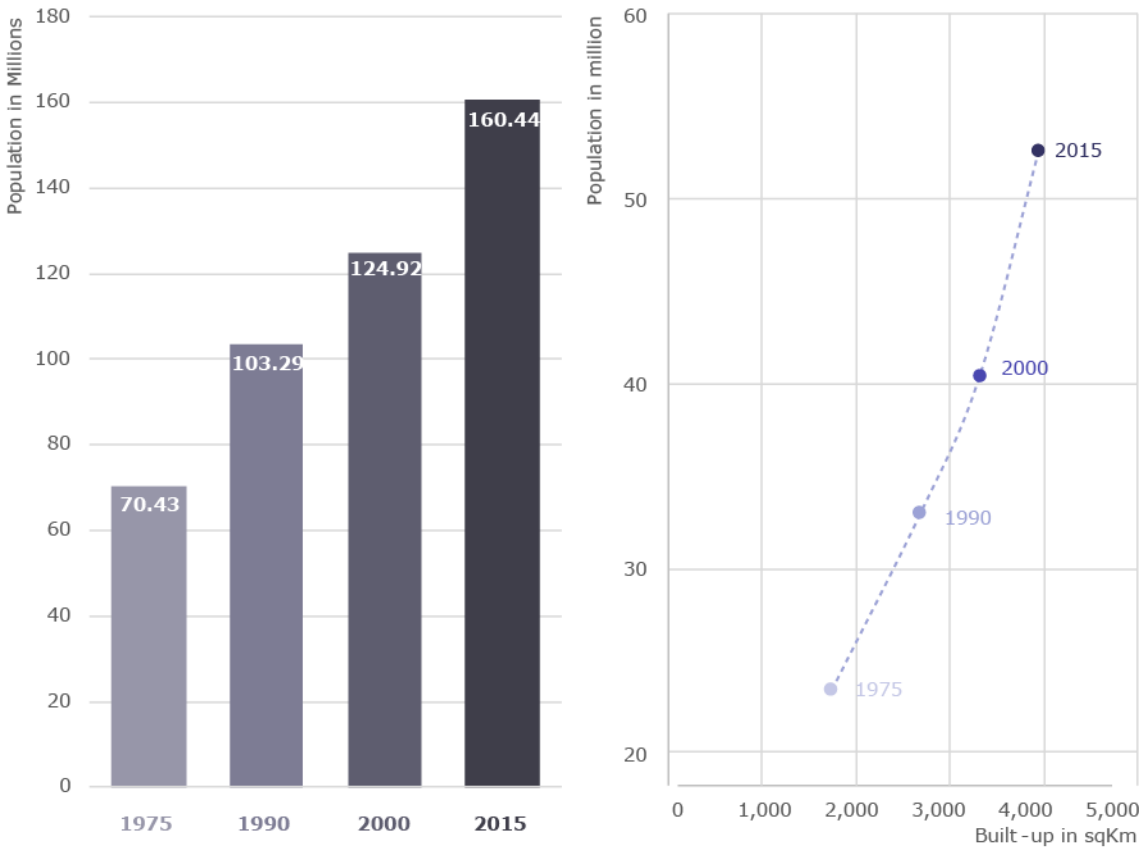


Chart 21 World urban population living on steep slopes

The world urban population living on steep slopes (greater than 15°)[26] has more than doubled in the last 40 years from 70 to 160 million people. Today, 2.6% of the global population lives on steep slopes in *Urban Clusters*. Thereby, the number of urban dwellers potentially exposed to landslides increases faster than the global urban population. In the last fifteen years it increased by nearly 30% equivalent to more than 35 million people worldwide.

The ten *Urban Clusters* with the highest amount of population living on steep slopes account for more than 11 million people. In Ta'izz (Yemen) more than 40% of *Urban Cluster* population live on steep slopes (1.82 million people), in Caracas (Venezuela) more than 25% (1.84 million), in Rio de Janeiro (Brazil) more than 12 % (more than 660 thousands).

Population in this slope class in Ta'izz, Lima and Guatemala City nearly doubled in 25 years, in Colombo it has more than doubled. Interestingly, the population growth on these slope areas is not accompanied by an equivalent growth of built-up. Certainly land constraints play a key role, which forces people to build vertically and to reduce the space per inhabitant.

Out of the 160 million people roughly one third (52 million people) live in the high-density *Urban Centres* of the world. Both built-up and population in these risk areas have increased by more than 120% in the last 40 years.

[26] Due to the unavailability of SRTM data at latitudes greater than 60 degrees North or South the USA, Canada, Norway, Greenland, Iceland, Sweden, Finland and Russia are excluded from the analysis

Table 6 Cities with the highest value of population living on steep slope (greater than 15°)

CITY	TOTAL POPULATION	POPULATION EXPOSED [%]
GUANGZHOU (CHINA)	66,403,832	2.79%
CARACAS (VENEZUELA)	6,858,198	26.84%
TA'IZZ (YEMEN)	4,324,957	42.06%
LIMA (PERU)	9,663,498	14.32%
WENZHOU (CHINA)	13,347,035	6.83%
COLOMBO (SRI LANKA)	12,915,053	7.03%
GUATEMALA CITY (GUATEMALA)	5,458,385	12.22%
RIO DE JANEIRO (BRAZIL)	10,112,469	6.58%
BUSAN (SOUTH KOREA)	5,118,223	11.99%
SEOUL (SOUTH KOREA)	25,516,898	2.39%

Image 15 © soft_light, fotolia.com

3.6 Vegetation in *Urban Clusters*

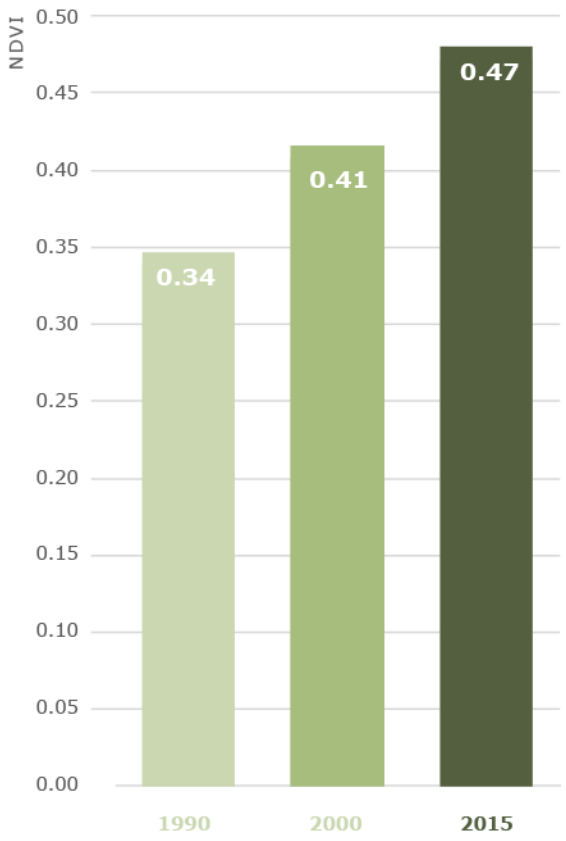


Chart 22 Global NDVI in urban clusters

Urban green is an important indicator for the quality of live in a city. The Normalised Difference Vegetation Index (NDVI) is widely used measure for the greenness of a city and high-resolution time-series are available for many years. The analysis of the NDVI in *Urban Clusters* reveals at global level an increase of 38% over the last 25 years.

The *Urban Clusters* are less densely built-up and often include private gardens and scattered agriculture. But even in the high-density *Urban Centres* we observe a similar trend. Although there is a strong variation in the increase of urban green in the ten most built-up city centres of the world with an increase between 4% for Jakarta and 52% for Tokyo, the general trend is positive. Some of this variability may be induced by climatic variability rather than a change in the urban green area.

Table 7 Greenness in the TOP10 *Urban Centres* by built-up in 2015

CITY	BUILT-UP [KM²]	POPULATION [MILLION]	AVERAGE GREENNESS (2015)	CHANGE IN GRENNESS[%]
LOS ANGELES	4734.24	14.20	0.318	15%
TOKYO	3873.57	33.74	0.354	52%
JAKARTA	3866.72	36.40	0.456	4%
GUANGZHOU/DONGUAN	3666.27	46.04	0.315	13%
NEW YORK	3540.23	15.19	0.501	13%
CHICAGO	3523.06	7.77	0.507	18%
JOHANNESBOURG/PRETORIA	3170.11	11.63	0.448	14%
DALLAS	2468.81	4.99	0.451	15%
MIAMI	2426.87	5.50	0.446	17%
OSAKA	2357.45	16.53	0.366	34%

3.7 Nightlights in *Urban Clusters* and *Urban Centres*

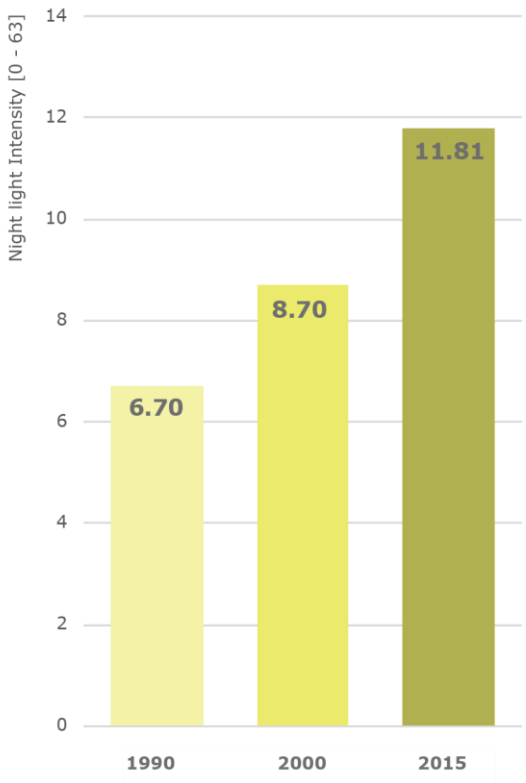


Chart 23 Global average night light in *Urban clusters*

The longest and most systematic series of satellite images acquired at night is acquired by the National Oceanic and Atmospheric Administration (NOAA) with the Defence Meteorological Satellite Program (DMSP), which is available since 1992. Originally it is designed for the detection of clouds at night for meteorological purposes, but it has since also been used for mapping of nightlights from urban areas, wildfires or gas flares.

In the context of the *Atlas of the Human Planet 2016*, night light data is not used for detection of urban areas or settlements, instead the nightlight intensity is used to characterise settlements in terms of economic activity. With GHSL it is now possible to focus only on the light emitted by urban areas excluding other emission sources. Therefore, we analyse in this section the evolution of global nightlight emissions in *Urban Clusters* and compare the country averages of *Urban Centres* per income class for different groups of countries.

Overall there is a strong increase in the nightlight emission. The emission of *Urban Clusters* increased steadily by 76% from 1990-2015. In the same period the global population increased by only 38%.

However, there a very strong differences from country to country and even within the country. Most of the urban nightlight is emitted by high density *Urban Centres*. The global average is 11.81 for *Urban Clusters*, but most of this light is emitted by *Urban Centres* with an average of 46.15. Focussing only on the *Urban Centres* provides a more pronounced view on nightlight emissions.

There is a strong change in the nightlight emission by income class. In 2015, 90% of the night light was emitted from *Urban Centres* that accounting for only 20% of the global population. The average nightlight emission of LDC's is less than half of the LMC. On average the *Urban Centres* in UMC emits more lights than the *Urban Centres* in all other income classes including HIC.

At a first glance this seems to be surprising as it could be expected that HIC emit the highest amount of light, but possibly countries start implementing mechanisms to reduce light emissions for environmental and energy efficiency purposes after reaching a certain level of wealth.

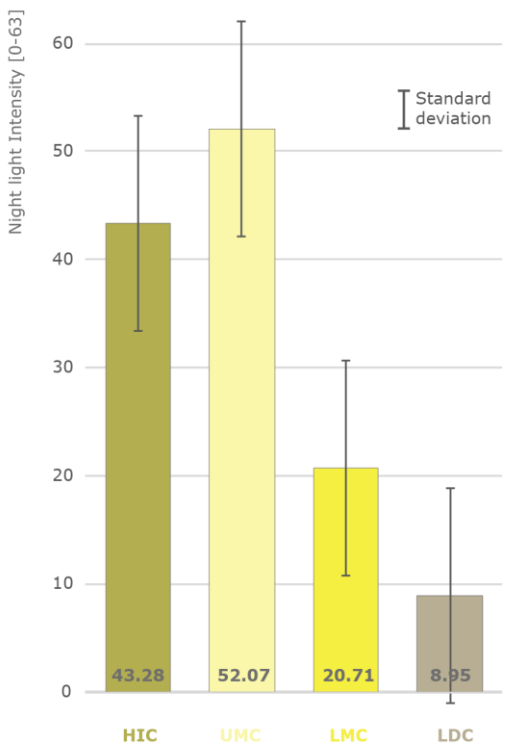


Chart 24 Average Nightlight per income in comparison to global average in *Urban Centres*

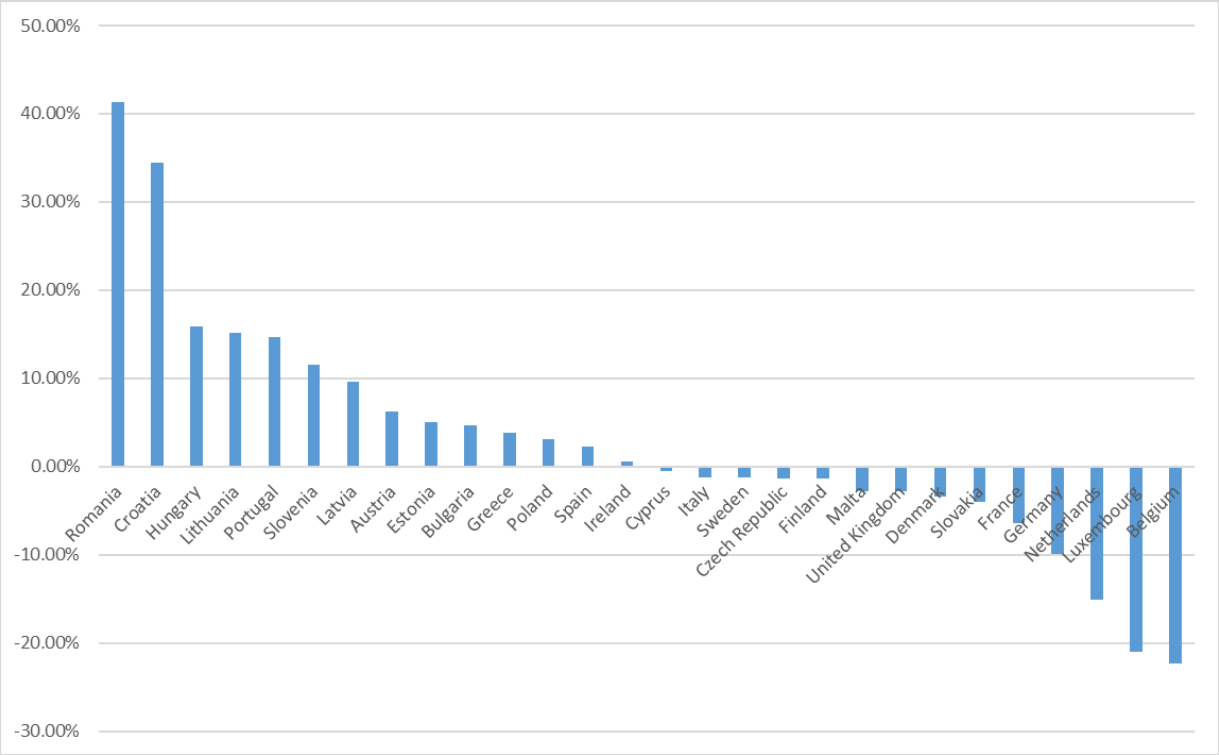


Chart 25 Change of average nightlight emission of *Urban Centres* per country between 1990 and 2000 for the EU-28 countries

In fact, countries including The Netherlands, Luxembourg and Belgium were reducing the nightlight emission by at least 15% in the last 25 years. Belgium, with the strongest decline, has for example decided in 2011 to drastically reduce the illumination of motorways[27]. Also, other countries or regions have started similar efforts including France, Slovenia, Lombardy (Italy) or Catalonia (Spain)[28].

The chart also illustrates a strong increase of nightlight emission in countries that joined the EU in 2004: Romania, Croatia, Hungary, Lithuania and Slovenia increased the night light emission by at least 11%. A large share of the money that the countries receive from the EU budget goes to its regions. The regional policy aims to reduce the economic, social and territorial disparities between Europe's regions. Regional funds invest in a wide range of projects supporting job creation, competitiveness, economic growth, improved quality of life and sustainable development. Romania, for example, received in 2013 almost 3 billion Euro for regional policy from the EU and transport is a top priority. The EU is helping build a new motorway between Orăştie and Sibiu[29].

[27] http://www.latribune.fr/actualites/economie/international/20110715trib000636543/la-belgique-plonge-ses-autoroutes-dans-le-noir-.html
[28] http://wua-wien.at/naturschutz-und-stadtoekologie/weiterfhrende-informationen-zum-thema17/gesetze-gegen-lichtverschmutzung-international
[29] http://ec.europa.eu/budget/mycountry/RO/index_en.cfm

