

JRC SCIENCE FOR POLICY REPORT

Atlas of the Human Planet 2017

Global Exposure to Natural Hazards

Martino Pesaresi, Daniele Ehrlich, Thomas Kemper, Alice Siragusa, Aneta J. Florczyk, Sergio Freire, Christina Corbane

2017



This publication is a Science for Policy report by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policy-making process. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of this publication.

Contact information

Name: Daniele Ehrlich Address: Via Fermi, 2749 21027 ISPRA (VA) - Italy - TP 267 European Commission - DG Joint Research Centre Space, Security and Migration Directorate Disaster Risk Management Unit E.1 E-mail: daniele.ehrlich@ec.europa.eu Tel.: +39 0332 789384

JRC Science Hub

https://ec.europa.eu/jrc

JRC 106292

EUR 28556 EN

PDF	ISBN 978-92-79-67959-9	ISSN 1831-9424	doi:10.2760/19837	
Print	ISBN 978-92-79-67958-2	ISSN 1018-5593	doi:10.2760/709471	

Luxembourg: Publications Office of the European Union, 2017

© European Union, 2017

Reproduction is authorised provided the source is acknowledged.

How to cite: Martino Pesaresi, Daniele Ehrlich, Thomas Kemper, Alice Siragusa, Aneta J. Florczyk, Sergio Freire, Christina Corbane, Atlas of the Human Planet 2017: Global Exposure to Natural Hazards, EUR 28556 EN, doi: 10.2760/19837

All images © European Union 2017, except:

Pag. 27 © spumador, Fotolia.com, Nepal Earthquake, 2015

Pag. 36 $\ensuremath{\mathbb{C}}$ hello_kosmos, Flickr.com, Isla de Ometepec, Nicaragua, 2014

Pag. 43 © Kariochi, Fotolia.com, Tsunami in Japan, 2011

Pag. 49 ${\rm \odot}$ Bartsadowski, Fotolia.com, Illinois, USA, 2007

Pag. 58 © jon11, Fotolia.com, Australia, 2016 Pag. 63 © kmiragaya, Fotolia.com, Havana, Cuba, 2016

(Unless otherwise specified)

Title Atlas of the Human Planet 2017. Global Exposure to Natural Hazards

Abstract

The Atlas of the Human Planet 2017. Global Exposure to Natural Hazards summarizes the global multi-temporal analysis of exposure to six major natural hazards: earthquakes, volcanoes, tsunamis, floods, tropical cyclone winds, and sea level surge. The exposure focuses on human settlements assessed through two variables: the global built-up and the global resident population. The two datasets are generated within the Global Human Settlement Project of the Joint Research Centre. They represent the core dataset of the Atlas of the Human Planet 2016 which provides empirical evidence on urbanization trends and dynamics.

The figures presented in the Atlas 2017 show that exposure to natural hazards doubled in the last 40 years, both for built-up area and population. Earthquake is the hazard that accounts for the highest number of people potentially exposed. Flood, the most frequent natural disaster, potentially affects more people in Asia (76.9% of the global population exposed) and Africa (12.2%) than in other regions. Tropical cyclone winds threaten 89 countries in the world and the population exposed to cyclones increased from 1 billion in 1975 up to 1.6 billion in 2015. The country most at risk to tsunamis is Japan, whose population is 4 times more exposed than China, the second country on the ranking. Sea level surge affects the countries across the tropical region and China has one of the largest increase of population over the last four decades (plus 200 million people from 1990 to 2015). The figures presented in the Atlas are aggregate estimates at country level.

The value of the GHSL layers used to generate the figures in this Atlas is that the data are available at fine scale and exposure and the rate of change in exposure can be computed for any area of the world. Researchers and policy makers are now allowed to aggregate exposure information at all geographical scale of analysis from the country level to the region, continent and global.

Atlas of the Human Planet 2017

Global Exposure to Natural Hazards

Martino Pesaresi, Daniele Ehrlich, Thomas Kemper, Alice Siragusa, Aneta J. Florczyk, Sergio Freire, Christina Corbane

2017

ACKNOWLEDGEMENTS

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

We would like to acknowledge the activity of the GHSL project team, led by Thomas Kemper, which has been working for many years to produce the data sets used in this Atlas. In 2017, the team comprises Donato Airaghi, Christina Corbane, Daniele Ehrlich, Aneta Florczyk, Sergio Freire, Fernand Haag, Luca Maffenini, Martino Pesaresi, Panagiotis Politis, Alice Siragusa, Filip Sabo and Luigi Zanchetta.