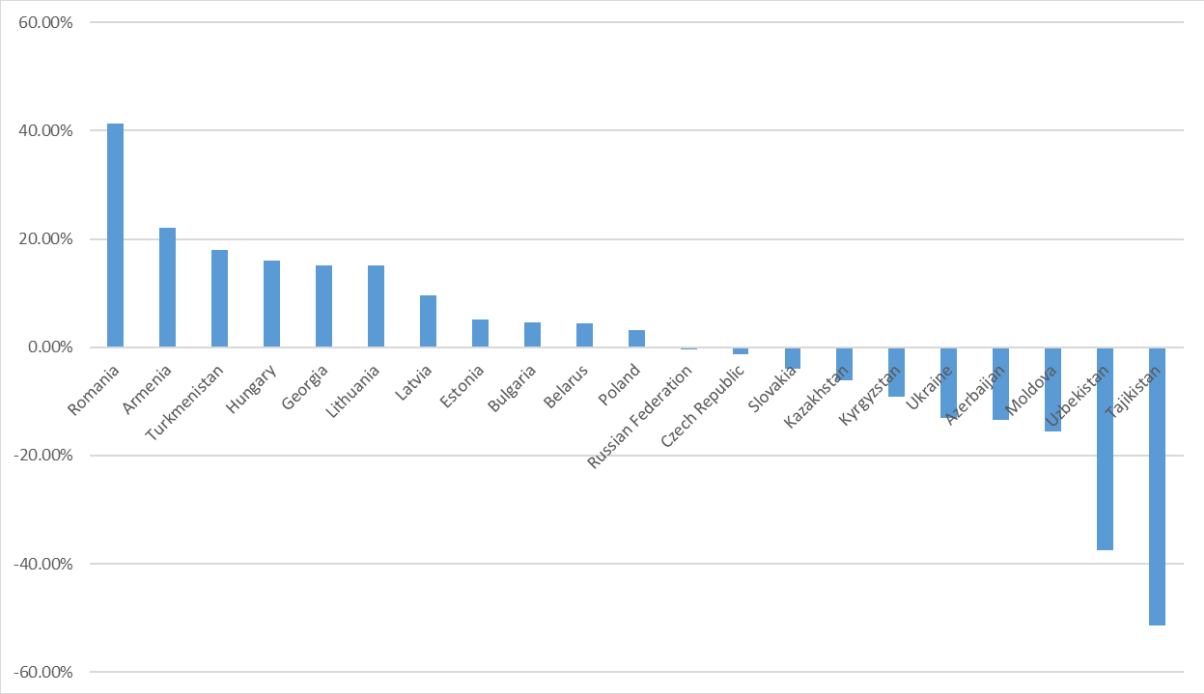
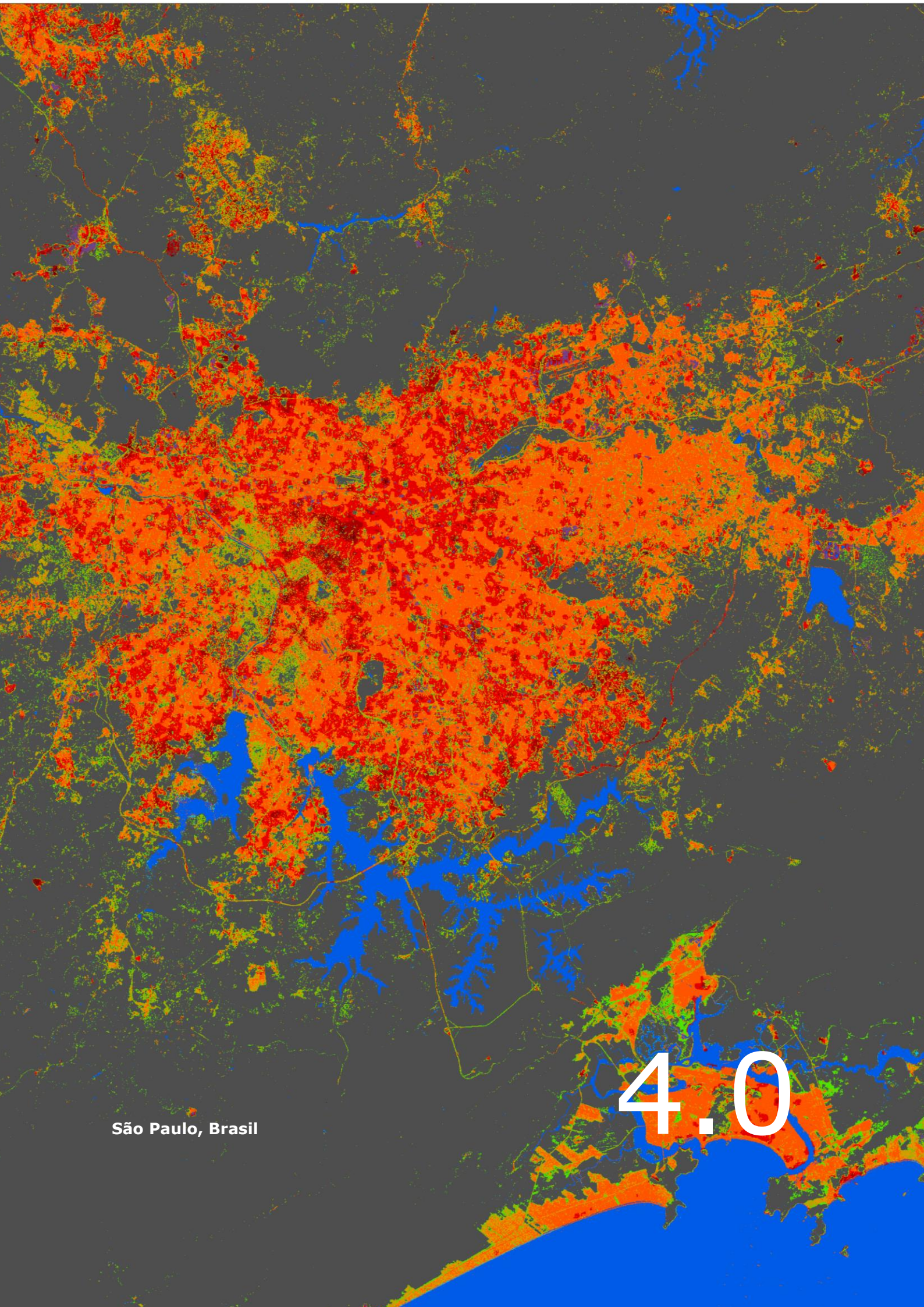


Chart 26 Change of average nightlight emission of *Urban Centres* per country between 1990 and 2000 for the former Warsaw Pact countries

Other regional trends can, for example, be observed in the Eastern Europe, the Russian Federation and former Soviet Union republic for the 1980's and 1990's time frame. While the Russian Federation maintained the level of night light illumination, two diverging trends occurred in its neighbourhood. A number of countries including those that joined the EU in 2004, as well as Armenia and Turkmenistan increased significantly the nightlight illumination. Other Central Asia Countries and former Soviet Union republic experienced severe drops in nightlight illumination. For example, Tajikistan halved its nightlight emissions in the last 25 years.

Image 16 © ver0nicka, fotolia.com


4.0
São Paulo, Brasil

4. GHSL application: a selection of showcases

The European Commission has adopted an open data policy[30], which is also a central aspect for the GHSL. Therefore, the GHSL data have been distributed for testing purposes to a number of experts from the GEO Human Planet Initiative[31] and to European Commission services. This chapter showcases some application examples of the global GHSL data set.

- The first three contributions (Deuskar & Stewart; Corbane, Pesaresi, Kemper & Freire; Birch & Steif) illustrate the possibilities offered by the GHSL to explore the several dimensions of the **urbanisation phenomenon** and to monitor the **implementation of international agreements** such as the SGDs.

- The GHSL provides a framework that can be applied not only to the Landsat data, which are the basis for the findings presented in this *Atlas*, but can be applied to other types of satellite imagery. In the last years several regional branches of GHSL were established that serve regions with higher spatial resolution data that is nevertheless compatible and transferable to the global data. The second group of cases explore these applications at **regional and country level**, in particular for Europe (Ferri & Siragusa), China (Lu, Guo, Li, Sui, Huang, Pesaresi, Ehrlich) and South Africa (Mudau, Mhangara, Politis and Kemper) and **a focus at city level** (Melchiorri & Siragusa).

- A third group of contributions illustrates the possibilities offered by the GHSL to contribute in **assessing global risk** (De Groeve & Vernaccini) and **humanitarian crisis**, such as in Syria (Corbane, Kemper, Freire, Louvrier and Pesaresi) and in the Horn of Africa (Kemper, Pesaresi, Melchiorri).

- The last four contributions link information provided by the GHSL about built-up and population and their uses in studying the consequences of **climate change and natural disasters** (Gao, Gravel-Miguel, O'Neill, Barton; Buchanan; Corbane, Ehrlich, De Groeve, Bogazici; Freire, Florczyk, Pesaresi).

[30]Communication on Open Data
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0882:FIN:EN:PDF
[31] Human Planet Initiative https://www.earthobservations.org/activity.php?id=51

4.1 Measuring Global Urbanization using a Standard Definition of Urban Areas –Analysis of Preliminary Results

Chandan Deuskar & Benjamin Stewart, World Bank

This paper discusses the application of a standard definition of urban areas, based on population size and density thresholds, to measure and compare global, regional, and national levels of urbanization. Most of our understanding of global trends in urbanization is based on inconsistent data as national definitions of urban vary widely from one country to the other.

The paper uses an approach originally developed by the European Commission, together with new gridded population distribution data sets based on satellite imagery and other inputs. We present and discuss preliminary results using two sources of population distribution data (GHS Pop and WorldPop), and compare these results to widely-used UN data on urbanization, which are based on varying national definitions.

New forms of data such as GHSL allow urban areas to be defined and measured in a standard way globally, presenting a more consistent global picture of urbanization. While there is no universal definition of 'urban', new forms of data, including newly available built-up area maps derived from satellite imagery and population distribution data, are helping to create a database of urban areas that allow more meaningful cross-country comparisons and global estimates of urbanization. As long as the limitations of the approach and the data sources, as well as the impact of variations in the definition, are well-understood, this could help create a more complete and consistent global picture of urbanization, which would enable more informed investment and policy decisions.

Globally comparable estimates of urbanization can have significant policy relevance. There are a number of widely-repeated 'stylized facts' about global urbanization: "no country has ever reached middle-income status without a significant population shift into cities" (Spence, Annez, and Buckley 2008); "[h]ome to more than half the world's people, urban areas will accommodate almost all population growth over the next four decades. The pace will be fastest in developing countries" (World Bank 2014); "[t]he Latin American and the Caribbean region is considered the most urbanized in the world" (United Nations Human Settlements Programme 2012); "Africa shows much lower income levels than other regions, such as East Asia or South Asia, at similar stages of urbanization" (Maria E. Freire, Somik Lall, and Danny Leipziger 2015); among others. These statements have far-reaching policy implications, but are typically based on inconsistent urban data. Globally comparable measures, like the ones tested here, can allow such statements to be validated, modified, or nuanced with more rigorous comparative analysis. For example, when standard definitions are applied, South Asia is more urbanized and Latin America is less urbanized than national definitions suggest.

The ability to test different definitions of urban at the global scale will also allow better monitoring of the SDGs and their implementation.

The full paper is forthcoming on the World Bank open knowledge repository (https://openknowledge.worldbank.org).

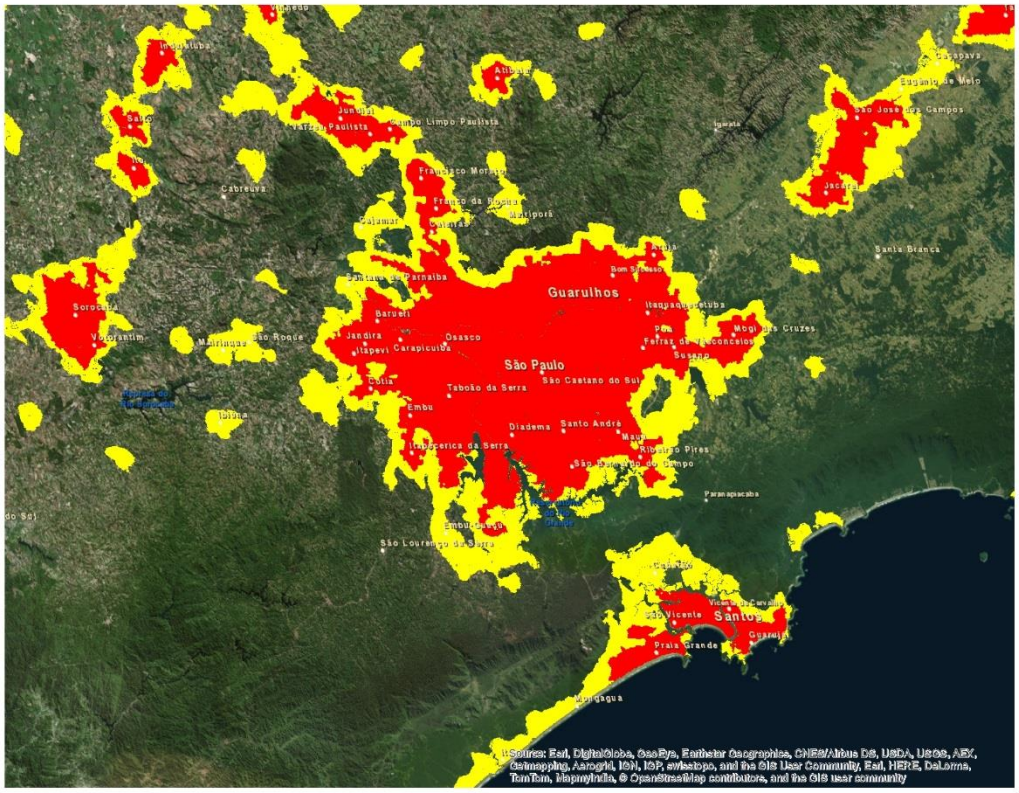


Figure 8. High-density clusters in red and *Urban Cluster*s in yellow, using original EC density and size thresholds on WorldPop. (Source: authors, using data from WorldPop)

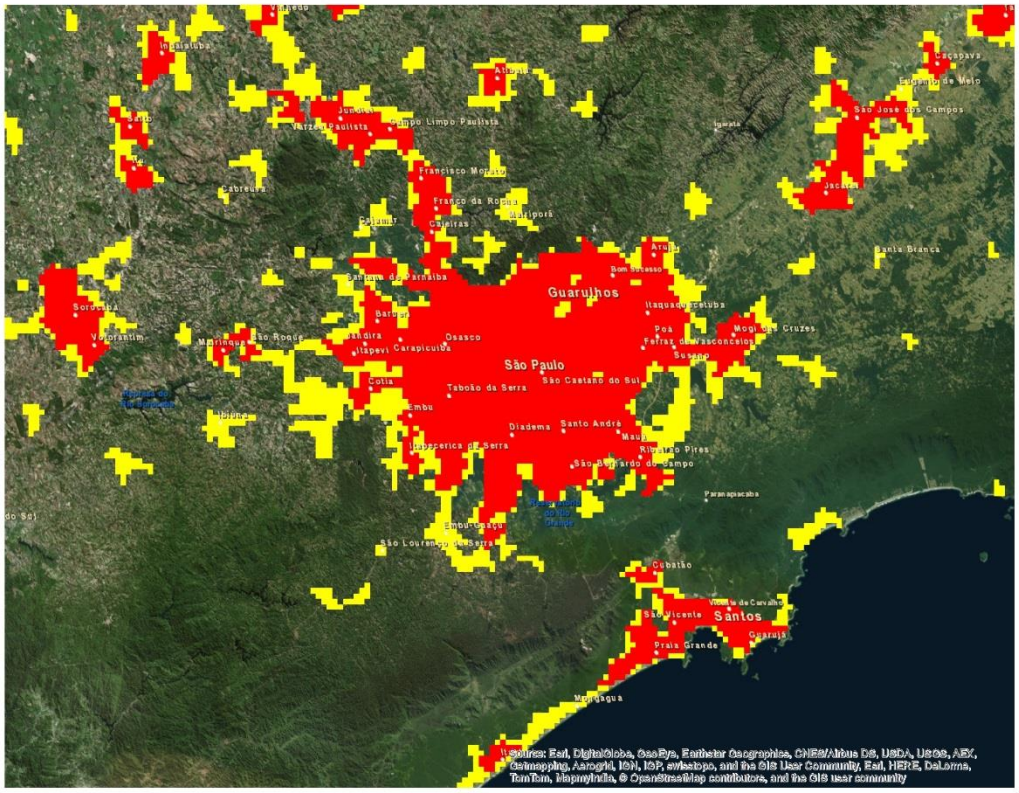


Figure 9 High-density clusters in red and *Urban Clusters* in yellow, using original EC density and size thresholds on GHS Pop. (Source: authors, using data from WorldPop and JRC)

4.2 Assessment of Land Use Efficiency using GHSL derived indicators

Christina Corbane, Martino Pesaresi, Thomas Kemper & Sergio Freire (European Commission, Joint Research Centre)

With the adoption of 2030 Agenda for Sustainable Development, Member States are called to measure, monitor and report on the targets of the SDGs. Crucial to the success of the SDGs will be the provision of high quality, consistent and timely data at different time stamps to allow monitoring progress towards the different targets. This study examines the possibility of utilizing the GHSL built-up and population data in the field of urban planning and management for the measurement and monitoring of the SDGs. In particular, the focus is on SDG Goal 11.3., which aims to "Enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlements planning and management in all countries".

Indicator 11.3.1 – "*Ratio of land consumption rate to population growth rate, at comparable scale*" is being discussed within the UN Sustainable Development Solutions Network (SDSN) for measuring Goal 11.3. This ratio actually measures the Land Use Efficiency and allows monitoring the relationship between land consumption and population growth. The proposed indicator may experience difficulties in capturing cities with negative or zero population growth; or cities that due to severe disaster have lost part of their territories. Besides, currently, the "urban extent" is proposed as the area of study, comprising the built-up areas and urbanized open space. An agreement on terminology of urban areas and on the delimitation of the spatial boundary of the urban agglomeration still needs to be reached due to the diverse methods for defining urban areas. To overcome those issues, we propose here an adapted formulation of the land-use efficiency indicator as "*Change rates in the built-up surface per capita*":

$$Idx_t = \frac{Y_t - Y_{t+n}}{Y_t} \quad \text{where} \quad Y_t = \frac{BU_t}{POP_t}$$

and BU_t and POP_t are respectively the built-up area and the population at time t.

The detailed spatial information on built-up and population provided at different time stamps offers an interesting framework for testing the new proposed indicator and for identifying change patterns and variations at different scales (from agglomeration to the regional scales). For this analysis, the GHS-BU and the associated GHS-POP data at 250 × 250 m cell grid for the years 1990, 2000 and 2014 were used for calculating the land-use efficiency indicator for two periods 1990-2000 ($Id_{1990\text{-}2000}$) and 2000-2014 ($Id_{2000\text{-}2014}$).

Figure 10 shows an example of the calculated indicator in the north-western region of Europe in the period 2000-2014. The values range between -1 and 1. They were rescaled between -0.1 and +0.5 for easier visualization and a key for interpretation is proposed here as follows:

- Negative values (red): population loss in constant amount of built-up or high increase in built-up for almost constant population.
- Positive values (green to blue): population gain faster than built-up surface increase (may include 3D-built-up increase or new expansion areas).
- Close to zero values (orange): stable areas or linear growth of built-up and population.

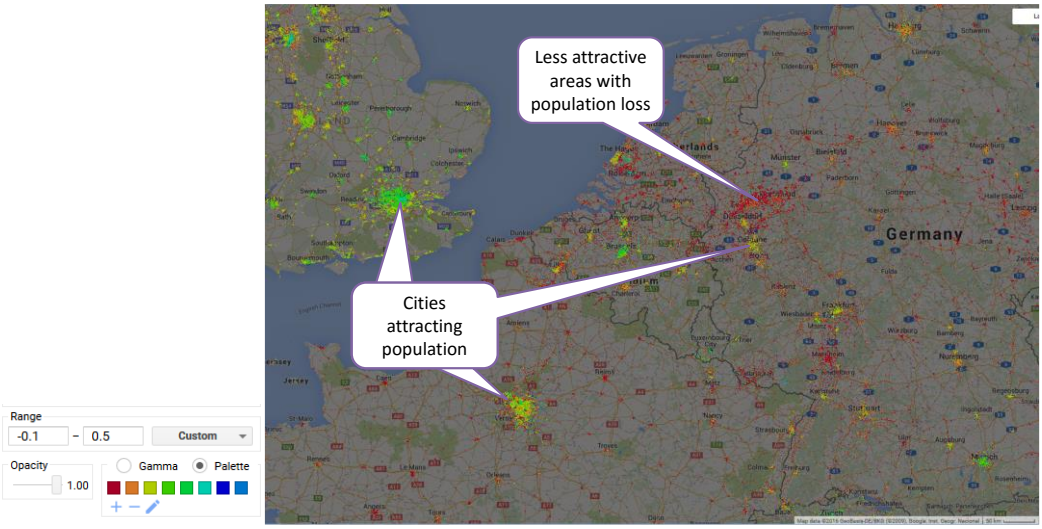


Figure 10 Land use efficiency (Id 2000-2014) shown over the north western region of Europe (250m grid cells)

The land-use efficiency indicator reveals interesting patterns highlighting regional inequalities: some European cities are evidently more attractive with increased urbanization (e.g. London) while some other cities (e.g. Düsseldorf, Duisburg, Dortmund in Germany) are witnessing population loss. Figure 11 shows another phenomenon that can be captured using the land use efficiency derived from GHSL. It highlights the effects of globalization and the rise of the manufacturing industry in China which attracts cheap labour (e.g. Shanghai) and is directly associated with an increase of rural-to-urban migration.

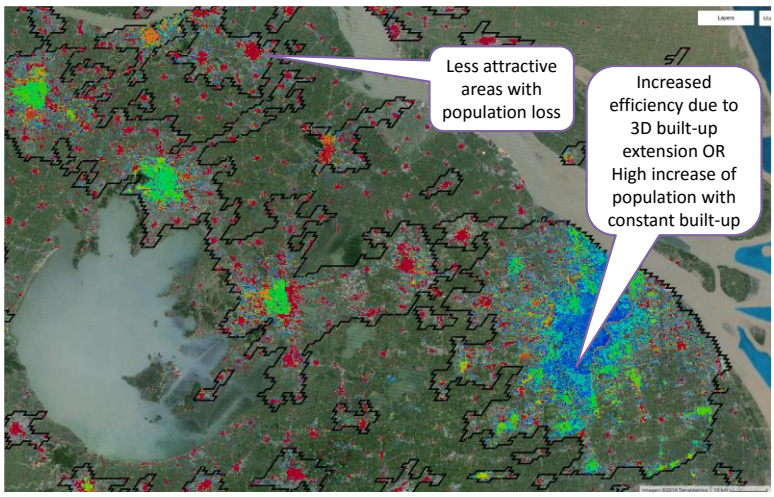


Figure 11 - Land use efficiency (Id 2000-2014) shown over Shanghai and its suburban area Europe (250m grid cells)

The globally consistent and detailed GHSL data offers an invaluable tool for computing the modified land use efficiency indicator. The assessment of the indicator at the grid level allows evidencing various dimensions of the land consumption: historical, economic, environmental, social. It also demonstrates the potential of exploiting the spatial component of the GHSL data for deriving cross-cutting metrics such a land use efficiency that are connected to several other indicators of the SDGs.

Datasets:
Global Human Settlement Layer (GHSL), Global Built-Up Grid, GHS_BUILT_LDSMT_GLOBE_R2015B
Global Human Settlement Layer (GHSL), Global Population Grids, GHS_POP_GPW4_GLOBE_R2015A

4.3 Using the GHSL for Monitoring Land and Population Growth for to Guide Public Policy

Eugenie L. Birch (University of Pennsylvania), Kenneth Steif (Urban Spatial)

With the approval of the 2030 Agenda for Sustainable Development in September 2015 and the subsequent discussion of indicators to monitor progress in 2016, the United Nations is endeavouring to establish basic standards and guidelines for nations to develop public policies responsive to the issues identified in 17 sustainable development goals (SDGs). For Goal 11 "Make cities and human settlements inclusive, safe, resilient and sustainable" and its seven associated targets, planning and managing the spatial development of metropolitan areas will provide a strong foundation for the execution of Goal 11 and several other SDGs. In particular, Target 11.3, "By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.," ratifies this idea. The UN is exploring ways to measure this sustainable urbanization/planning concept, realizing that it will need to consider demographic and spatial data, an idea that has become realizable with the emergence of the Global Human Settlements Layer (GHSL) and associated population data. The GHSL helps support the target's underlying assumption that enhancing sustainable urbanization through planning requires understanding changes in population and in land consumption. This brief begins to explore this idea, also querying whether regional differences might exist. It looks at metropolitan areas having populations of a million or more in 1970 in the UN's eight regions. A first look at growth and rate change through traditional demographic data offered by the United Nations Population Division in Table 1 illustrates the absolute numbers and rates. It offers directional signals but does not offer any other guidance.

Table 8 Eight Cities in Eight UN Regions (in thousands) (Source: UN Population Division World Urbanization Prospects 2014)

City	1970	2000	2010	% change 2000-2010	% change 1970-2010
Ankara TKY	1,341	3,179	4,166	**31%**	211%
Atlanta GA	1,182	3,522	4,544	**29%**	284%
Bangalore IN	1,615	5,567	8,275	**49%**	412%
Cape Town SA	1,114	2,715	3,345	**23%**	200%
Harbin CH	1,696	3,888	4,896	**26%**	189%
Lisbon PTGL	1,817	2,672	2,812	**5%**	55%
Medellin CO	1,260	2,724	3,510	**29%**	179%
Surabaya IND	1,474	2,611	2,768	**6%**	88%

A second look, through the GHSL allows an exploration of the rate of change in the ratio of land consumption rates and population rates in the eight places. (Note the demographic data is drawn from the data set associated with the GHSL) and offers a different perspective of change in these cities.

Table 9 Changes in Area/Population Ratio (Source: GHSL/Penn IUR/Urban Spatial)

City	Square mile/person 2000	Square mile/person 2014	% change 2000-2014
Ankara TKY	157	111	-29%
Atlanta GA	881	759	-14%
Bangalore IN	49	42	-14%
Cape Town SA	355	263	-26%
Harbin CH	83	83	0%
Lisbon PTGL	223	225	0
Medellin CO	48	44	-9%
Surabaya IND	65	99	52%

The figures in Table 9 illustrates a growth dynamic different from that of the simple demographic data shown earlier. Here, the analyst can explore the drivers at the local

level that explain the performance. Where these data become even more helpful is in the mapped version that pinpoints the variation within each agglomeration. For example, the overall figure for Lisbon displays no change in the ratio over the period, yet the map in Figure 12 underlines the wide variation within the agglomeration: the centre (yellow) experienced loss population while the periphery gained (green to blue). Harbin with a similar overall figure had a far different experience in terms of the location of the changes within: gains in the centre and some losses at the edges.

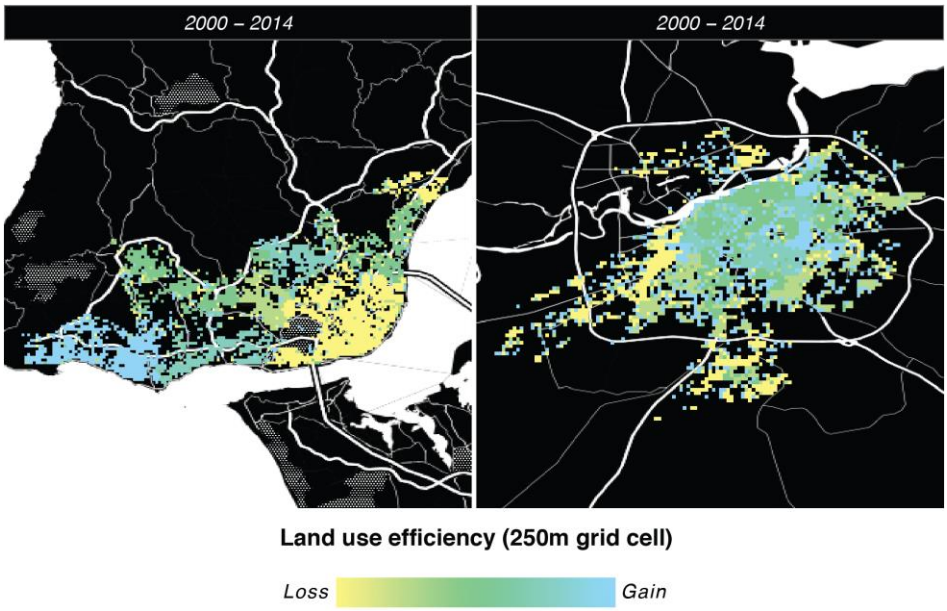


Figure 12 Lisbon (left) and Harbin (right) LUE 2000-2014 (Source GHSL/Penn IUR/Urban Spatial)

The addition of other datasets would offer more insights to guide decision-making. Having the administrative boundaries would be useful. For example, Lisbon and Harbin each encompass 18 administrative units, not shown in Figure 12. Understanding the GHSL-revealed land/population dynamics needs to occur within the framework of each place's existing political jurisdictions and their associated powers and responsibilities. For example, layering the jurisdictions over the GHSL could provide a sound evidence-based argument for regional-scale planning and management of land. Other data to consider are land suitability to illustrate vulnerable lands in need of attention, assessment of public space could demonstrate lack of street connectivity and/or the absence of common space and using GHSL to portray the built up areas nationally to provide the basis for devising national urban policies that consider balanced territorial development. As a free, open-access platform, the GHSL provides a much-needed tool to support sustainable urban development for public and private decision-makers, for researchers and other observers. The dissemination and explanation of the GHSL as a basic tool is an essential next task. The UN or some international body will need to develop an instructional manual, perhaps in the form of a website to assist in GHSL application interpretation. See for example, the indicator catalogue developed in the United States for the Partnership for Sustainable Communities.

References and Datasets:

Global Human Settlement Layer (GHSL), Global Built-Up Grid, GHS_BUILT_LDSMT_GLOBE_R2010B
Global Human Settlement Layer (GHSL), Global Population Grids, GHS_POP_GPW4_GLOBE_R2015A
Pesaresi, Presentation at Expert Group Meeting, Monitoring the SDG 11, New York, 19-20th May-, 2016
UN Habitat, Monitoring of Sustainable Development Goal 11.3, Report on the Expert Group Meeting New York, 19-20th May-, 2016

4.4 The European Settlement Map

A very-high-resolution map of Europe based on GHSL
Ferri Stefano (European Commission, Joint Research Centre), Siragusa Alice (Piksel Inc.)

The European Settlement Map (ESM) (Ferri et al. 2014; Florczyk et al. 2015) is the first complete European Map of built-up and it was published by the JRC in July 2014. The ESM products have been financed by the Directorate-General for Regional and Urban Policy (DG REGIO) in the frame of the URBA project.
The aim of the project was to produce a complete and homogenous map of the European settlements with a high spatial resolution and to use this map for downscaling the European population grid. The first version was realised at 100m resolution, and recently (15th April 2016) the layer at 10m has been published, offering more detailed information (higher resolution) and green components. The ESM 2.5m resolution version will be released in 2017. The technology used to produce the ESM derives from the Global Human Settlement Layer 2013 (GHSL) methodology (Martino Pesaresi, Huadong, et al. 2013) adapted and tuned on the Copernicus Core 003 dataset.

The Copernicus Core 003 dataset (Burger, Matteo, and \AAstrand 2012) is based on SPOT-5 imagery with 3 bands (NIR, RED, GREEN) at 2.5m of spatial resolution, which with more than 3800 scenes covering all European countries.

The urban green component (Ferri, Siragusa, and Halkia 2016) is a value added to the project, that exploits the spectral derived information available in the Core 003 dataset. In early versions of the ESM a modified NDVI index was used as one of the main image-derived information features used to detect the built-up class. The final built-up layer has been complemented with residual vegetation information. In the ESM community this complementary information arouse interest in spite of its limitations. Its high resolution of information supports a variety of applications at urban scale. In the response to growing interest in urban green in the community, the new version of the ESM offers an improved green component.

The European Commission has, in recent years, been increasing its focus on urban issues, as a response to the fact that by 2020 it is estimated that almost 80% of EU citizens will be living in cities. Fine scale and urban focus make the ESM a valid input for European projects that need information over all European countries and enough details that permit studies at urban scale.

The European Union and the European Space Agency founded a new VHR acquisition campaign that will be repeated every 3 year taking the 2012 as starting reference. Under this condition shall be produced at least 2 European mosaic, one 2015 referenced, and one 2018 referenced. The new dataset aims at consolidating predefined needs requiring Earth Observation data. “LIFE”, “The European Green Capital project”, “the Green Capital Award (EGCA)” are some projects that mostly will benefit from it. The political importance of these issues is demonstrated by the inclusion in the 7th Environmental Action Programme (7EAP) of the priority Objective 8, entitled Sustainable Cities.

The GHSL tools that produced the ESM in 2014, and contributed to the 6th Cohesion Report, can address the new challenges proposed by the European commission by the 2020 supporting urban studies at local scales, and by the 2020 allowing to evaluate finer urbanization changes in Europe.

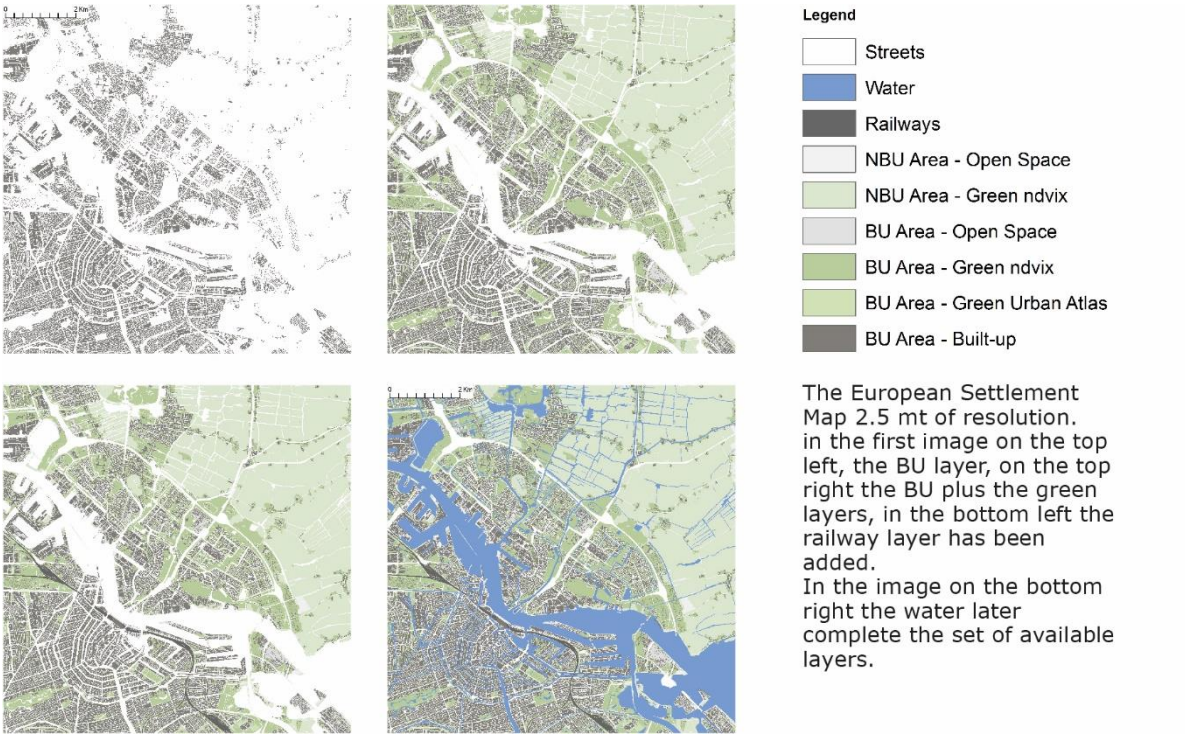


Figure 13 ESM – 2.5m of resolution – Amsterdam – produced by JRC – European Commission

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Datasets:
Copernicus Core 003 (source) ~3800 scenes (SPOT5 and SPOT6), 2.5m pixel resolution, 3 bands (NIR, RED, GREEN), acquisition years 2010 (1%), 2011 (64%), 2012 (19%), 2013 (17%).
ESM-2014 (1st ESM version produced), 100m pixel resolution, http://land.copernicus.eu/pan-european/GHSL/EU%20GHSL%202014.
ESM-2016 10m, 100m (2nd release, model updated, same source), 100m, 10m pixel resolution, http://land.copernicus.eu/pan-european/GHSL/EU%20GHSL%202014
ESM-2017 2.5m (3rd release in 2017), 2.5m pixel resolution.

Image 17 © Sergii Figurnyi, fotolia.com

4.5 Monitoring urbanization dynamics in mega cities in China

Linlin Lu, Huadong Guo, Qingting Li, Yue Sui, Jinhua Huang (RADI, CAS), Martino Pesaresi, Daniele Ehrlich (European Commission, Joint Research Centre)

The global proportion of urban population has greatly increased in the past decades. Urbanization and expansion of built-up areas across the world has profound effects on environment, biodiversity, ecological processes and regional sustainability. Measuring and understanding the process of urbanization would help the city planners to reduce problems associated with increased urban area, population and build a sustainable city. Beijing, Shanghai and Guangzhou are the three largest mega cities in China. They are urbanizing at an unprecedented rate in the last four decades (Lu et al. 2014; Gueguen et al. 2013).

The Global Human Settlement Layer from Landsat data of four epochs 1975, 1990, 2000, and 2014 produced by European Commission provides reliable built-up area presence information at a global scale (Martino Pesaresi et al. 2016). The objective of our study is to understand the urban dynamics in the three mega cities in last four decades through analysing GHSL Landsat products. To understand the spatial pattern of urban growth, the cities were divided into 4 zones based on directions - Northwest (NW), Northeast (NE), Southwest (SW) and Southeast (SE), respectively based on the Central Business District. The growth of the urban areas in respective zones was analysed through the computation of urban density for different periods.

Figure 14 shows the intuitive changes of the three mega cities. The built-up areas increased from 1331 sqkm in 1975 to 3061 q km in 2014 in Beijing. The built-up areas of Shanghai increased from 598 sqkm in 1975 to 2673 sqkm in 2014. In Guangzhou, the built-up areas increased from 268 sqkm in 1975 to 1216 sqkm in 2014. The built-up areas show continuous outward expansion in Beijing during the last four decades (Figure 14 (a)). Surrounding the Shanghai administrative unit, the built-up areas and the traffic network grew rapidly between 1975 and 2014 (Figure 14(b)). The expansion was in a concentric shape. In western Guangzhou newly built areas and settlements were developed from the west to east, and the city grew rapidly (Figure 14 (c)). The extension was limited in eastern Guangzhou due to the altitude of mountainous areas. The statistical results of density of built-up areas (BU density) changes are illustrated in Figure 15 Changes of built-up density in mega cities from 1975 to 2014. (a) Beijing, (b) Shanghai, and (c) Guangzhou. Each direction shows different growth rates. In Beijing (Figure 15 (a)), the southeast is the fastest growing direction with a BU density increasing from 13.75% in 1975 to 38.46% in 2014. The growth rate in northeast and northwest is lower than the other two directions. For Shanghai (Figure 15 (b)), the BU density increased from 3.11% to 27.35% in southeast direction with the highest growth rate during the past 40 years. The northwest section of the Shanghai city shows the highest built-up density, while the northeast has the lowest. For Guangzhou (Figure 15 (c)), the southwest direction shows a highest BU density, while the southeast direction shows a highest BU density growth rate.

With the GHSL Landsat product as baseline data, remote sensing data from different sensors can be integrated for detailed urbanization pattern and impacts analysis in mega cities in China.

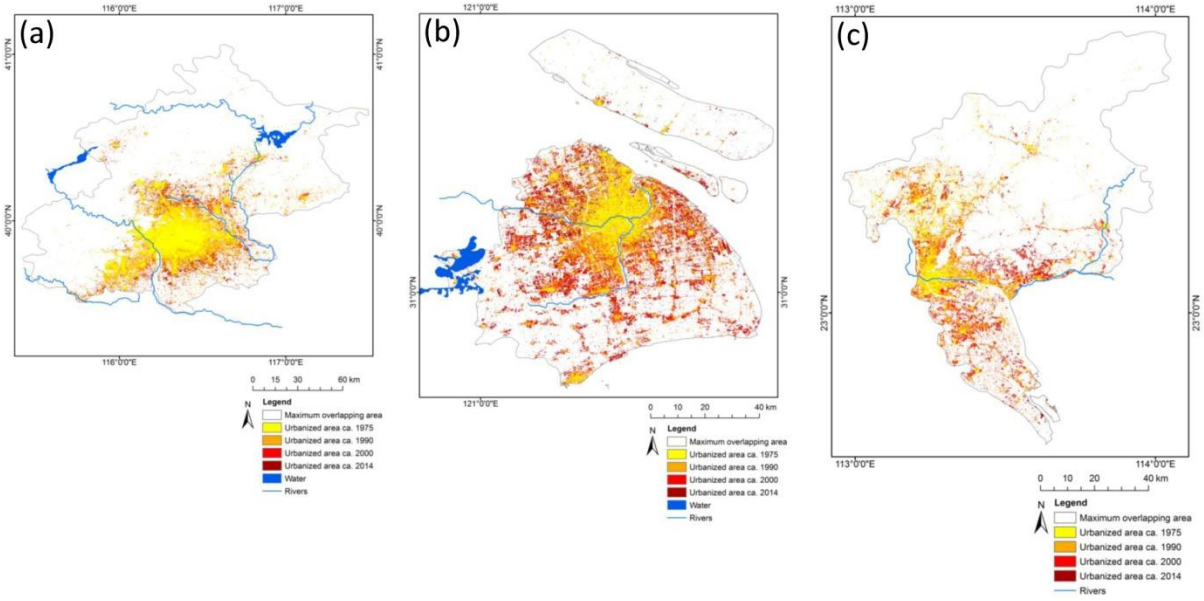

Figure 14 Changes of built-up areas in mega cities from 1975 to 2014. (a) Beijing, (b) Shanghai, and (c) Guangzhou.