The preparation of the Human Planet *Atlas* included: a) preliminary stage for the preparation of datasets; b) investigation of databases, data mining and analysis; c) elaboration of findings and drafting of chapters; d) verification and ranking of main findings; e) final editing. The GHSL geospatial data products are one of the outcomes of the GHSL Framework, as illustrated in the second chapter.

We would like to acknowledge the work of our JRC colleagues that provided us with data and information on the hazard data: especially Luca Vernaccini and Tom De Groeve (INFORM), and Francesco Dottori and Lorenzo Alfieri (GloFAS).

EXECUTIVE SUMMARY

Policy context

The Atlas of the Human Planet 2017 highlights the importance of exposure in the context of risk analysis by reporting on the global exposure and its changes over time to six major natural hazards: earthquakes, volcanos, tsunamis, tropical cyclone winds, tropical cyclone storm surge and floods. The exposure is measured as built-up surface and population. Both are global datasets produced by the Global Human Settlement Layer (GHSL) of the European Commission, Joint Research Centre.

The exposure data and the findings of the Atlas aim at supporting the monitoring of the implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030 (DRR). The GHSL baseline data provides a framework that allows learning from the last 40 years and closely monitoring the impact of policies of today and for the future. It aims at supporting the monitoring of implementation of the the post-2015 international frameworks: the UN Framework Convention on Climate Change, the Sendai Framework for Disaster Risk Reduction 2015-2030 (DRR), the Sustainable Development Goals (SDGs), and the New Urban Agenda (Habitat III).

The Atlas of the Human Planet 2017 is the second outcome of the GEO Human Planet Initiative. Launched in October 2014 under the GEO programme, this initiative supports the implementation of the Agenda 2030 by enabling the testing and the collective discussion of alternative options in operationalization of the indicators for monitoring post-2015 frameworks.

Key conclusions

The Atlas sheds new light on the global exposure to natural hazard and its evolution. Often the discussion on changing disaster risk was dominated by the impact of climate change related hazards. This Atlas highlights the importance of major changes of exposure to global population and economic growth. This is possible thanks to the global, fine-scale, synoptic, and multi-temporal datasets that provides a historical record of the past 40 years.

The GHSL layers used to generate the figures enable scientists and policy makers to aggregate exposure information at different scales ranging from the city level to national, regional and global levels. It will put them in the position to evaluate better the impact of disaster risk reduction measures and policies.

Main findings

The empirical evidences supporting this release of the Atlas have been collected and processed within the Global Human Settlement Layer (GHSL) of the European Commission, Joint Research Centre. The GHSL dataset has been combined with the best available global hazard maps to measure the potential exposure to natural hazards over time. The analysis is based on a single return period for each hazard, in order to focus the attention on the change over time.

According to this analysis, the global exposure of population and built-up surface to natural hazards increased in the last 40 years. Some hazards, due to their nature and characteristics, pose a threat to a large number of people in different regions of the world. Earthquake is the hazard that accounts for the highest number of exposed population. The number of people living in seismic areas has increased by 93% in 40 years (from 1.4 billion in 1975 to 2.7 billion in 2015). In 2015, 414 million people lived near one of the 220 most dangerous volcanoes and could suffer from the consequences of eruptions. Tsunamis affect coastal areas in many regions, but dangerous areas are more concentrated in Asia. Japan has by far the highest amount of built-up surface exposed to tsunamis, followed by China and by

the United States of America. Flood, the most frequent natural disaster, potentially affects more people in Asia (76.9% of the global population exposed) and Africa (12.2%) than in other regions. The world population potentially exposed to flood is around 1 billion in 155 countries in 2015. 11% of the area built-up on Earth is potentially exposed to this hazard, too. Cyclone winds pose a threat to 89 countries in the world and exposed population increased from 1 billion in 1975 up to 1.6 billion in 2015, (about 24% of the world population). In 2015, 640 million people are exposed to extremely strong cyclone winds. China is by far the country with the largest number of people potentially exposed to storm surge as consequence of tropical cyclones: 50 million of Chinese people live in coastal areas included in the hazard area and this number increased by a factor of 1.5 in the last 40 years.

Related and future work

The GHSL is one of the core datasets used in the GEO Human Planet initiative, and is the main baseline used in releases the Atlas of the Human Planet 2016 and 2017. 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 GROW) are working towards a regular and operational monitoring of global built-up surface 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, but also the Index for Risk Management (INFORM), the Global Flood Awareness System (GloFAS), the Global Disaster Alert and Coordination System (GDACS) and the Copernicus Emergency Management Service (Copernicus EMS). 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 present *Atlas of the Human Planet* 2017 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 surface and population. In the current release supporting the *Atlas* 2017, it covers the epochs 1975, 1990, 2000 and 2015 combined with hazard maps. The data sets are used to understand, where and in which built environment people live in hazard-prone areas, and how settlements and population changed over time. This knowledge can be used to assess the increment in exposure to natural disasters.