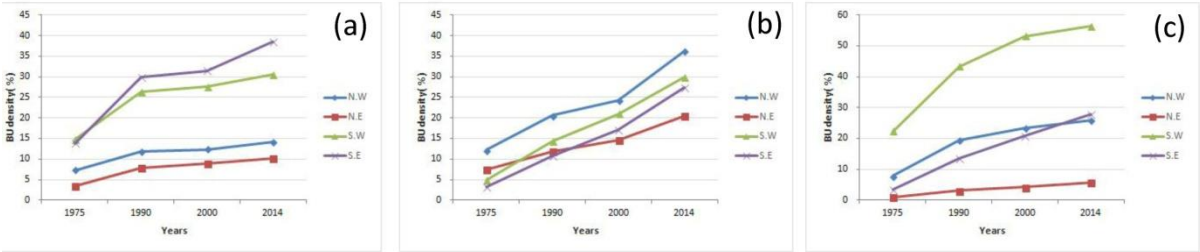

Figure 15 Changes of built-up density in mega cities from 1975 to 2014. (a) Beijing, (b) Shanghai, and (c) Guangzhou

4.6 Country-wide Mapping & Monitoring of settlements in South Africa

Regional cooperation with the South African National Space Agency
Nale Mudau and Paida Mhangara (SANSA), Panagiotis Politis and Thomas Kemper (European Commission, Joint Research Centre)

Understanding the dynamics of human settlements is a pre-requisite for sustainable development and environmental management. In 2005, Africa had 43 cities with more than one million inhabitants compared to 28 cities a decade earlier. Most of these cities are unable to respond to the challenges of urbanisation because old colonial plans and practises did not include the marginalised poor populations in services and infrastructure investments. With low economic development, most cities cannot cope with high demands of services and environmental management consequence of urbanisation. The National Development Plan, recognises the value of geospatial information in national spatial development and calls for the establishment of a national observatory for spatial data and analysis. The mapping of human settlements and built up areas is therefore important to provide urban and rural planners working in the different spheres of government with spatial-temporal information critical to monitor urban and rural development. Remote sensing is an integral part of any national spatial observatory since satellite imagery and aerial photography are an effective and reliable means of monitoring spatial infrastructure developments over time.

The human settlement layer derived from SPOT 5 is substantially contributing to enabling the Department of Human Settlements in meeting its mandate. Human settlements maps are being used to assess and monitor informal settlements. The JRC has developed a dedicated GHSL application, which is installed at the SANSA premises and allows SANSA to process their archived SPOT-5 imagery that date back until the year 2006. SANSA is also planning to produce annual updates in the future with SPOT-6/7 data. With open access to other medium to high resolution imagery, SANSA plans to partner with other African agencies to produce human settlements data for other Africa countries that do not have access to high resolution human settlement data.

The human settlements information that is being developed through the Global Human Settlement Layer in collaboration between JRC and SANSA has far reaching applications and supports a plethora of legislative mandates assigned to the different government departments and public entities in South Africa. Some of the most prominent legislative acts that will be supported by the human settlement information include: Electoral Act through the demarcation of voting districts and verification of voting stations, the Statistics Act through supporting the dwelling frame and census planning, National Human Settlements Land Inventory Act through the quantifying of areas occupied by human settlements, Conservation of Agricultural Resources Act by monitoring encroachment of human settlements in fertile agricultural land, the Spatial Planning and Land Use Management Act through the provision of information relating to the spatial extends of human settlement and the Disaster Management Act since information on human settlements is critical for post disaster verification, disaster risking profiling and assessment , and for monitoring and evaluating the impacts of passive and active disasters.

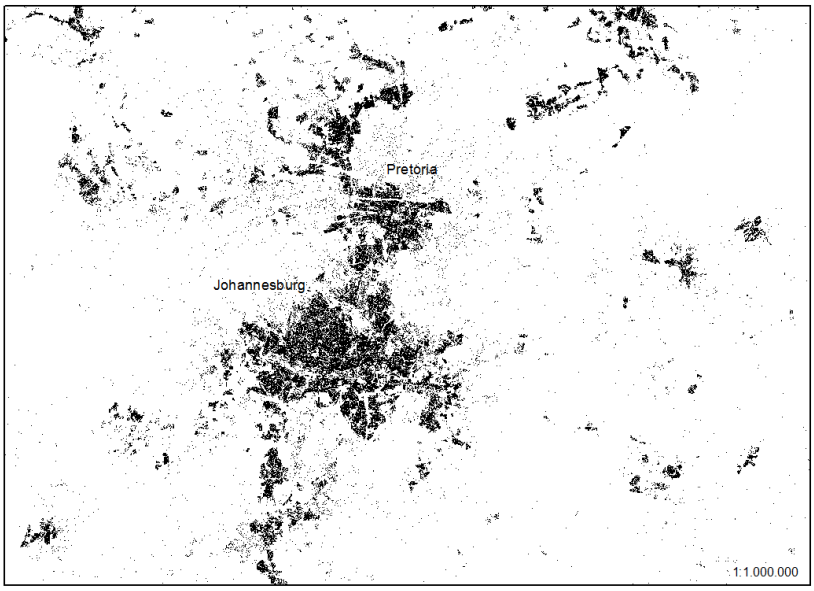

Figure 17 GHSL South Africa for the year 2014 based on SPOT-5 satellite imagery for the Gauteng Province

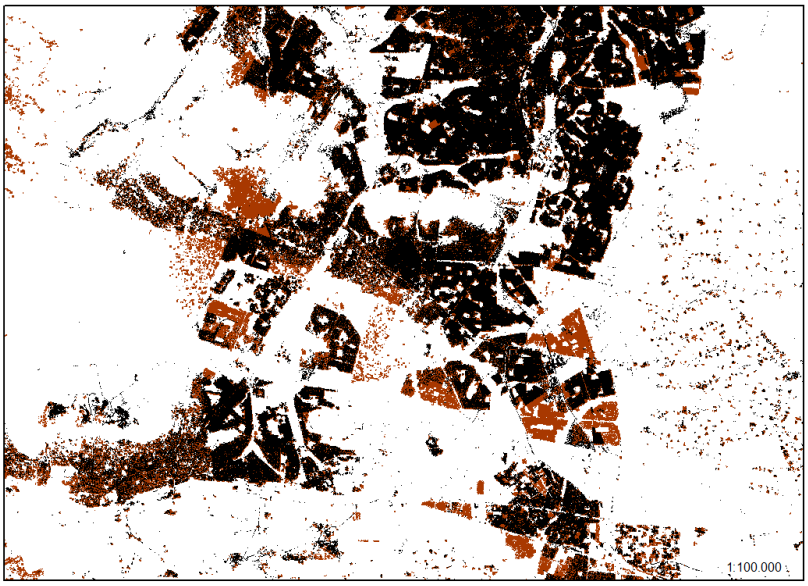

Figure 16 Example of built-up change 2006-2014 as mapped by GHSL. Built-Up 2006 in black, built-up 2014 in red.

Datasets:

SPOT-5 imagery for 2006 and 2014 multispectral 10m, and panchromatic mode 2.5 m spatial resolution (970 scenes); images were automatically georeferenced using 25cm aerial photography and 20m Digital Elevation Model (DEM) and projected to Universal Transverse Mercator (UTM) system using the SARMES system;

South African National Land Cover (NLC) land cover 2000; land cover data set derived using multi temporal LandSat 7 ETM imagery acquired in 2000-2003; Vegetation and natural environmental land cover classes mapped using pixel based classification where as human settlements and other spectral heterogeneous, land use classes mapped through manual digitisation;

SPOT Building Count (SBC) generated using SPOT 5 imagery acquired in 2012; developed through visual interpretation and manual digitisation of the building structures.

4.7 City Analysis Using the GHSL

An example of city ranking

Melchiorri Michele (European Commission, Joint Research Centre), Siragusa Alice (Piksel Inc.)

The comparative analysis of human settlements at the city level has been a desire of researchers, analysts, and policy makers for long. The GHSL and especially its settlement model in time series, merges the automatic processing and acquisition of built-up information with population census. Accordingly, it is possible to study and compare in a consistent way all settlements on the globe, both *Urban Centre*s or *Urban Cluster*s. Such opportunity can be taken to monitor important features of human settlements like built-up surfaces, population and land consumption over time. This showcase illustrates a practical application of the GHSL dataset to identify the 10 most populated cities (*Urban Centre*s with highest number of inhabitants), the 10 with highest values of built-up areas and settlement surface -largest. The list of cities was extracted by sorting the desired feature over the 13,000 *Urban Centre*s mapped in the GHSL.

Table 10 Cities belonging to top10 lists

	TOP10		
city	Built-up	Population	Area
TOKYO	2	4	4
JAKARTA	3	3	3
GUANGZHOU	4	1	1
LOS ANGELES	1		5
NEW YORK	5		8
CHICAGO	6		6
JOHANNESBOURG	7		9
DALLAS	8		10
CAIRO		2	2
KOLKATA		6	7
MIAMI	9		
OSAKA	10		
NEW DELHI		5	
DHAKA		7	
SHANGHAI		8	
MUMBAI		9	
MANILA		10	

Cities in the TOP10 lists are illustrated in Table 10. Three cities (Tokyo, Jakarta and Guangzhou) are in the top 10 of built-up, population and size. The ranking per surface is always coupled with at least another feature, and especially built-up (7 out of 10), but Cairo and Kolkata are both among the most populated and the largest. Other cities are ranked in the TOP10 for a unique feature, like Miami (9th per built-up) or New Delhi (5th per population). All *Urban Centre*s except of Chicago, Miami and Dallas (ranking for built-up, surface or a combination of both) are also megacities (above 10 million inhabitants).

The TOP10 cities per built-up account for 4% of the global one, and the TOP10 per population for 3% of global one. Half the TOP10 cities per built-up are in the United States of America, while 9 of the TOP10 per population are in Asia, of which 3 in India. Among the TOP10, 8 of the most built-up are in HIC, while 7 of the most populated are in LMCs or LIC.

Chart 27 (left) shows three cluster of cities: a) the one in the top right (Guangzhou, Jakarta and Tokyo) that rank high for both built-up population and area; b) the one in the upper left, which are the most populated (i.e. Dhaka, Kolkata, Mumbai and Manila) but are substantially less built-up; c) the one in the bottom right which cities are most built-up but considerably less populated. Chart 27 (right) shows instead the trajectories of cities development to reach the position shown on Chart 27 left. Most of the TOP10 cities per built-up shows nearly "flat" trajectories whereas built-up growth built-up is not accompanied by corresponding population growth (i.e. Dallas and Chicago); most of the built-up was detected already in the period 1975-1990 (also in Chart 28). Instead, very steep patterns are evident in cities in Asia in the TOP10 per population, i.e. Dhaka and Delhi where fast population growth is accounted especially in the last fifteen years, between 2000 and 2015.

Chart 28 tracks the epochs and extent of built-up expansion (i.e. the rapid and recent growth in Guangzhou) and the inequalities in built-up per capita in the 17 analysed cities. Most of the cities in which built-up expansion occurred from 1990 onwards have relatively low levels of built-up per capita; not surprisingly those cities are mostly in Asia and in rapidly developing countries.

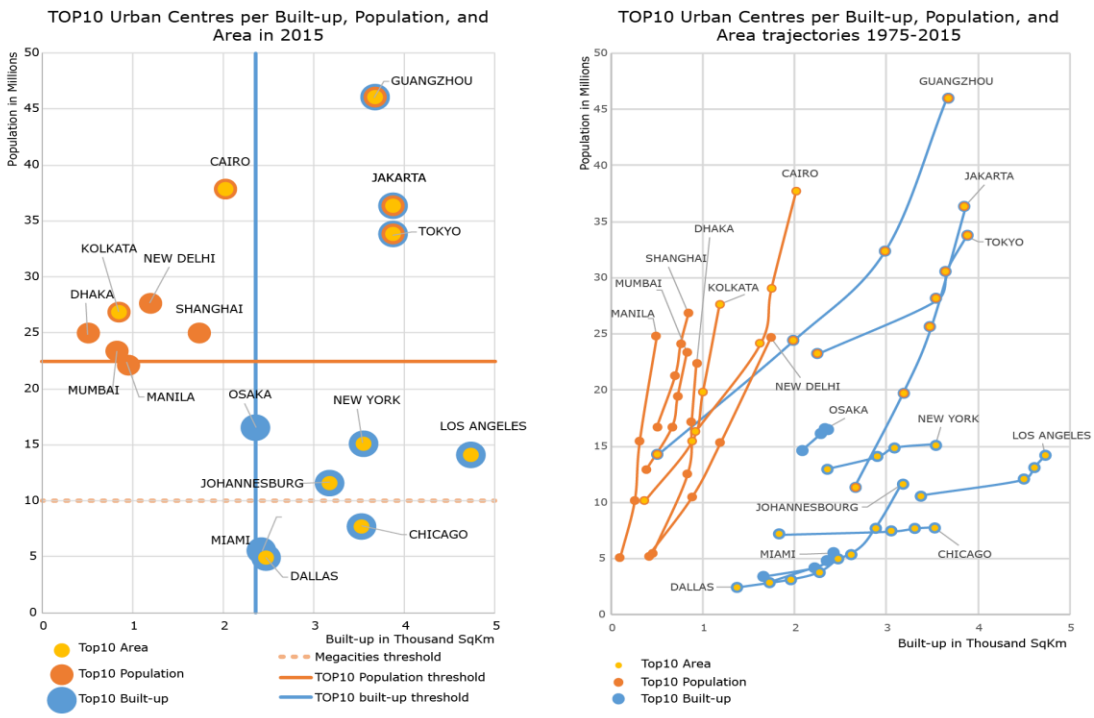

Chart 27 Right) Scatter-plot of the 17 cities being analysed with reference to Megacity population threshold, TOP10 built-up and TOP10 population thresholds; Left) trajectories of built-up and population growth between 1975 and 2015

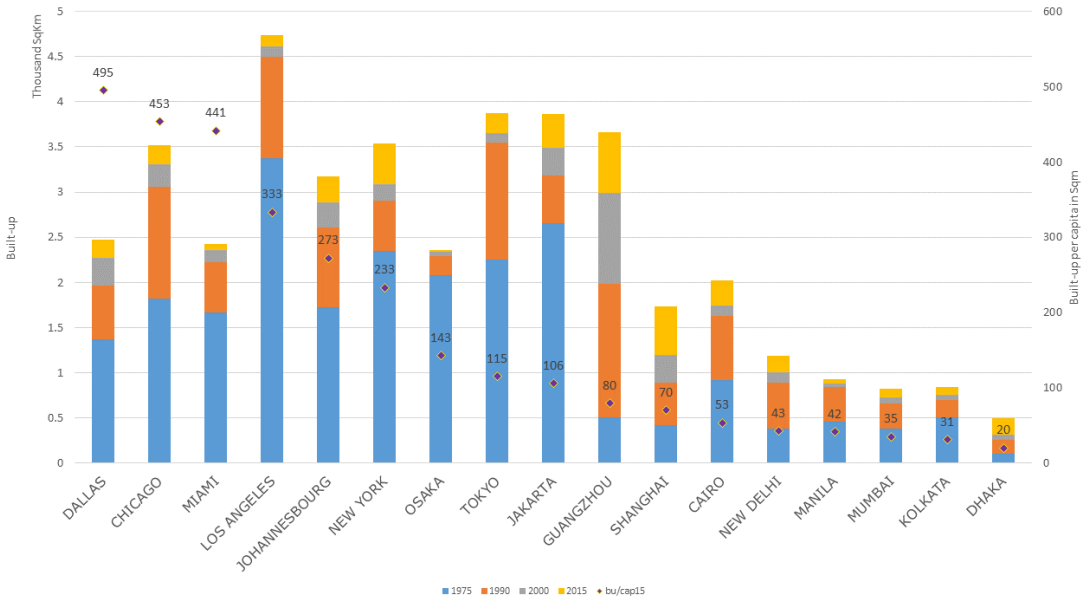

Chart 28 Built-up growth per epoch and amount of built-up per capita in 2015

Datasets:
Global Human Settlement Layer (GHSL), Global Built-up Grid, GHS_BUILT_LDSMT_GLOBE_R2015B
Global Human Settlement Layer (GHSL), Global Population Grids, GHS_POP_GPW4_GLOBE_R2015A

4.8 A Global Risk Assessment: INFORM Index for Risk Management

Integration of GHSL Global Population Grids exposure layer in the INFORM methodology
Tom De Groeve (European Commission, Joint Research Centre), Luca Vernaccini (AHRS Development Belgium)

The Index for Risk Management INFORM is a global, open-source risk assessment tool developed by JRC for understanding the risk of humanitarian crisis and disasters. The INFORM index supports a proactive crisis and disaster management framework. The INFORM initiative began in 2012 as a convergence of interests of UN agencies, donors, NGOs and research institutions to establish a common evidence-base for global humanitarian risk analysis. INFORM is a joint initiative of the European Commission and the Inter-Agency Standing Committee Task Team (IASC) for Preparedness and Resilience, in partnership with Office for the Coordination of Humanitarian Affairs (OCHA), UK Department for International Development (DFID), World Bank, the Assessment Capacities Project (ACAPS), UN agencies (UNISDR 2015), among others.

The INFORM model is based on risk concepts published in scientific literature and envisages three dimensions of risk: Hazards & Exposure, Vulnerability and Lack of Coping Capacity. The INFORM model is split into different levels to provide a quick overview of the underlying factors leading to humanitarian risk and builds up the picture of risk on the bases of more than 50 core indicators.

The Hazard & Exposure dimension reflects the probability of physical exposure associated with specific hazards. The dimension is multi-hazards, including natural (earthquakes, tsunamis, tropical cyclones, floods and droughts) and human hazards (conflicts). Exposed population is defined as the expected number of people located within the hazard zone for each type of hazard, and for each return period per country. The hazard zones are obtained from hazard maps for the specific hazard type and return period, and encompass the areas prone to occurrence of an event of at least a minimum intensity level that could trigger significant damage causing a disaster. Hazard zones are then overlaid with a model of a population distribution in order to derive the total population living in the hazard zone. This is the exposed population of the specific hazard type and return period.

From the 3rd release of the index in 2017, the Global Human Settlement Layer (GHSL) Global Population Grids will be the exposure layer in the Global INFORM model. The GHSL Global Population Grids is already used as exposure layer in most of the INFORM Subnational model, specifically in Lebanon, Sahel, Great Horn of Africa, Southern Africa and Central Asia and Caucasus. The GHSL Global Population Grids fits all the INFORM's requirements, being global coverage, open source, transparent methodology and high resolution for the Subnational models. Another advantage of the GHSL Global Population Grids is the link with physical footprint of building, mapping of the resident people. This is very important for assessing the population exposed to natural hazards such as earthquakes and floods, where most of the causalities are caused by the destruction of the buildings. The INFORM Index is published yearly, and therefore a regular update of the GHSL Global Population Grids is needed in order to monitor the changes in exposure to natural hazards.