The first chapter introduces the topic and main challenging in measuring exposure. The second illustrates the GHSL key elements, concepts and methodology. The third chapter presents the main findings per each hazard. In the conclusion, final remarks regarding both limitation and future development of this work are presented. The annexes contain technical details and references.

8

CONTENT

ACKNOWLEDGEMENTS	
CONTENT	
1. INTRODUCTION	
2. THE GHSL TO MEASURE EXPOSURE	
2.1 Remote sensing data to map human settlements2.2 The GHSL dataset	
2.2.1 From Earth's surface to built-up surface	
2.2.2 From Built-up surface to population grid	
2.2.3 An example from the city of Madrid, Spain	
2.3 Key concepts to measure exposure	
2.4 Methodology and input data	
3. EXPOSURE TO NATURAL HAZARDS	
3.1 Earthquake	26
3.2 Volcano	
3.3 Tsunami	
3.4 Flood	
3.5 Tropical Cyclone Wind	
3.6 Tropical Cyclone Storm Surge	
4. CONCLUSIONS	
5. REFERENCES	
6. ANNEXES	
6.1 Methodology and input data	71
6.1.1 Exposure data	71
6.1.2 Hazard data	72
Earthquake	
Volcano	
Tsunami	
Flood Tropical Cyclone Wind	
Tropical Cyclone Storm Surge	
6.1.3 Geospatial aggregation for analysis	
Country layer	
Geographical classification	
Income classification	
6.2 Disclaimer	82
Maps and country borders	
Use constraints	
LIST OF ABBREVIATIONS	
DEFINITIONS	
LIST OF FIGURES	
LIST OF MAPS	
LIST OF TABLES	
LIST OF BOXES	

1. INTRODUCTION

Exposure represents the people and assets at risk of potential losses or that may suffer damage to a hazard impact. It covers several dimensions like the physical (e.g. the built-up environment), the social (e.g. population distribution) and the economic dimensions. The first two dimensions typically describe human settlements which patterns have been shaped by dynamic and complex socio-economic and ecological processes.

Particular attention to understanding exposure is required for the formulation of policies and actions to reduce disaster risk (UNISDR 2015a) as highlighted by the Sendai Framework for Disaster Risk Reduction: "Policies and practices for disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets. hazard characteristics and the environment. Such knowledge can be leveraged for the purpose of pre -disaster risk assessment, for prevention and mitigation and for the development and implementation of appropriate preparedness and effective response to disasters.

The article 17 of the Sendai Framework clearly calls for actions to avoid the creation of "new risk" and reduce the existing: the aim of the Framework is to "Prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience." (UNISDR 2015c, 12)

Exposure is one of the drivers of disaster together with the frequency and intensity of hazardous events and the effectiveness of protection measures or any other form of adaptation (Stevens et al. 2015). All of these drivers can change over time so a full analysis of disaster risk

should consider the evaluation of how these drivers evolve both historically and into the future (via scenario analysis). While there are many studies on changes in hazards and future hazard projections, retrospective analysis in the analysis of exposure is still missing. Assessing changes and trends in exposure to disaster risk is typically very complex due the interdependent and dynamic dimensions of exposure and their variability across spatial and temporal scales: human settlements where people live, work, and move - experience variations that census and administrative geographical unit definitions often are unable to depict. The tools and methods for defining exposure need to consider the dynamic nature of human settlements which evolves over time as a often unplanned result of urbanization, demographic changes, modifications in building practice, and other socio-economic, institutional and environmental factors (World Bank, GFDRR 2014).

Among the different tools for collecting information on exposure and monitoring its changes over time, earth observation represents an invaluable source of up-to-date information on the extent and nature of human settlements ranging from city level (using very high spatial resolution data) to the global level (using global coverage of satellite data) (Deichmann et al. 2011; Dell'Acqua, Gamba, and Jaiswal 2013; Ehrlich and Tenerelli 2013). Besides, change detection techniques based on satellite images can provide timely information about changes to the builtenvironment (Bouziani, Goïta, and He 2010). The coupling of recent remote sensing technologies and spatial modelling offers the opportunity to deliver worldwide geodatasets depicting built-up surfaces and population distribution that are consistent for global risk modelling, impact analysis, and policy-making in the field of disaster risk reduction.