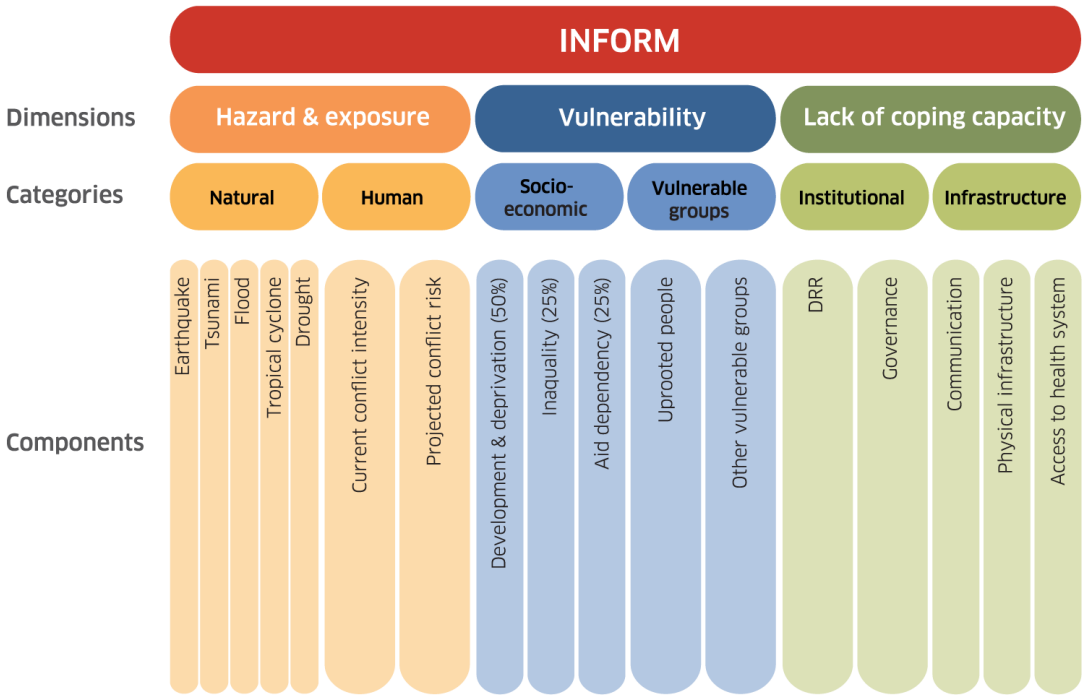

Figure 18 INFORM conceptual framework

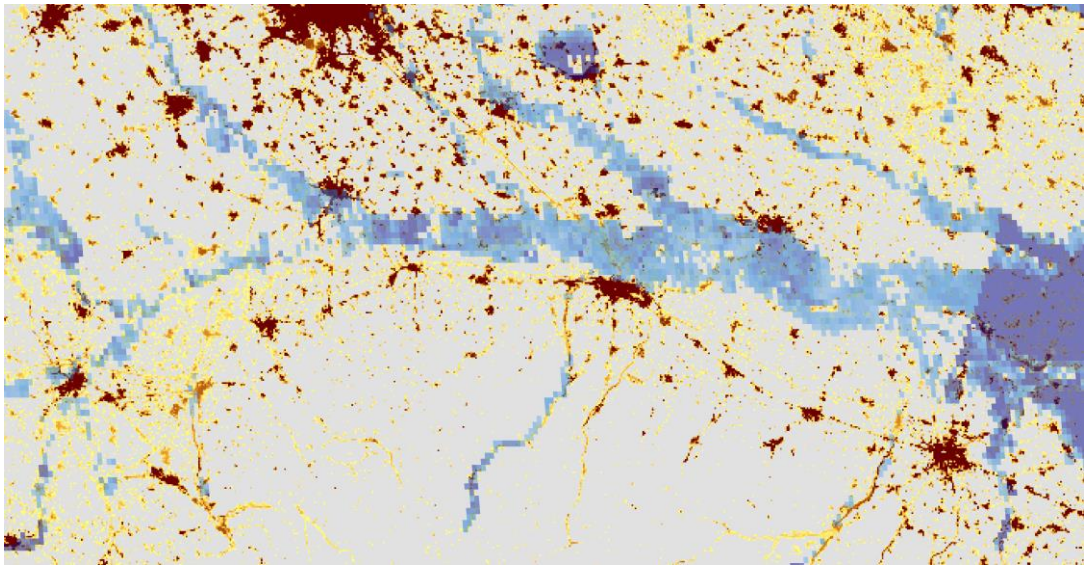

Figure 19 - Flood hazard map 100 return period (ISDR, GAR2015) encompassing the GHSL Population Grid 250 meters in the Po river plain, North of Italy.

Datasets:
Global Human Settlement Layer (GHSL), Global Population Grids, GHS_POP_GPW4_GLOBE_R2015A

4.9 Monitoring the Syrian Humanitarian Crisis with the JRC's Global Human Settlement Layer (GHSL) and Night-Time Satellite Data

Christina Corbane, Thomas Kemper, Sergio Freire, Christophe Louvrier and Martino Pesaresi (European Commission, Joint Research Centre)

The on-going Syrian conflict which broke out in April 2011 is the worst humanitarian crisis since World War II. Over 250,000 people have been killed and over one million injured. 4.6 million Syrians have been forced to leave the country, and 6.6 million are internally displaced (IDPs), making Syria the largest displacement crisis globally. Currently witness reports are the main sources for the Syrian crisis evaluation which makes it difficult to appraise in terms of neutrality, and comprehensiveness. Besides, while the number of registered refugees is regularly updated by UN OCHA, estimates of IDPs are more difficult to obtain. Attempts to enumerate or estimate IDPs may be clouded by political interests, fundraising, and intra-organizational relationships and often lack continuity and consistency. Taking stock of open and free Earth Observation data, the JRC developed an approach for assessing the humanitarian impact of the Syrian conflict which builds on the integration of population data (GHS-POP) derived from the JRC's Global Human Settlement Layer (GHSL) with monthly composite images derived from night-time data of the Visible Infrared Imaging Radiometer Suite sensor (VIIRS) (Christina Corbane et al. 2016).

The assessment of affected population is based on the assumption that night-time light imagery allows observing the impact of conflict since humanitarian disasters typically cause a decline in nigh-time lightning. Differences in light intensities were calculated between each two consecutive months for the period January 2014- December 2015. The magnitude of night-time variations (light loss) was considered as a proxy to affected people assuming Israel as a reference for stable lights. The results are shown in Figure 20 and Figure 21 in terms of estimated affected people per governorate (Figure 20) and for the whole Syrian territory (Figure 21).

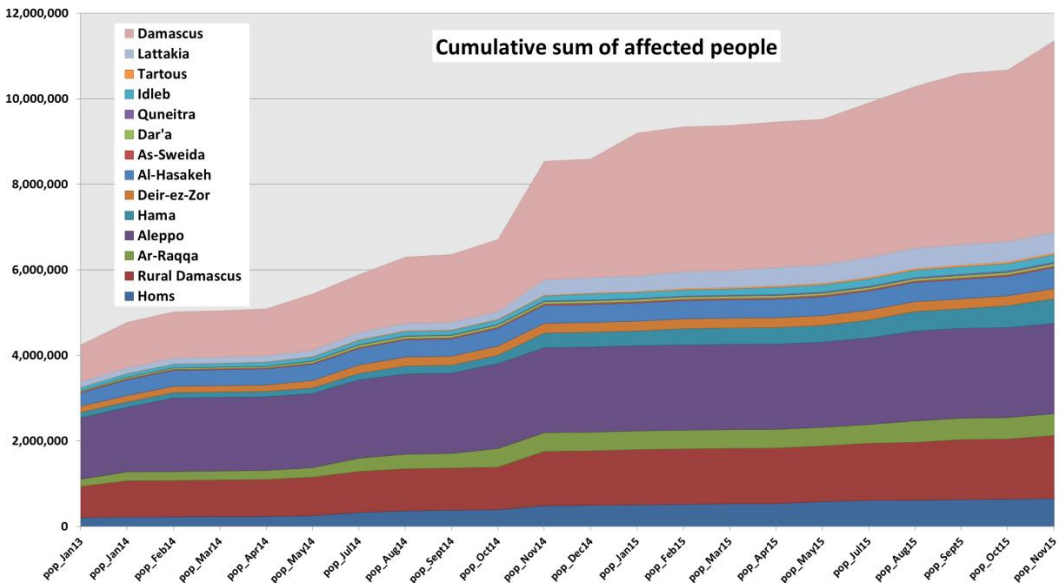

Figure 20 Estimated number of affected people per governorate

In Figure 21, the number of affected people obtained from remote sensing data is compared to monthly reports of registered refugees (source: UN OCHA[32]) and to key events of the conflict[33]. A total of 11.9 million affected people was obtained using geospatial data integration and analysis. These estimates converge with the estimates reported by the Syrian Observatory for Human Rights, UN OCHA and Worldvision[34]: "4.6 million Syrians are refugees, and 6.6 million are displaced within Syria".

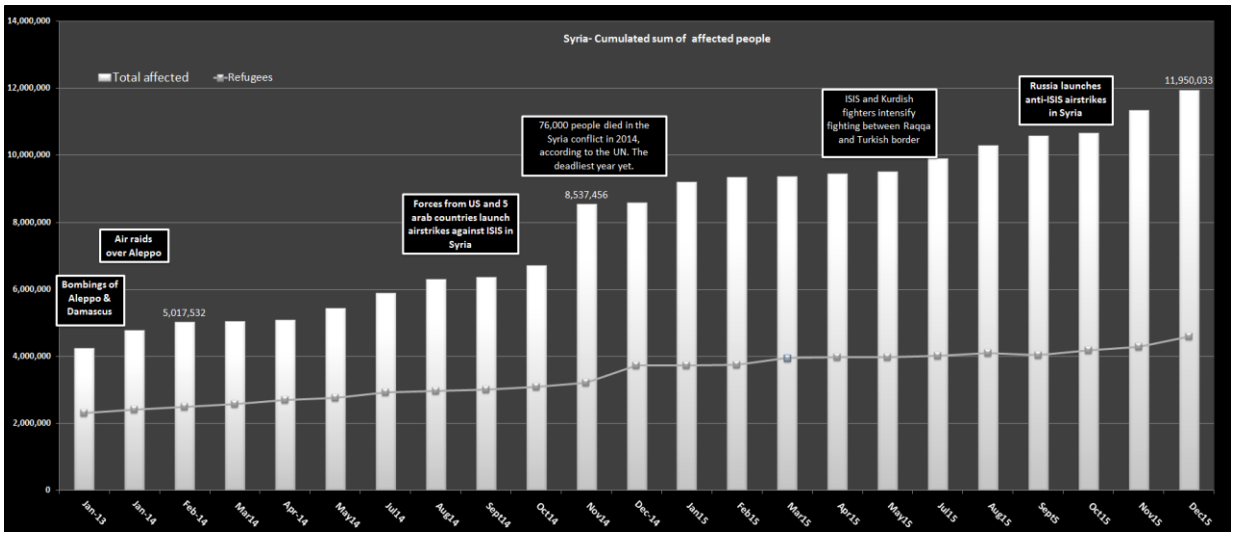

Figure 21 Comparison of the number of affected population derived from geospatial analysis with the number of registered refugees (source: UN OCHA) and key events in the conflict

The foresight methodology developed by the JRC has many potential applications for the assessment of affected people in crisis situations. It demonstrates that humanitarian impacts of both natural and man-made disasters (including conflicts) can be monitored in near-real time using open and free earth observation data. The approach has been also developed in an open-source platform to achieve reproducibility. The use of the globally available VIIRS imagery offers a neutral and independent tool to monitor the impacts of disasters with open and timely data. The assessments obtained from this technology can feed into migration forecasting models, whose inherent uncertainty is compounded by the intrinsic errors in scarce data.

Image 18 © dimamoroz, fotolia.com

[32] Source: http://data.unhcr.org/syrianrefugees/regional.php
[33] Source: https://news.vice.com/article/syria-after-four-years-timeline-of-a-conflict
[34] http://www.worldvision.org/news-stories-videos/syria-war-refugee-crisis

4.10 Putting the refugees on the map

Thomas Kemper, Martino Pesaresi, Michele Melchiorri (European Commission, Joint Research Centre)

The GHSL concept is holistic by definition. Developed with the constraints of crisis management, it is imperative to map not only the formal part of population, but also to include the informal population in slums or refugee/IDP35 camps. They are often the most vulnerable part of the population. High resolution EO data proofed to be an important tool for mapping and monitoring of refugee/IDP camps (Kemper & Heinzel 2014), but also the GHSL is able to map the larger camps and their population (provided the population was accounted for in the last census).

Today, the biggest agglomeration of refugees is located around the small semi-arid town of Dadaab, Garissa county, Kenya. The camps of Dagahaley, Hagadera and Ifo were constructed in 1992 for Somali refugees that were escaping the civil war in the country. With a continuously instable situation in the Somalia and a severe drought in the Horn of Africa in 2011 the camps increased significantly in size to host more than 400,000 refugees in June 2013. After the decision of the government of Kenya to close the camps and to repatriate the refugees to Somalia the number dropped to 263,000 in August 2016[36]

The settlement detection of GHSL delineates clearly the three main camps (Dagahaley, Ifo I&II and Hagadera) and the town of Dadaab as clusters of built-up area (mapped as black areas) despite the relatively coarse resolution of the Landsat sensor. Since the camps were existing for many years they are even reported in the census of Kenya and hence also the population data maps the camps. The town of Dadaab, Hagadera and Ifo I and Ifo II are mapped as urban centres. The Dagahaley camp and parts of Hagadera are mapped as urban clusters.

Obviously, for a better detection higher spatial resolution imagery would be desirable. This example illustrates the potential of GHSL also for identifying large (and to some extend stable) refugee/IDP camps.

Image 19 © EU/ECHO/Ian Van Engelgem

[35] Internally Displaced Person

[36] Refugee numbers published by UNHCR: http://data.unhcr.org/horn-of-africa/region.php?id=3&country=110

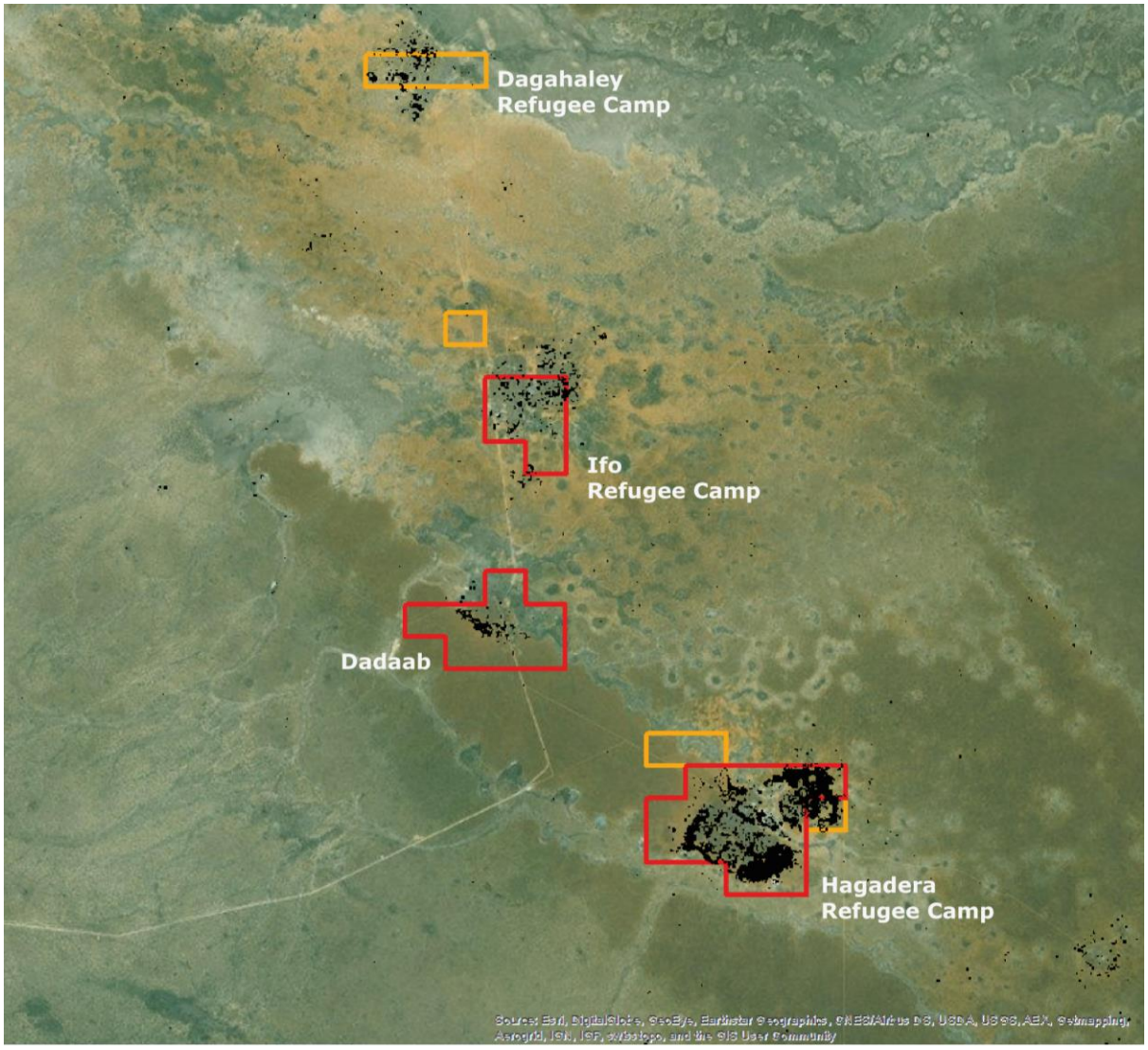

Figure 22 Refugee camps detected as *Urban Centres* and *Urban Clusters* in the GHS S-MOD

References:

Thomas Kemper and Johannes Heinzel, Mapping and Monitoring of Refugees and Internally Displaced People Using EO Data. In book: Global Urban Monitoring and Assessment through Earth Observation, Edition: Remote Sensing Applications Series, Publisher: CRC Press, Editors: Qihao Weng, pp.195-216, 2014, DOI: 10.1201/b17012-14

4.11 Linking human and earth system models to assess regional climate change impacts and adaption in urban systems and their hinterlands

Jing Gao [1], Claudine Gravel-Miguel [2], Brian O'Neill [1], & Michael Barton [2]
1 Climate & Global Dynamics Laboratory, National Center for Atmospheric Research
2 School of Human Evolution and Social Change, Arizona State University

Climate change, global development, and urbanization can have varied and profound impacts on human well-being within the 21st century, especially in the developing world. Understanding how human and earth system trajectories will interact is essential for making adaptive decisions that can reduce potential negative consequences facing our society and ecosystems. This research aims to improve our understandings about the joint effects of socio-economic development and regional climate change throughout the 21st century, by developing and applying a suite of new analytical and computational tools – the Toolbox for Human-Earth System Integration and Scaling (THESIS) – that offers improved integration of human and earth system models. Our work focuses on the integrative synthesis of the Community Earth System Model (CESM) and the integrated Population-Economy-Technology-Science model (iPETS) supported by the U.S. National Center for Atmospheric Research, but the resulting toolkit can be applied to other earth and human system models.

Key components of the THESIS tools require global data on current and past spatial distributions of the extent and the morphology of built-up areas. We have carried out a set of independent assessments that indicate GHSL's unique suitability over other existing global datasets to meet these needs.

With the time series of the built-up land extent over the past 40 years provided by GHSL, we analyze the spatiotemporal patterns of built-up developments, and their relationship to other relevant socio-economic variables, e.g. population, GDP. Using these understandings, we construct a global built-up land expansion model, and simulate potential future spatial distributions of built-up lands evolving through the 21st century under various socio-economic scenarios.

With the experimental built-up land volume layer of GHSL (Martino Pesaresi et al. 2016, chap. 5.1.3), we calculate histograms of various urban morphological classes within built-up areas. We simulate changes to urban morphology under different socio-economic scenarios, by altering the histograms to reflect different forms of urban developments (e.g., sprawl vs. high intensity).

These two components are then used in combination with climate modeling results to investigate climate change impacts on urban populations and built-up environments. For example, we use them to estimate thermal properties of built-up areas across the world under different climate scenarios, and examine how different socio-economic and climate conditions impact human exposure to extreme heat events. We also use them to estimate how climate change might affect building energy use for space cooling or heating.

Our findings will help planners and policy makers understand the potential consequences of alternative socio-economic decisions in compound with a rapidly changing climate, and provide scientific foundations for designing effective adaptation plans coping with the impacts of anticipated climate and population changes.