Earth observation together with spatial modelling techniques are the cornerstone of the Global Human Settlement Layer (GHSL) which is the first global, fine scale, multi-temporal, open data on the physical characteristics and the dynamics of human settlements. Drawing from 40 years of satellite observations, multi-temporal arids describing the built-up environment and population distribution have been produced for the periods 1975, 1990, 2000, 2015 epoch (Martino Pesaresi, Melchiorri, et al. 2016).

At present, the GHSL datasets represent an unprecedented source of information for understanding global changes and trends in exposure to natural disasters (Martino Pesaresi, Melchiorri, et al. 2016). The availability of such consistent information on physical and human exposure and its changes over time at a fine spatial resolution is the driving force behind this report.

Thus acknowledging the need for detailed, updated, and consistent geodata on exposure and building on the GHSL baseline data released in 2016 in the First Atlas of the Human Planet, this second Atlas presents the global status and trends of human settlements exposure to selected natural hazards. The purpose is to shed light on the spatiotemporal patterns of exposure and their relation to socio-economic vulnerability. The analysis brings together the best available global hazard data and multi-temporal exposure data on built-up surface and population with the aim of drawing attention to geographical areas or hotspots where necessary refinements are needed for a comprehensive understanding of disaster risks.

2. THE GHSL TO MEASURE EXPOSURE

2.1 Remote sensing data to map human settlements

Human settlements are typically measured based on the amount of population and on the size of the built environment, two information aspects that are also used to quantify exposure to disaster risk. Remote sensing technologies combined with spatial modelling are one of the most costeffective tools for monitoring human settlements at the global level.

The first attempts to map settlements globally using satellite images relied on coarse and medium scale resolution imagery available since the 1990's (300m - 1000m spatial resolution) (Potere and Schneider 2007) and with figures that vary significantly (Schneider, Friedl, and Potere 2010). Over time, changes in the physical size of settlements have been mapped and measured from a combination of coarse and moderate resolution imagery as well as from medium resolution imagery. In 2016, the JRC published the first public release of the GHSL, the most complete, consistent, global, free, and open **dataset on human settlements.** The GHSL maps all human settlements from the village to the megacity. By applying a specific spatial disaggregation methodology, the GHSL provides information about the number of inhabitants and their density at a fine scale. Thanks to the use of historical input imagery data (Landsat series for circa 1975, 1990, and 2000 and 2015), both population and built-up layers are produced for the four epochs, allowing to measure the expansion of human settlements over the last forty years in a consistent way. Using homogenous and wall-towall grid, the GHSL provides information on much of the Earth's surface is covered by settlements, where, how much and how fast are settlements growing. These new sets of information on physical size of cities and their growth impact societal processes at all levels, and are necessary to guide country development plans towards more sustainable societies (United

Box 1 Sendai Framework for Disaster Risk Reduction – UNISDR **UN World Conference on** Disaster Risk Reduction 2015 Sendai Japan The Sendai Framework was adopted by UN Member States on 18 March 2015 at the Third UN World Conference on Disaster Risk Reduction in Sendai City, Miyagi Prefecture, Japan. The Sendai Framework is a 15-year, voluntary, non-binding agreement which recognizes that the State has the primary role to reduce disaster risk but that responsibility should be shared with other stakeholders including local government, the private sector and others. It aims for the following outcome: The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries The Sendai Framework is the successor instrument to the Hyogo Framework for Action (HFA) 2005-2015: Building the Resilience of Nations and Communities to Disasters. It is the outcome of stakeholder consultations initiated in March 2012 and inter-governmental negotiations held from July 2014 to March 2015, which were supported by the UNISDR upon the request of the UN General Assembly. UNISDR has been tasked to support the implementation, follow-up and review of the Sendai Framework. Source: http://www.unisdr.org/we/coordinate/sendai-framework

.

Nations, General Assembly 2015). Producing such

a high cost and that is why earth observation is the most promising and cost-effective technology to address the assessment of human settlements from local to national and global scale (Martino Pesaresi et al. 2013).

The need for global settlement information goes beyond scientific enquiries and has practical implications related to local and global sustainability.

Human settlement information are used for improving our disaster risk knowledge and for monitoring the four post-2015 international frameworks including:

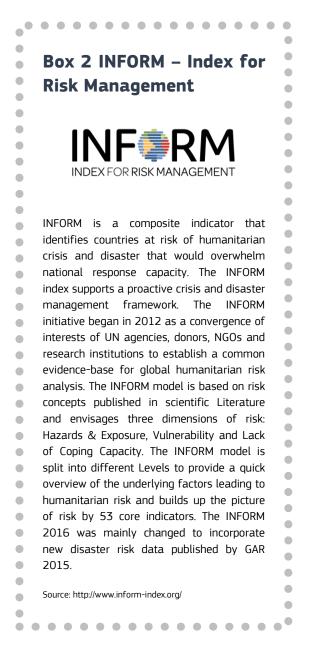
- Sendai framework for Disaster Risk Reduction (DRR) (United Nations 2015) (see Box 1),
- Sustainable Development Goals (SDGs) with particular focus on Goal 11 (make cities and human settlements inclusive, safe, resilient, sustainable),
- Paris Climate Agreements
- New Urban Agenda (adopted in Quito, Ecuador in October 2016).

information from the field observations has usually

In particular, the implementation of the SDGs, is contingent to the availability and access to data and statistics, to ensure that no one is left behind in the information gaps.

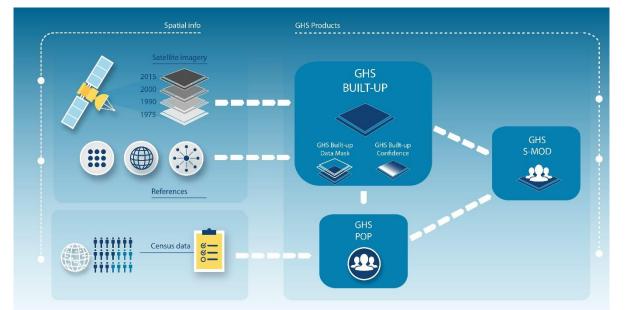
As highlighted during the Habitat III preparatory process, up-to-date information about land use and cover, cadastral systems and vulnerable areas should be incorporated in the planning process, especially at local level. "Open and easily accessible geospatial data can support monitoring in many aspects 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).

Information on location and size of human settlements can be used to measure **exposure** (to natural / man-made hazards, disasters, and pollution). 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 Aid¹, 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. The different phases of crisis management, including risk assessment, alerting of disaster and emergency response, all require exposure information and all at fine detail, something that is not available to the degree of detail. Global alert systems such, as the Global Disaster Alert and Coordination System (GDACS)², and INFORM (De Groeve, Vernaccini, and Poljansek 2015) (see Box 2), rely on models with exposure and vulnerability. The more precise the information, the better will be the outcome of the alert. Similarly, disaster risk models rely on the same exposure variables with the difference that they may need to take into account also the expanding settlements in the coming age. These are some of the reasons why is import to have accessible, homogenous and free data on settlements.



¹ http://ec.europa.eu/europeaid/about-development-andcooperation-europeaid_en http://ec.europa.eu/echo/

² http://www.gdacs.org/



2.2 The GHSL dataset

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). The GHSL consists of three main information components hierarchically placed at three different levels of abstraction:

- Global Human Settlement built-up areas (GHS-BU),
- GHS population grids (GHS-POP)
- GHS settlement classification model (GHS-SMOD).

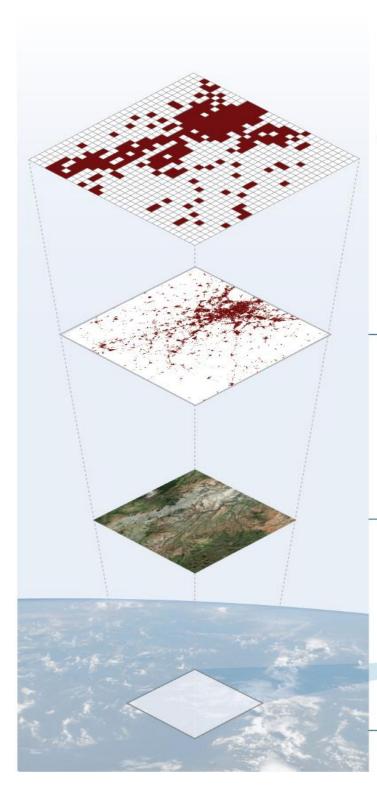
The first two products have been used in this report.