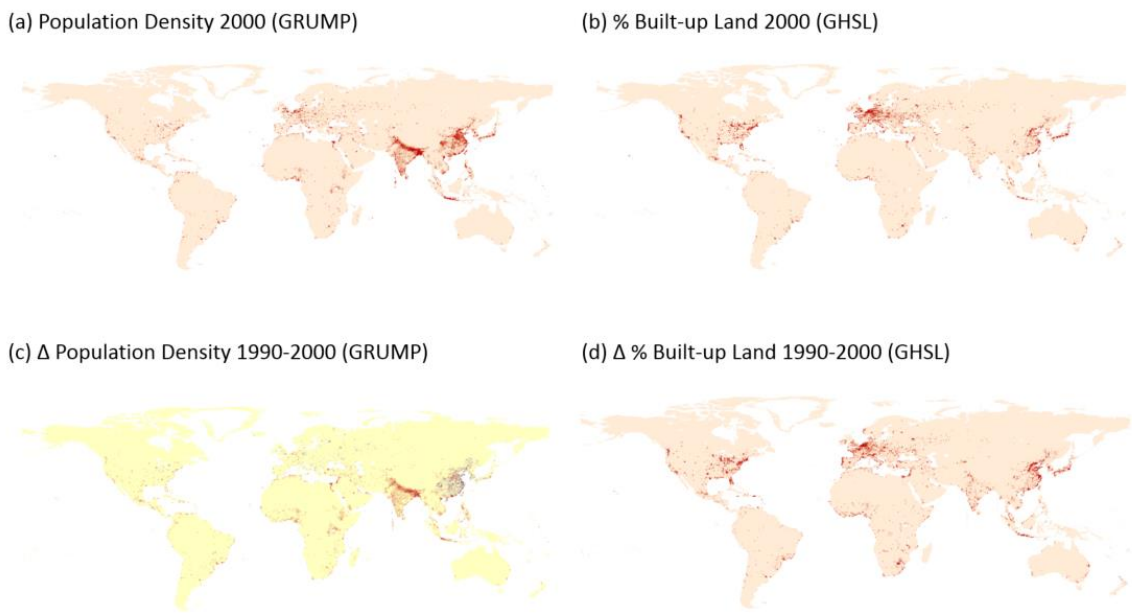

Figure 23 Comparing global development intensity with population density. (based on GHSL built-up extent and GRUMP population density)

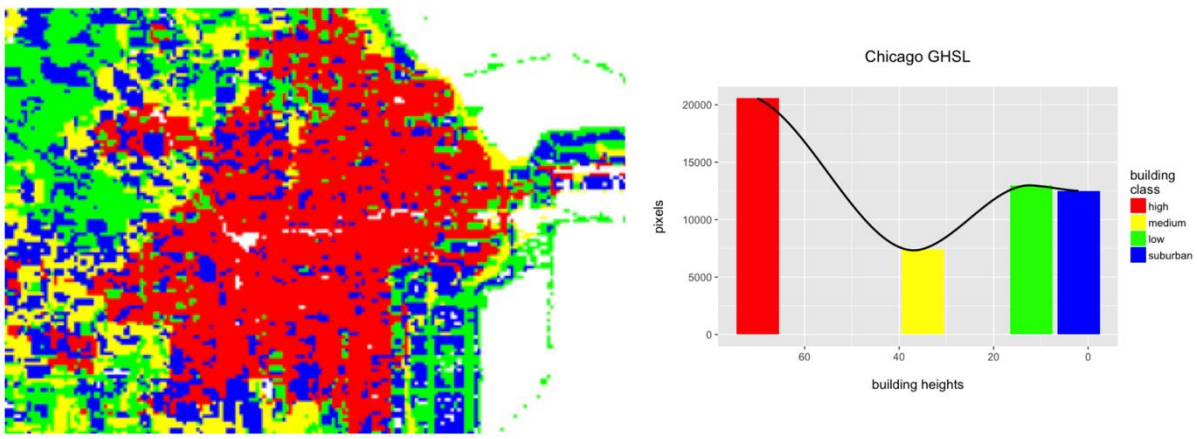

Figure 24 Urban morphology map and morphology histogram of central Chicago, USA. (based on GHSL built-up volume)

Dataset:
Center for International Earth Science Information Network - CIESIN - Columbia University, International Food Policy Research Institute - IFPRI, The World Bank, and Centro Internacional de Agricultura Tropical - CIAT. 2011. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Population Density Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4R20Z93.

4.12 Developing a Statistical Structure Inventory from GHSL Data

Estimating the Consequences of Dam Breach Flood Inundation
Kurt Buchanan (US Army Corps of Engineers)

The United States Army Corps of Engineers (USACE) dam portfolio consists of 700 projects. The dams are prioritized based on economic damages and life safety risks. The USACE Modelling, Mapping, and Consequences Center of Expertise (MMC MCX) uses hydraulic model outputs with GIS-enabled software to estimate life safety and economic consequences which could result from a dam breach.

In the spring of 2016, USACE began work on a consequence estimate for a hypothetical Mosul Dam breach in Iraq. A key data requirement to accurately estimate consequences in the inundation area is to have an inventory of the structures and population in the form of geospatial information system (GIS) shapefiles. On projects within the United States, standardized national Census datasets provide adequate structure and population information for creating statistical structure inventories, but there are no similar datasets for Iraq. Therefore, MMC MCX personnel utilized the GHSL gridded population data as the basis for the statistical structure inventory.

The team clipped the GHSL data to the model inundation area below the Mosul Dam. The gridded data was a reasonable base for estimating consequences, however, the data resolution required adjustments to provide results at the desired accuracy. For example, if 20% of a GHSL grid cell is inundated it would not be correct to assume the entire population, or 100%, of that cell is at risk. Also, life loss estimates are dependent on depth of flooding and the arrival time of water, which differ across areas of a grid cell. The MMC MCX team developed a GIS workflow process to convert the GHSL gridded data into a usable statistical point structure inventory format.

The workflow included: converting GHSL data into polygon format; dividing population values by the average household size of Iraq (7.7 persons per household) to determine the approximate number of structures within each cell; creating random points within the cells corresponding to the approximate number of structures; and preventing points from being placed inside the river channels. The population per structure was joined to each remaining structure point, and structure story numbers were randomly assigned to account for potential vertical evacuation via structure rooftops. Additional structure attributes, such as value and type, were assigned generic values based on research and judgement. The final point structure inventory contained minimum attributes necessary to estimate potential ranges of damage, population at risk, and life loss resulting from a dam breach. The team used a beta version of the HEC-LifeSim software and hydraulic outputs from HEC-RAS hydraulic software modeling to conduct this analysis.

A primary benefit of using this method was the minimal amount of time and resources required to produce the structure inventory, which was a primary concern given that the inundation zone extends for several hundred miles. Since the GHSL is a global dataset, similar analytical methodologies could be used to estimate potential consequences of flooding in any area of the world that lacks specific location-based national population and housing inventories.

Figure 25 GHSL Iraq 2015 Population Grids, 250 meter resolution in Mosul

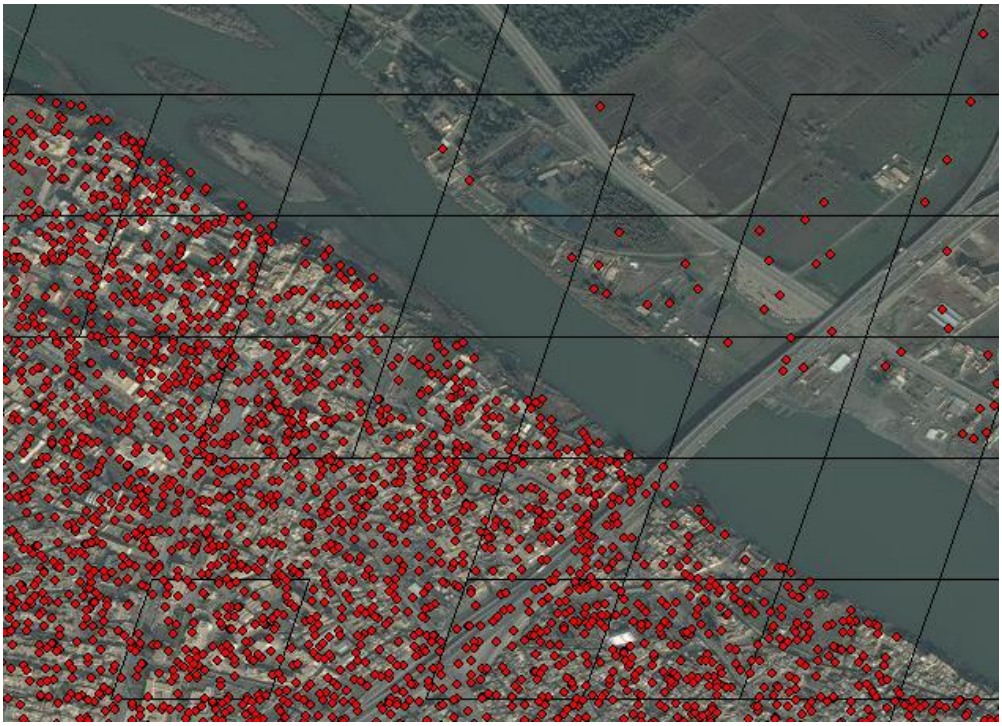

Figure 26 Statistical Structure Inventory points in Mosul created from the GHSL data

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Datasets:
Global Human Settlement Layer (GHSL), Global Built-Up Grid, GHS_BUILT_LDSMT_GLOBE_R2015B
Imagery from ESRI Streaming Imagery Base map Layer

4.13 Population Exposure in Seismic Risk Assessment

Christina Corbane, Daniele Ehrlich, Tom De Groeve (European Commission, Joint Research Centre), Bogazici University (Kandilli Observatory and Earthquake Research Institute)

Natural disasters can be very difficult to predict and fully prepare against. Their far-reaching impacts on the safety and the well-being of communities represent a major concern for the governments and a hinder to social and economic development. According to available global statistics, least developed countries represent 11% of the population exposed to hazards but account for 53% of casualties while the most developed countries account for 1.8% of all victims (Peduzzi et al. 2009) with a population exposure of 15%. In the last decade, there has been has been a general shift of focus in risk modelling away from hazard impacts towards the determination and modelling of risk, which incorporates information on vulnerability and exposure (OECD- Global Science Forum 2012).

The accuracy of risk assessment models is strongly influenced by the availability of input data to parameterize the models. This brief, based on (Corbane et al. 2016), places emphasis on the effect of exposure modelling in risk assessment. The example of seismic risk assessment is considered with an analysis of epistemic uncertainties, which are related to the variability of the input variables including the sensitivity analysis of the resulting seismic risk assessments with regard to different exposure datasets. It provides a comparative analysis of casualty estimates as outputs of seismic risk assessments by introducing a new population exposure data layer derived from the Global Human Settlement Layer (GHSL).

The purpose here is to draw attention to the areas in seismic risk assessment where necessary refinements are necessary and to stimulate efforts to benchmark different. The Earthquake Loss Estimation Routine (ELER) developed under the NERIES FP6 project (2006-2010) was selected for running the end-to-end scenario-based risk analysis and for the estimation of earthquake damages and casualties. A basic but comprehensive European database (at 150 sec arc resolution grids) was available for all EU countries and provided within ELER as the default data for the analysis. The countrywide approximated building database was obtained from Corine Land Cover and population data derived from LandScan global population data. LandScan global population data has an approximate resolution of 1x1 km^2 resolution at the equator (30 sec arc grids) and represents 'ambient population'. The GHS-POP population data produced in the framework of the GHSL represents an interesting input dataset for the sensitivity analysis to the input exposure data and for benchmarking with the LandScan grids. For the sensitivity analysis, we selected an area of approximately 110 x 110 km around Rome in Italy. Figure 27 shows the differences in the level of detail between the default grid based population data provided in ELER on the basis of LandScan and the GHS-POP data.

The assessment of the casualties is based on the vulnerability relationships developed in the RISK-UE project and that evaluate the consequences of building damage on people only with respect to collapsed buildings. The correlations which refer to building damage grades provide the results in terms of four severity levels: S1 for light injury, S2 for injury requiring hospital treatment, S3 for S3 severely injured and S4 Death. Keeping constant the input hazard map and building exposure, the exercise consisted in varying the population data in the model and comparing the results in terms of casualty estimates. The calculated casualty estimates (for severity levels S3 and S4) obtained by the use of the two population datasets for the area of interest around Rome gave the following total casualties (S3+S4): 6,665 with LandScan derived population data and 10, 399 with GHSL derived population data. The more detailed population data provides predictably higher casualty estimates. The large percentage difference of 44%[37] in the results can be possibly attributed to: i) the difference in the resolution and accuracy of the demographic

[37] The percentage difference is calculated as the difference between two values divided by the average of the two values shown as a percentage.

data, which can significantly affect the results of seismic risk assessment and ii) the differences in the concepts between LandScan, which represents ambient population, and the population data derived from GHSL, which is based on built-up areas. Knowing that casualty estimates are directly derived from building damage, it is then plausible to obtain higher casualties when exploiting the GHSL derived population data. From this analysis, one may conclude that the results of the seismic risk assessment tend to show large variations related to differences between the default input LandScan population data and user defined data.

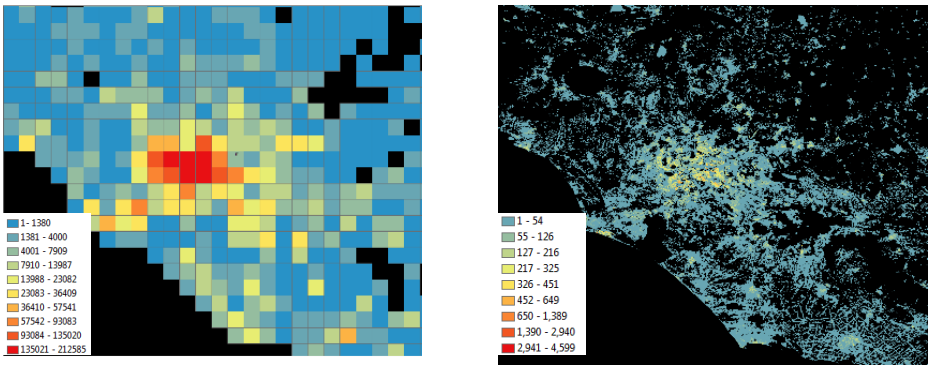


Figure 27 Gridded population data obtained from LandScan (150 sec arc grids) and from the GHSL-POP (100 x 100m) shown for Rome, Italy.

The results of this analysis demonstrate that the model outputs are sensitive to variations in population exposure. Due to the different reallocation methods between LandScan and GHSL derived population data, the number of estimated casualties differ with respect to the two datasets. LandScan presents a highly modeled population distribution derived from landcover data. In contrast GHS-POP datasets was derived from the GHSL building density and population census data and originally developed in order to reallocate census population to built-up areas.

For the purpose of seismic risk assessment, GHS-POP data may be more suitable for estimating human losses due to the underlying modelling concept that is linked to building distribution and hence to estimated building damage. Understanding the whole range of uncertainties and communicating their implications is essential for communicating risk information to decision makers and for designating accurate altering models in early warning systems. There are number of areas that require improvements and further research in view of building European and global exposure databases. One area that deserves investigation is the use of the GHSL for deriving a multiple hazard exposure database including building typologies and socio-economic information as a baseline for multi-hazard risk assessments.

4.14 World population exposed to volcanic hazards

Sergio Freire, Aneta F. Florczyk, Martino Pesaresi (European Commission, Joint Research Centre)

Volcanoes are among the most powerful and destructive natural hazards on the planet, capable of causing extensive damages and harm to people from direct impacts and disturb livelihoods from indirect effects. Volcanic activity can be harmful to human in different ways. Eruptions are the most devastating volcanic hazards with the flow of lava covering everything on their path, hot ask and pyroclastic flow reaching far from the volcanic locations, other dangerous cascading effects are related to volcano hazard. The slopes of volcanoes have been attracting people that cultivate its fertile slopes. Also, many large cities have developed in the proximity of volcanoes. Today volcano regions like Indonesia or Central America, the Philippines are highly densely populated and societies have learned to live with volcanoes and to suffer the consequences when hazard strikes. The impact of the volcanoes can reach people far away from the actual location of the volcano. Until recently, a global analysis was not possible due to the unavailability of data on population and built up with sufficient detail to be able to conduct an analysis.

A new population distribution dataset, the Global Human Settlement Population layer (GHS-POP) is now available. It depicts the distribution of resident-based population in built-up, in 1990, 2000, and 2015 (Freire Sergio, Kytt MacManus, et al. 2016). This analysis compares the global population dataset with that of the location of volcanoes and it estimates the amount of people in the proximity of volcanoes globally. Two datasets of volcanoes have been used, namely the Holocene Volcano List v 4.4.1 of the Smithsonian Institution's Volcanism Program (GVP, 2013) and the NOAA Significant Volcanic Eruption Database (SVED). The Holocene Volcano List (HVL) is a global listing of over 1500 volcanoes believed to have been active during the Holocene epoch (the past 12,000 years). The Significant Volcanic Eruption Database is a global listing of over 500 significant eruptions that have caused fatalities, moderate damage, with a Volcanic Explosively Index (VEI) of 6 or larger, or associated with a tsunami, or major earthquake (Figure 28). Global population distribution has been analyzed as a function of distance to volcanoes in 1990, 2000, and 2015, using the GHS-POP 250 m population grids. The population distribution is analyzed within a radial distance of 100 km from volcanoes (since lethal pyroclastic flows and surges, and lahars may occasionally extend to these distances), by buffering each volcano in 5 km steps and conducting zonal analysis of GHS population grids. The overall global quantification of population in proximity to volcanoes is reported in Figure 29.

Results indicate that almost 6% of the world's 2015 population lives within 100 km of a volcano with at least one significant eruption, and more than 12% within 100 km of a Holocene volcano, with human concentrations in this zone increasing since 1990 above the global population change rate. Population densities are also high in vicinity of volcanoes, on average peaking around a distance of 15-25 km, and these have been increasing with time in last 25 years. In 2015, almost 13% of the global population is estimated to live within a range of potential direct impact of volcanic eruptions. Concerning volcanoes with significant eruptions (SVED), the proportion of the global population living within 100 km has decreased slightly from 2000 to 2015 (to 5.6 %), although absolute values have increased by 18.7% in this period to total 414 million people, following global population rise (Figure 29). Figure 29 shows that relatively high population densities occur in the vicinity of all volcanoes, especially of those with significant eruptions, and those densities have been increasing considerably since 1990. However, it is at a distance of 10 to 25 km from Holocene volcanoes that the absolute increase in population density has been greatest (additional 45 people/Km^2), from 1990 to 2015. In all periods population density increases with proximity to volcanoes, this pattern is even more striking for volcanoes with significant eruptions (SVED), where overall population densities are higher (up to 300 people/Km^2). While this work has focused on volcanism, GHS-POP grids can be combined with any type of hazard, both natural and man-made, enabling advancing modeling and analyses at all stages of the emergency management cycle.

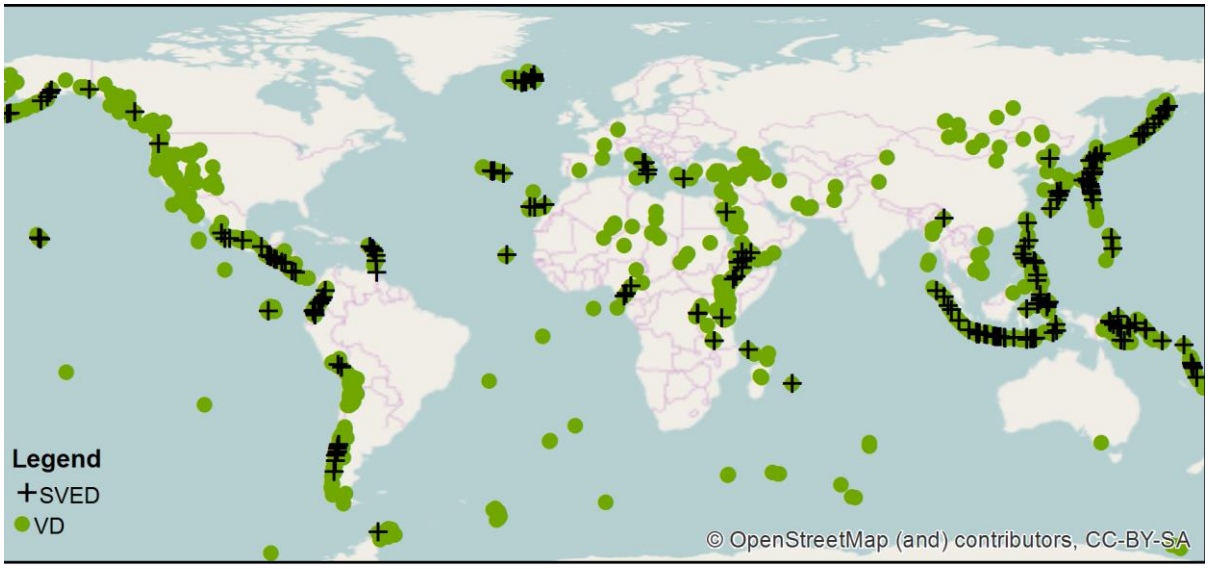


Figure 28 Distribution of final datasets of volcanoes (VD) and volcanoes with at least one significant eruption (SVED), overlaid on OpenStreetMap

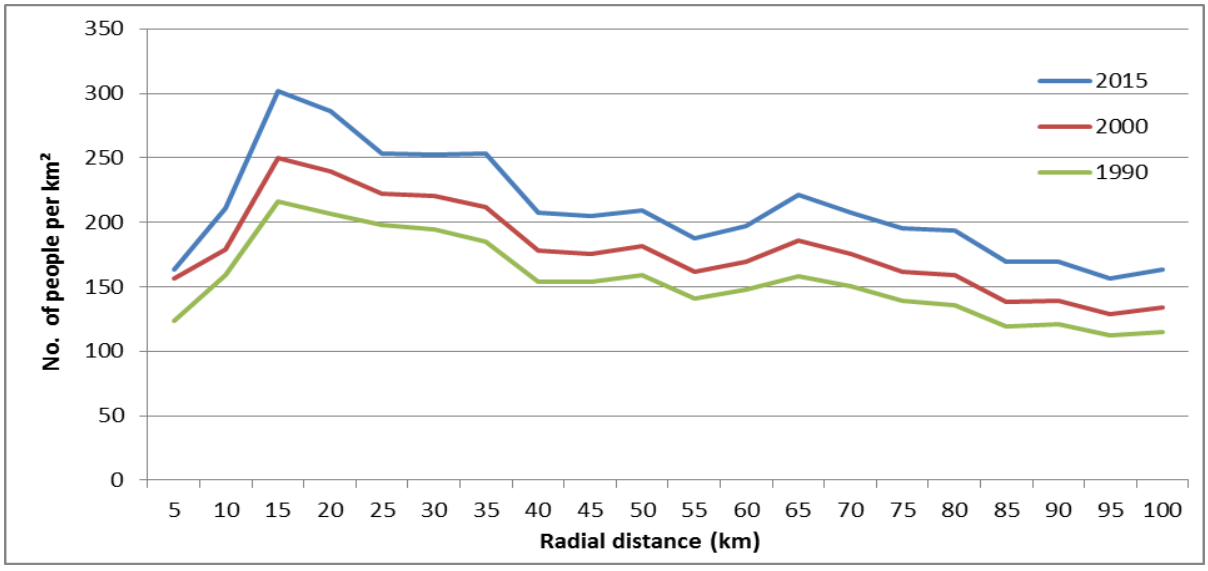
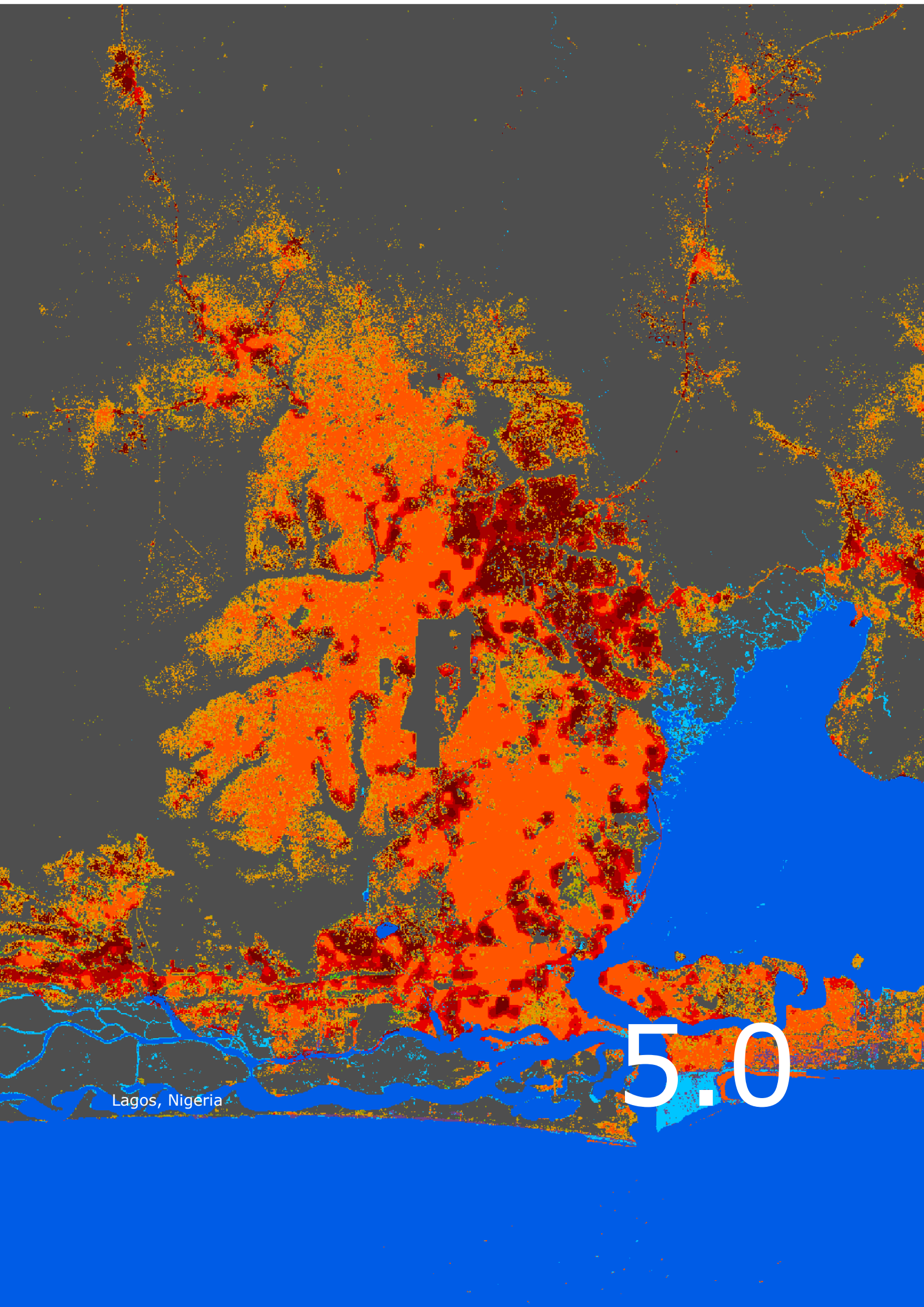


Figure 29 Population density as a function of radial distance to volcanoes in Significant Volcanic Eruption Database (SVED), in 1990, 2000, and 2015.

Datasets:

GVP (Global Volcanism Program) (2013) Volcanoes of the World, v. 4.4.1. Venzke, E (Ed.). Smithsonian Institution. Downloaded 21 Jan 2016. http://dx.doi.org/10.5479/si.GVP.VOTW4-201.

NOAA (National Oceanic and Atmospheric Administration) (2015) National Geophysical Data Center / World Data Service (NGDC/WDS): Significant Volcanic Eruptions Database. National Geophysical Data Center, NOAA. doi:10.7289/V5JW8BSH.



5.0

5. Conclusion

The release 2016 of the *Atlas of the Human Planet* illustrates the rationale and the first results obtained from the processing of large masses of data collected from three main sources: Earth Observation satellite sensors, national statistical surveys, and crowd sources as volunteered geographic information. These data have been processed by exploiting novel spatial data analytics tools allowing to handle their complexity, heterogeneity and large volume, and generating information and knowledge about the human presence on the planet Earth from the years 1975 to 2015. For the first time globally-consistent and detailed data of the built-up human environment is available in the public domain. The empirical evidences supporting this release of the *Atlas* have been collected and processed within Global Human Settlement Layer (GHSL) of the European Commission, Joint Research Centre.

The GHSL baseline data released with the *Atlas* provide a framework that allows learning from the last 40 years and closely monitoring the impact of the policies of today and in the future. It demonstrates how new open data and innovative data processing technologies may practically support novel global awareness on urbanization trends and dynamics. It provides a new view on global urbanisation processes. The systematic global assessment is a pre-requisite to apply uniform definitions of settlements such as the degree of urbanisation[38] used by Eurostat. Most urban indicators are extremely sensitive to where boundaries are drawn, such as air quality, presence of open space or access to public transport. Comparing cities internationally using a collection of national definitions will generate many distortions. Cities defined very tightly will have worse air quality, less open space, but better access to public transport than cities defined more widely. Therefore, a uniform definition is needed to make meaningful comparisons and allow cities to learn from each other.

Main findings

While the number of people on the globe is considered well monitored by statistical offices, there is little consistent, open and detailed information on the spatial distribution of population, and hardly any information on the built-up areas with complete, global coverage. For the first time, with the GHSL baseline it is possible to analyse in a consistent, detailed frame the development of built-up areas, population and settlements of the whole planet in the past 40 years.

This *Atlas* shows that in the past 40 years built-up areas increased by approx. 2.5 times globally, while population increased by a factor of 1.8. The changes in population and built-up areas show big regional differences. The strongest growth is observed in Low Income Countries (LIC). In the past 40 years the population of Africa tripled and the built-up area quadrupled. Instead the population of Europe kept stable while the built-up area doubled.

Today, most of the world's population is living in agglomerations with a density greater than 1,500 people per square kilometre and more than 50,000 total inhabitants. These agglomerations are qualified as *Urban Centres* in the *Atlas*. More than 13,000 individual *Urban Centres* have been reported in the GHSL baseline of the year 2015. *Urban Clusters* capture the dense *Urban Centres*, as well as the surrounding suburbs and towns. They are defined as clusters of cells with more than 300 people per square kilometre and at least 5,000 inhabitants. Over the past 40 years, their extent has virtually doubled. *Urban Clusters* increased from 4% of the global land mass in 1975 to 7.6% in 2015, this is approximately half the size of the European Union.

Most of the population and built-up areas increases took place in locations potentially at risk to natural disasters. For example, the world urban population of coastal areas has doubled in the last 40 years from 45 to 88 million people. The different growth trends lead also to an unequal distribution of *Built-up per capita*. *Built-up per capita* in *Urban Clusters*

[38] Dijkstra & Poelman, "A harmonised definition of cities and rural areas: the new degree of urbanisation"

in Northern America is almost ten times that of Asia. National variability is even greater. Similarly, large regional and income inequalities are reported in accessing the electric energy as observed from night light emissions of *Urban Centres*. Moreover, a relative decline of night light emissions can be observed in *Urban Centres* of high income countries (compared to upper middle class countries), possibly related to the implementation of environmental protection and energy saving policies. Finally, accordingly to the evidences collected by the GHSL and reported in this *Atlas*, our *Urban Centres*, towns and suburbs are getting greener: the average intensity of vegetation associated to built-up areas in the whole *Urban Clusters* of the planet has increased by 38% in the past 25 years.

New insights

This Atlas represents a first step in the direction of a general vision where Earth Observation technologies describe and account the surfaces used by humans to settle in the Planet Earth as it is done already successfully for the atmosphere, ocean, ices, forests, and other natural land surfaces. This Atlas collects and aggregates systematically information about built-up areas and people living there. The built-up areas are the first human influence zone on the environment: the closest space, accumulating most of the symbolic, economic and social values. Humans are made with a metric scale and build houses, shelters, production and commerce sites at the metric or decametric scale. In order to observe and directly account these, also Earth Observation sensors at metric or decametric scale are necessary as well as data analytics that are able to handle the volume and complexity of the fine-scale, planetary-size data. These data and these tools are now available and they are open and public. They allow describing and sharing information on global human settlements.

Open issues

These facts are great achievements but also an opening of next challenges. The new data and new tools supporting the *Atlas of the Human Planet 2016* are still in their infant phase. Along the road of their maturity many open issues will need to be fixed. Multi-sensor, multi-source information standardization, validation and cross comparison at the metric scale of detail and planetary-size coverage will be the next data science challenges. If successfully solved they will support the next releases of the Atlas with more robust baseline data.

Final remark

The Open and public Earth Observation data and derived product such GHSL are of critical importance. A strategy of storing and preserving data records of Earth surface is the only way we have to understand the past and discuss about next possible human development pathways. This work also introduces the concept of the "built-up areas" that is central to the narrative of this Atlas. Our aim would be to have concepts such as *built-up*, *built-up per capita* as key variables acknowledged by the international scientific community and decision makers as contributing to describe human development and living conditions. These variables are currently measured as quantities embedded within spatial datasets. Understanding the spatial dimensions of the human progress will be the key to understand the limits and the possibilities of the forthcoming societal human advances, in a finite planetary space development paradigm.

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List of abbreviations and definitions

Abbreviations

ACAPS	Assessment Capacities Project
BU	Built-up
CESM	Community Earth System Model
CIESIN	Center for International Earth Science Information Network
DFID	UK Department for International Development
DG DEVCO	EU Directorate-General for International Cooperation and Development
DG ECHO Operations	EU Directorate-General for European Civil Protection and Humanitarian Aid
DG GROWTH SMEs	EU Directorate-General for Internal Market, Industry, Entrepreneurship and
DG REGIO	EU Directorate-General for Regional and Urban Policy
DMSP	Defence Meteorological Satellite Program
DRR	Sendai Framework for Disaster Risk Reduction 2015-2030
ELER	Earthquake Loss Estimation Routine
FROM-GLC	Monitoring of Global Land Cover
GCM	Global Crisis Management
GDACS	Global Disaster Alert and Coordination System
GHSL	Global Human Settlement Layer
GIS	Geospatial Information System
GUF	Global Urban Footprint
HDI	Human Development Indicator
HIC	High Income Countries
IASC Resilience	Inter-Agency Standing Committee Task Team for Preparedness and
IDPs	Internally Displaced Persons
IPCC	Intergovernmental Panel on Climate Change
iPETS	Population-Economy-Technology-Science model
JRC	Joint Research Centre, European Commission
LDC	Least-Developed Countries
LIC	Low Income Countries
LMC	Low Middle Income Countries
MMC MCX	USACE Modelling, Mapping, and Consequences Center of Expertise
NDVI	Normalised Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
NUA	New Urban Agenda
OCHA	Office for the Coordination of Humanitarian Affairs

SDGs	Sustainable Development Goals
SDSN	UN Sustainable Development Solutions Network
SRTM	Shuttle Radar Topography Mission
SVED	volcanoes with significant eruptions
THESIS	Toolbox for Human-Earth System Integration and Scaling
UMC	Upper Middle Income Countries
UN	United Nations
UN OCHA	United Nations Office for the Coordination of Humanitarian Affairs
UN-Habitat	United Nations Human Settlements Programme
USACE	United States Army Corps of Engineers
VGI	Voluntary Geographic Information
VIIRS	Visible Infrared Imaging Radiometer Suite sensor

Definitions

Built-up per capita	Ratio between built-up and population
Built-up	Built up area is typically expressed with a continuous values representing the proportion of building footprint area within the total size of the cell.
Geodata	An image that has geographic information embedded in the file, like GeoTIFF
Giga-city	A gigacity is an urban settlement hosting more than 100 million of people
Land mass	Land mass is the total surface of continental land excluding inland water bodies
Megacity	A megacity is an urban settlement hosting more than 10 million of people
NDVI	Normalised Difference Vegetation Index introduced by Rouse et.al. (1973)
Nightlight	Emission of light measured in watt per m^2
Population	Resident population accounted in national censuses
Raster	An image composed of a complete grid of pixels.
Urban area	Area covered by the *Urban Cluster*s or the *Urban Centre*s in km^2
Urban Centre	Continuous grid cells of 1km2 with a density of at least 1,500 inhabitants per km2 or built-up of at least 50%, and a minimum population of 50,000
Urban Clusters	Continuous grid cells of 1km2 with a density of at least 300 inhabitants per km2 and a minimum population of 5,000
Urbanisation ratio	ratio between population living in urban settlement over national population

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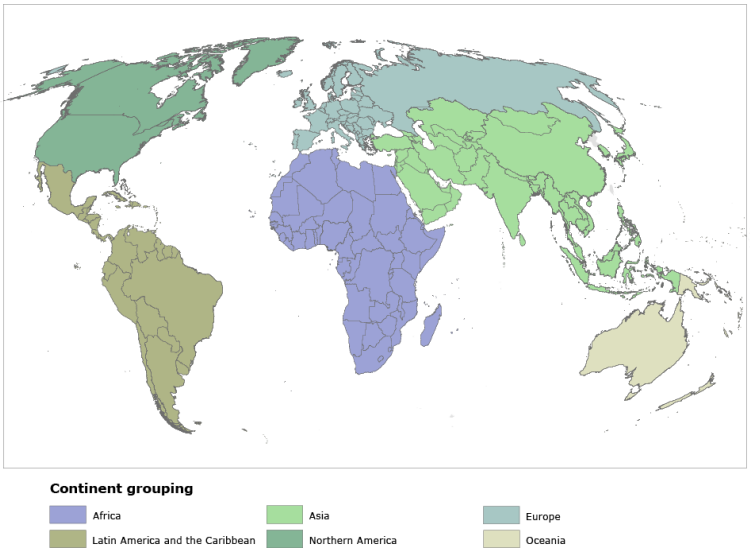
Annexes

Annex 1 Geographical classification

This report includes multi-temporal global data. Data are also presented in aggregated formats.

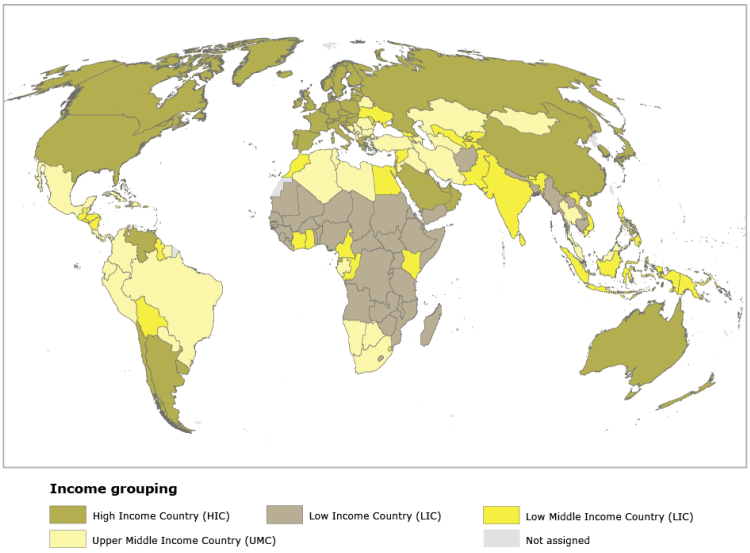


Map 11 Country classification per regions of the world

Country data for analysis purposes have been grouped according to the country classification by Major Area and Regions of the World as per the United Nations Population Division Department of Economic and Social Affairs World Population Prospects, 2015 Revision.

Countries are grouped in 6 regions: Africa, Asia, Europe, Latin America and the Caribbean, Northern America and Oceania.

Annex 2 Income classes



Map 12 Country classification per income class

Countries are divided in 4 income classes: High Income, Upper-Middle, Lower-Middle and Low Income Countries.

Classification of countries per regions and income classes is inspired by The Classification Of Countries By Major Area And Region Of The World (World Population Prospects: The 2015 Revision) [39].

[39] https://esa.un.org/unpd/wpp/General/Files/Definition_of_Regions.pdf

Annex 3 Disclaimer

The disclaimer informs readers about specific arrangements adopted in the analysis of data published in this Atlas and other specifications related to information and views contained in this report.
To facilitate the reading in this *Atlas* data are referred to 1975, 1990, 2000, 2015, but for specific reference to satellite input data please see (Martino Pesaresi et al. 2016).

The empirical evidences about built-up areas and population supporting this release of the Atlas are based on the compilation of the best available open satellite data records collected since 1975 by the Landsat space program, the best available methods for automatic satellite data classification and the best available globally-harmonized national census spatial statistics collected by the CIESIN SEDAC.

Despite the best efforts done, unavoidable information gaps in specific locations of the Earth surface and specific points in time, can result from unavailability of suitable satellite data or census data. Moreover, because the method for mapping built-up areas is based on physical observable characteristics as collected from space orbiting sensors, some settlements may be hardly detectable or simply invisible. Just to mention typical cases: settlement carved in rock cliffs, underground settlement, or settlements made by straw huts under large tree canopies are nearly invisible with the data technology used to support the Atlas.