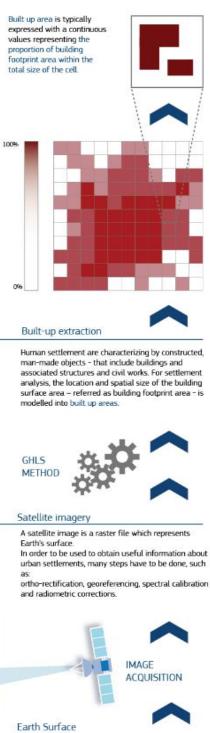
Global Human Settlement built-up areas (**GHS-BU**) is a layer providing information on observable presence of built-up structures or buildings. The "building" constitutes the physical part of the human settlement fabric or spatial extension that is observable and measurable using the available global sensors. The GHSL reports about *built-up areas* (GHS-BU, resolution 38m), as *areas* (*spatial units*) where buildings can be found (Martino Pesaresi et 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 (Martino Pesaresi et al. 2013). Since this definition excepts the condition of the permanency of the structure the GHSL allows for inclusion of refugee camps, informal settlements, slums and other temporary settlements and shelters in the notion of built-up area in the GHSL paradigm.

The GHSL *population grid* or *GHS-POP* (250m resolution). This layer is derived from the combination of global collections of national population census data and global built-up areas (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 same space and time domains as the GHS-BU 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 Sergio et al. 2016).

The following sections help the reader to understand the extraction of information from satellite imagery, the built-up surface definition (2.2.1), the process of combining built-up grids with census data to produce the population grids (2.2.2), and an example (2.2.3).

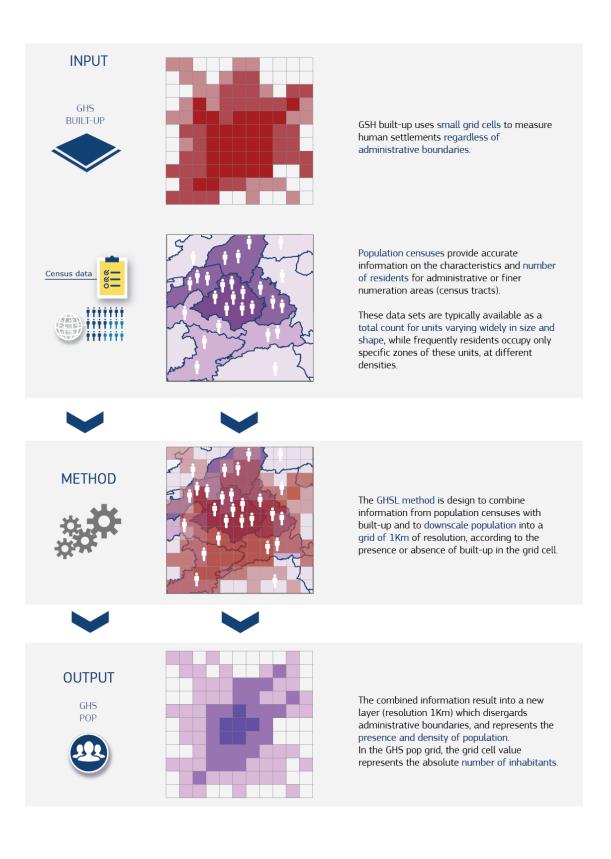
2.2.1 From Earth's surface to built-up surface



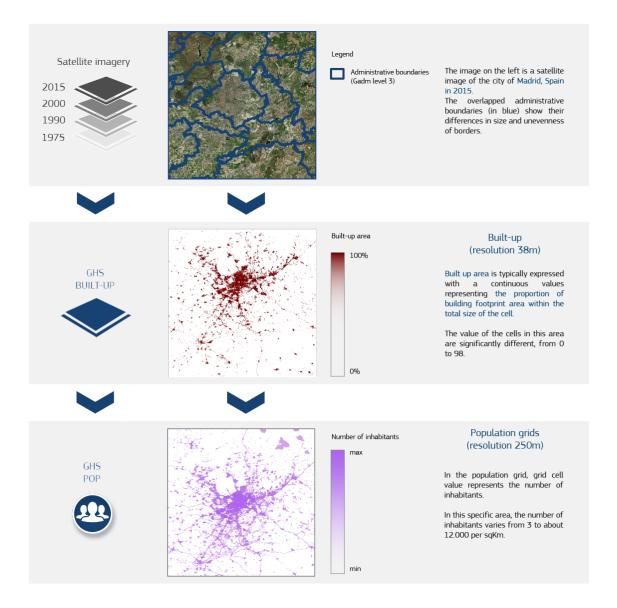


Earth observation satellites regurarly provide images of its surface. These images have different resulution and characteristics.

2.2.2 From Built-up surface to population grid



2.2.3 An example from the city of Madrid, Spain



2.3 Key concepts to measure exposure

This paragraph introduces the methodology used to measure exposure combing the GHSL and the best available global hazard maps. Before presenting the methodology, some key concepts related to risk and natural disaster are presented as they have been treated in the Atlas. These key concepts are presented both we the international agreed definitions and as they have been integrated in the report.