Accordingly to the quality control procedures implemented so far using validated fine-scale cartographic reference data, the built-up areas quantities as estimated by GHSL are the best estimation available today using global open remote sensing data (Martino Pesaresi et al. 2016). The reader interested in understanding if specific issues or reported spatial-temporal data anomalies may be present in the global satellite-derived baseline data supporting the Atlas are invited to access the quality control information layers GHS built-up confidence grid "GHS_BUILT_LDSMTCNFD_GLOBE_R2015B" and GHS built-up data mask grid "GHS_BUILT_LDSMTDM_GLOBE_R2015B" that are included in the current open data release of the GHSL (see Annex 4 GHSL Instructions for data access).

Maps and country borders

The term 'country' as used in this Report refers to territories or areas; the designations employed and the presentation of the material do not imply the expression of any opinion whatsoever on the part of the European Commission concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. In addition, the designations of country groups are intended solely for statistical or analytical convenience and do not necessarily express a judgement about the stage of development reached by a particular country or area in the development process. The boundaries and names shown and designations used on the maps presented in this publication do not imply official endorsement of acceptance by the European Commission. The views expressed in this publication are those of the authors and do not necessarily reflect those of the European Commission or its senior management, or of the experts whose contributions are acknowledged.

If not otherwise indicated, all maps have been created by European Commission - Joint Research Centre. The boundaries and names shown on maps do not imply official endorsement or acceptance by the European Union.
Kosovo: This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo Declaration of Independence.

City names have been used for the only purpose of the *Atlas* and do not imply any official status recognition by the European Union.

The analysis included in the Atlas, not necessarily include statistics for the following countries (ISO Country Codes): ABW, AIA, ALA, AND, ASM, ATF, ATG, BES, BLM, BLZ, BMU, BVT, CCK, COK, CPV, CUW, CXR, CYM, DMA, ESH, FLK, FRO, FSM, GGY, GRD, GRL, GUF, GUM, HMD, IMN, IOT, JEY, KIR, KNA, LCA, MAF, MDV, MKL, MNP, MSR, MYT, NCL, NFK, NIU, NRU, PLW, PYF, SGS, SHN, SJM, SLB, SMR, SP-, SPM, SWZ, SYC, TCA, TGO, TKL, TON, TUV, UMI, VCS, VCT, VIR, VUT, WSM, XAD, XCN.

The exclusion of the above mentioned countries can be due to incomplete input data (such as population, built-up, area of settlement, detection of *Urban Centre*s) or missing continuous values across time.

Naming of *Urban Centre*, *Urban Cluster*, megacities

Urban Centre name refers, when possible, to the name of the most populated settlement identified in the WUP.

Urban Cluster name refers, when possible, to the name of the most populated *Urban Centre* identified in the WUP.[40]

Urban Settlements with more than 10 million inhabitants are considered "MEGACITIES".

An *Urban Cluster* can include no *Urban Centre*, one or more *Urban Centres*.

Nightlight and Greenness

Two criteria are considered in the calculation of the night light (NL):

- The resolution of DMSP-OLS which is 1 km
- The presence of BU (based on the BU mask at 250 m resolution)

Hence, to be able to extract an **average** NL value for an *Urban Centre*/*Urban Cluster*, the latter should have a size of more than 2 pixels of 1 km (the resolution of the DMSP) and include more than 4*4 pixels of BU at 250 m (the resolution of the BU).

The same criteria have been applied to calculate the Greenness.

Nightlight 1990: Calculated from yearly CALIBRATED composite DMSP-OLS Nighttime Lights Time Series Version 4 for 1992.

Nightlight 2000: Calculated from yearly CALIBRATED composite DMSP-OLS Nighttime Lights Time Series Version 4 for 2000.

Nightlight 2015: Calculated from yearly CALIBRATED composite DMSP-OLS Nighttime Lights Time Series Version 4 for 2012.

The band avg_lights_x_pct is used: The average visible band digital number (DN) of cloud-free light detections multiplied by the percent frequency of light detection. The inclusion of the percent frequency of detection term normalizes the resulting digital values for variations in the persistence of lighting. For instance, the value for a light only detected half the time is discounted by 50%. Note that this product contains detections from fires and a variable amount of background noise (Reference: https://explorer.earthengine.google.com/#detail/NOAA%2FDMSP-OLS%2FNIGHTTIME_LIGHTS)

Greenness 1990: Description: Calculated from Landsat 5 composites made from Level L1T orthorectified scenes, using the computed top-of-atmosphere (TOA) reflectance. See

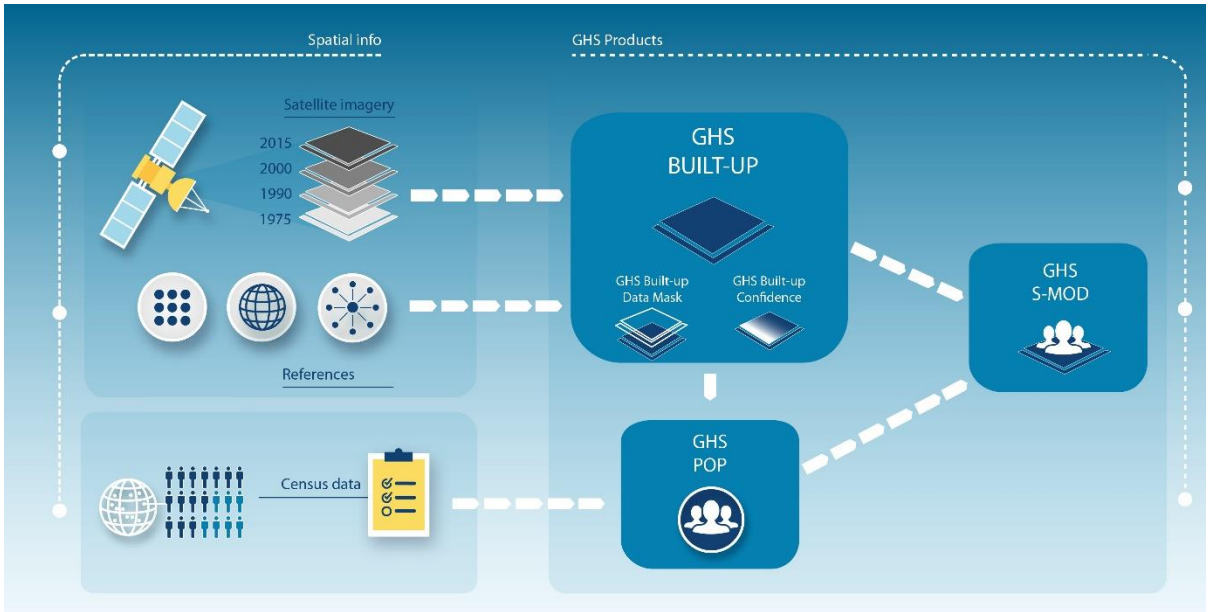
[40] https://esa.un.org/unpd/wup/

Chander et al. (2009) for details on the TOA computation. These composites are created from all the scenes in each annual period beginning from the first day of the year and continuing to the last day of the year. All the images from each year are included in the composite, with the greenest pixel as the composite value, where the greenest pixel means the pixel with the highest value of the Normalized Difference Vegetation Index (NDVI). For 1990 GREENESS the average of the greenness for the period '1988-01-01', '1992-12-31' was taken to fill a maximum number of gaps due to the sensor. Original greenness at 30 m is aggregated at 250 m prior to averaging.

Greenness 2000: Calculated from Landsat 7 composites made from Level L1T orthorectified scenes, using the computed top-of-atmosphere (TOA) reflectance. See Chander et al. (2009) for details on the TOA computation. These composites are created from all the scenes in each annual period beginning from the first day of the year and continuing to the last day of the year. All the images from each year are included in the composite, with the greenest pixel as the composite value, where the greenest pixel means the pixel with the highest value of the Normalized Difference Vegetation Index (NDVI). For 2000 GREENESS the average of the greenness for the period '2000-01-01', '2000-12-31 was considered for the calculation. Original greenness at 30 m is aggregated at 250 m prior to averaging. Original greenness at 30 m is aggregated at 250 m prior to averaging.

Greenness 2015: Calculated from Landsat 8 composites made from Level L1T orthorectified scenes, using the computed top-of-atmosphere (TOA) reflectance. See Chander et al. (2009) for details on the TOA computation. These composites are created from all the scenes in each annual period beginning from the first day of the year and continuing to the last day of the year. All the images from each year are included in the composite, with the greenest pixel as the composite value, where the greenest pixel means the pixel with the highest value of the Normalized Difference Vegetation Index (NDVI). For 2014 GREENESS the average of the greenness for the period '2014-01-01', '2015-12-31' was considered for the calculation. Original greenness at 30 m is aggregated at 250 m prior to averaging (REFERENCE: https://explorer.earthengine.google.com/#detail/LANDSAT%2FLC8_L1T_ANNUAL_GREENEST_TOA)

Annex 4 GHSL Instructions for data access



Where can I get the GHSL?

JRC Open Data Portal http://data.jrc.ec.europa.eu/collection/GHSL
GHSL web page http://ghsl.jrc.ec.europa.eu/

How can I get the GHSL?

The GHSL can be downloaded for free. No registration is needed.

What are the use constraints?

The GHSL has been produced by the JRC – European Commission for non-commercial uses. For more information, please read the use conditions (European Commission Reuse and Copyright Notice).

How can I open the files?

The dataset can be opened by means of GDAL-compatible GIS/Remote Sensing tools, such as **QGIS (open source software)** or **ArcGIS (commercial software by ESRI)**.

What can I do with the GHSL data?

Examples of main applications and uses of the GHSL are:

Comparison of settlements in a consistent way

Monitoring the implementation of international frameworks

Empowering communities and building trust in data and analyses.

What can I download?

Three main type of products:

- built-up (GHS-BUILT)
- population (GHS-POP) grids
- city model (GHS-SMOD)

Format: the dataset is distributed in compressed ZIP, that contains raster files together with pyramids (i.e., TIF and OVR files).

Coverage: globe

Temporal resolution: 1975, 1990, 2000, 2015

TYPE OF PRODUCT	*DETAILS*	*38M*	*250M*	*1KM*
GHS-BUILT	Built-up grid	yes	yes	yes
	Quality information on remote sensing data availability (data mask grid)	yes	no	no
	Quality information on built-up presence (confidence grid)	yes	no	no
GHS-POP	Population grid	no	yes	yes
GHS-SMOD	Settlement model grid	no	no	yes

How shall I cite the data?

The dataset citations can be found at JRC Open Data portal.

GHS BUILT-UP GRID

These data contain a multitemporal information layer on built-up presence as derived from Landsat image collections (GLS1975, GLS1990, GLS2000, and ad-hoc Landsat 8 collection 2013/2014).

The data have been produced by means of Global Human Settlement Layer methodology in 2015.

Product name: GHS_BUILT_LDSMT_GLOBE_R2015B

Projection: Spherical Mercator (EPSG:3857)

Resolutions available: approx. 38m, 250m, and 1Km

Description: multi-temporal classification
Layer names (size): *38m of resolution - Spherical Mercator (EPSG:3857)*
GHS_BUILT_ LDSMT_GLOBE_R2015B_3857_38 (13Gb)
Legend:
0 = no data
1 = water surface
2 = land no built-up in any epoch
3 = built-up from 2000 to 2014 epochs
4 = built-up from 1990 to 2000 epochs
5 = built-up from 1975 to 1990 epochs
6 = built-up up to 1975 epoch

Description: built-up presence by epoch
Layer names (size): *38m of resolution - Spherical Mercator (EPSG:3857)*
GHS_BUILT_LDS1975_GLOBE_R2016A_3857_38 (700Mb)
GHS_BUILT_LDS1990_GLOBE_R2016A_3857_38 (800Mb)
GHS_BUILT_LDS2000_GLOBE_R2016A_3857_38 (850Mb)
GHS_BUILT_LDS2014_GLOBE_R2016A_3857_38 (900Mb)
Legend: values are expressed in byte from 1 to 101 [0 = no data]

Description: built-up presence by epoch
Layer names (size): *250m of resolution - World Mollweide (EPSG54009)*
GHS_BUILT_LDS1975_GLOBE_R2016A_54009_250 (200Mb)
GHS_BUILT_LDS1990_GLOBE_R2016A_54009_250 (260Mb)
GHS_BUILT_LDS2000_GLOBE_R2016A_54009_250 (300Mb)
GHS_BUILT_LDS2014_GLOBE_R2016A_54009_250 (350Mb)
Legend: Values are expressed as decimals (Float) from 0 to 100

Description: built-up presence by epoch
Layer names (size): *1Km of resolution - World Mollweide (EPSG54009)*
GHS_BUILT_LDS1975_GLOBE_R2016A_54009_1k (35Mb)
GHS_BUILT_LDS1990_GLOBE_R2016A_54009_1k (52Mb)
GHS_BUILT_LDS2000_GLOBE_R2016A_54009_1k (62Mb)
GHS_BUILT_LDS2014_GLOBE_R2016A_54009_1k (73Mb)
Legend: Values are expressed as decimals (Float) from 0 to 100

GHS BUILT-UP CONFIDENCE GRID

This layer is a complementary information to the multitemporal GHS built-up grid (1975, 1990, 2000, 2014), which has been produced by means of Global Human Settlement Layer methodology in 2014.

This dataset is an aggregated confidence map about built-up area presence. Value represent the confidence of the model in the built-up presence.

Product name	GHS_BUILT_LDSMTCNFD_GLOBE_R2015B
Projection	Spherical Mercator (EPSG3857)
Resolutions available	approx. 38m

Description	aggregated gaps-filled confidence to the built-up class in 2014
Layer name (size)	*GHS_BUILT_LDSMTCNFD_GLOBE_R2015B_3857_38 (9Gb)*
Legend	Continuous values in the range [0 to 255] 0 127 255  0 = 100% confidence of no built-up 127 = 50% decision cut off 255 = 100% confidence of yes built-up

GHS BUILT-UP DATAMASK GRID

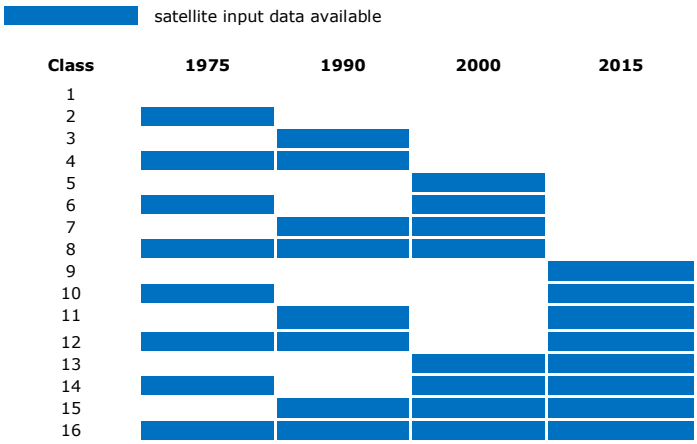
This layer is a complementary information to the multitemporal GHS built-up grid (1975, 1990, 2000, 2014), which has been produced by means of Global Human Settlement Layer methodology in 2014.

This dataset contains a data mask layer that supports the main product, i.e., the multitemporal information layer on built-up presence derived from Landsat image collections (GLS1975, GLS1990, GLS2000, and ad-hoc Landsat 8 collection 2013/2014).

Product name	GHS_BUILT_LDSMTDM_GLOBE_R2015B
Projection	Spherical Mercator (EPSG3857)
Resolutions available	approx. 38m

Description
Layer names (size)
Legend

mosaic of data availability in the different epochs
GHS_BUILT_LDSMTDM_GLOBE_R2015B_3857_38 (1.8Gb)



GHS POPULATION GRID

This spatial raster dataset depicts the distribution and density of population, expressed as the number of people per cell. Residential population estimates for target years 1975, 1990, 2000 and 2015 provided by CIESIN GPWv4 were disaggregated from census or administrative units to grid cells, informed by the distribution and density of built-up as mapped in the Global Human Settlement Layer (GHSL) global layer per corresponding epoch.

Product name	GHS_POP_GPW4_GLOBE_R2015A
Projection	World Mollweide (EPSG54009)
Resolutions available	250m and 1Km

Description	distribution and density of population, expressed as the number of people per cell
Layer names (size)	*Resolution of 250m (1.4Gb)* GHS_POP_GPW41975_GLOBE_R2015A_54009_250 GHS_POP_GPW41990_GLOBE_R2015A_54009_250 GHS_POP_GPW42000_GLOBE_R2015A_54009_250 GHS_POP_GPW42015_GLOBE_R2015A_54009_250 *Resolution of 1Km (280Mb)* GHS_POP_GPW41975_GLOBE_R2015A_54009_1k GHS_POP_GPW41990_GLOBE_R2015A_54009_1k GHS_POP_GPW42000_GLOBE_R2015A_54009_1k GHS_POP_GPW42015_GLOBE_R2015A_54009_1k
Legend	Values are expressed as decimals (Float) and represent the absolute number of inhabitants of the cell.

GHS SETTLEMENT GRID

This data package contains an assessment of the REGIO-OECD "degree of urbanization" model using as input the population GRID cells generated by the JRC in four epochs and named GHS-POP_2015, GHS-POP_2000, GHS-POP_1990, and GHS-POP_1975.

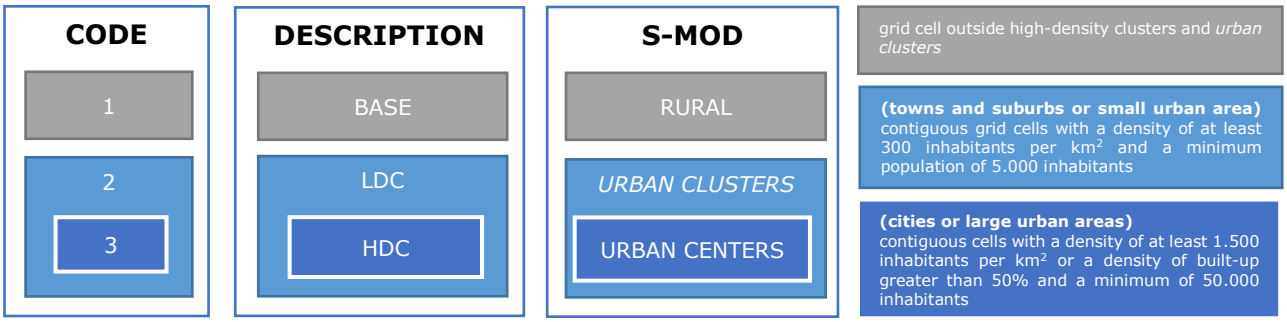
They are generated by integration of built-up areas extracted from Landsat image data processing, and population data derived from the CIESIN GPW v4.

In this assessment, the REGIO-OECD model concerning the selection of the "high density clusters" (HDC) has been modified as follows "*contiguous cells (4-connectivity, gap filling) with a density of at least 1500 inhabitant/km^2 <u>or a density of built-up greater than 50%,</u> and a minimum of 50K inhabitants*". It will be referring to it as to the S-MOD.

Product name	GHS_SMOD_POP_GLOBE_R2016A
Projection	World Mollweide (EPSG54009)
Resolutions available	1Km

Description	model that classify the human settlements on the base of the built-up and population density
Layer names (size)	*Resolution of 1Km (30Gb)* GHS_SMOD_REGIO1975_GLOBE_R2016A_54009_1k GHS_SMOD_REGIO1990_GLOBE_R2016A_54009_1k GHS_SMOD_REGIO2000_GLOBE_R2016A_54009_1k GHS_SMOD_REGIO2015_GLOBE_R2016A_54009_1k
Legend	1 = "rural cells" or base (BAS) 2 = "*Urban Clusters*" or low density clusters (LDC) 3 = "*Urban Centres*" or high density clusters (HDC)

Description	layers that identify the settlement with a unique ID
Layer names (size)	GHS_SMOD_REGHDC2015_GLOBE_R2016A_54009_1k GHS_SMOD_REGLDC2015_GLOBE_R2016A_54009_1k
Legend	The raster value are the unique ID of the *Urban Centres* and *Urban Clusters*, respectively, in the epoch 2015.



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