RISK = HAZARD **x** EXPOSURE **x** VULNERABILITY

RISK

The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period (United Nations General Assembly 2016) When addressing the risk from natural hazards we may comprise three elements to compute the risk: Hazard intensity, Exposure, and Vulnerability.

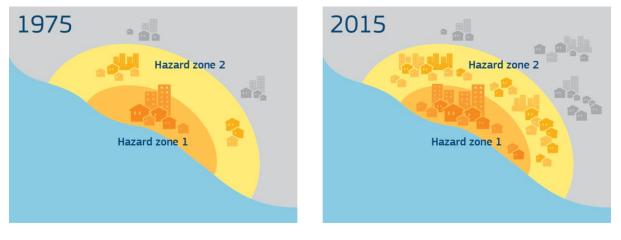
EXPOSURE

The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas (United Nations General Assembly 2016) The Atlas of the Human Planet 2017 focuses on the **exposure to natural hazards.** This Atlas addresses **changes over time in exposure of human settlements expressed as population and built-up surface)** to six natural hazard types (earthquakes, tsunamis, volcanic eruptions, floods, tropical cyclone winds, and tropical cyclone storm surge).

VULNERABILITY

The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. (United Nations General Assembly 2016) With a growing population and urbanizing area, also exposure is expected to increase. With growing exposure, also risk is likely to increase unless vulnerabilities are reduced. Despite the fact that vulnerability is widely discussed, it is not measured globally, mostly because of the lack of global and reliable data. The measurement of vulnerability represents the next global challenge in terms of disaster risk assessment. This element of the risk assessment is not discuss in this report.

HAZARD AREAS



Hazard maps are produced using probabilistic methods based on different return periods. These hazard layers illustrate the probabilistic model and represent the probability that a hazardous event will occur in the future in a given geographical area.

PROBABILISTIC HAZARD MODEL all potential hazardous events within the return period

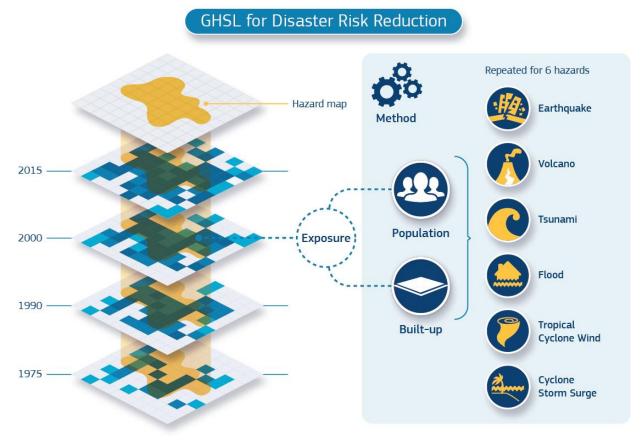
RETURN PERIOD

Average frequency with which a particular event is expected to occur (UNISDR 2015) Disaster probability and related potentially affected area depend on a time frame considered and are usually provided for several return periods, according to the nature of the hazard and the selected probabilistic model.

The approach applied in the case of the Atlas 2017 was to use only one return period for each hazard. This simplification allows focusing the analysis on the increment of exposure in relation to urbanisation processes that come with the increment of global population, improving of living conditions, economy and changes in lifestyle, as well as migrations to cities. This approach has been chosen to make a call to the international arena for addressing the consequences of increasing exposure as currently occurs with the other part of the "risk equation", intensity of the hazard, increment of the events and vulnerability.

Given that climate change might have a significant effect on the frequency and severity of some hazards (IPCC 2012), such as future flood events, more variables should be considered in multi-return-period analysis (Jongman, Ward, and Aerts 2012). In this analysis we did not include disaster risk reduction strategies or defences that countries could or have put in place (such as the Netherlands for flood, i.e.). Also coping capacity, *is the ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters*³, was not considered in the study.

³ https://www.unisdr.org/we/inform/terminology#letter-c



2.4 Methodology and input data

Image 1 Method applied to calculate exposure to natural hazards

The analysis of the exposure in this Atlas benefits from the global hazard data produced by different research teams for purposes of global hazard and risk analysis. GHSL data on built-up surface and population have been combined with geospatial datasets on natural hazards commonly used at international level or developed at the JRC. The methodology adopted for the Atlas 2017 prescribes to overlay hazard maps for a selected return period with population grids (GHS-POP) and built-up layer (GHS-BU) in order to derive the total population living in the hazard zone and the total built-up surface potentially exposed to the specific hazard. This method has been repeated both for population and built-up surface for the four GHSL available epochs (1975-1990-2000-2015)4.

The hazard zones are obtained from the best available hazard maps for the specific hazard type⁵ (see Table 1). For each hazard, the input hazard maps with descriptive information are detailed in the technical annexes (see annex).

Data for the **seismic hazard elaborated for the GAR 2013** (UNISDR 2013) at global level are presented for the four levels of risk, derived from the Modified Mercalli Intensity Scale (MMI). The 475 year RP used in this analysis is prescribed by the national building codes in Europe for standard buildings ("Eurocode 8: Seismic Design of Buildings Worked Examples" 2012, 7). Besides, it is the most common standard used in the insurance industry for assessing seismic risk, and it is also the basis for most building codes for seismic design.

⁴ GHSL data area free and open. The whole collection is available for download: <u>http://data.jrc.ec.europa.eu/collection/GHSL</u>

⁵ The input hazard maps for each hazard with relative technical information is illustrated at the end of each paragraph (for the technical details, see 0).

JRC elaborated the hazard map for volcano by creating a buffer zone of 100km around the 220 volcanoes included in the NOAA database⁶. This analysis does not include underwater volcanoes that mainly cause tsunami, that have been studied separately.

For the analysis of exposure to **tsunamis**, the GAR dataset has been used with 500 year RP: this RP has been considered a common standard, and even though the GAR 2015 has been produced for more RPs, it has been highlighted that longer return periods imply more uncertainties and limitations, since the model includes estimations on infrequently occurring tsunami causing earthquakes, lacking of reliable long records (UNISDR 2014).

The JRC elaborated a high-resolution global hazard map for **floods**, called Global Flood Awareness System (GloFAS) that has been used for measuring exposure to this hazard⁷. 100 year RP selected to analysis this hazard is the RP used for the preparation of the flood hazard and flood risk maps, set forth in Article 6 of the European Flood Directive (European Parliament and the Council of

the European Union 2007, para. 7).

Results for tropical cyclone wind provide information on two levels of hazard: the lowest correspond to strong winds up to 177 km\h (SS1-2), the highest refers to extreme strong winds greater than 178 km\h (SS3-5). To measure the exposure to tropical cyclone storm surge, JRC has elaborated the hazard map by using different input data, as illustrated in the technical annex. For both cyclone hazards 250 year return period has been used. Higher return periods (500 and 1000 year), covering the maximum potential exposure as people and buildings, were available for cyclones. However, the definition of the areas exposed would become more uncertain, due to the extrapolation error in fitting the extreme value distribution to such high return periods.

Table 1 Synthesis of the input hazard maps and selected return period

Hazard	Source	Return period	
Earthquake	GAR13	475 years	
Volcano	JRC (baseline: NOAA Significant Volcanic Eruption Database)		
Tsunami	GAR15	500 years	
Flood	JRC - GloFAS	100 years	
Tropical Cyclone Wind	GAR15	250 years	
Tropical Cyclone Storm Surge	JRC (baseline: GAR15)	250 years	

Box 3 GAR15 - Global Assessment Report 2015

The 2015 Global Assessment Report on Disaster Risk Reduction (GAR15) is the fourth in the series coordinated by the United Nations Office for Disaster Risk Reduction (UNISDR) in the context of the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters (HFA). The HFA is an international framework adopted by 168 UN member States in Kobe, Japan in January 2005 to achieve an expected outcome of the substantial reduction of disaster losses, in lives and in the social, economic and environmental assets of communities and societies. Every biennium governments have self-assessed their progress towards the achievement of this outcome using the online HFA Monitor. In 2007 UNISDR published Disaster Risk Reduction: Global Review 2007, which assessed progress in the first two years of the HFA. Shortly afterwards, work began on the first edition in the GAR series, which has compiled and analysed data and information on disaster risk patterns and trends, government self-assessments of progress, and critical challenges to disaster risk reduction since 2009. Source: https://www.unisdr.org/we/inform/gar

⁶ https://www.ngdc.noaa.gov/hazard/volcano.shtml

⁷ http://globalfloods.jrc.ec.europa.eu

3. EXPOSURE TO NATURAL HAZARDS

This chapter analyses the change in exposure to six different hazards of one return period each in the past 40 years (1975-1990-2000-2015).

The analysis is carried out by hazard for one return period for different geographical scales at global, regional⁸, and country level. It takes into account only a single return period per each hazard in order to focus the attention on the change in exposure.

The selected return periods and the data sources are reported in the annexes.

In the following paragraphs, every natural hazard is briefly introduced and the key elements of the input data are presented For each hazard, a global outlook of exposure is introduced both for population and built-up surfaces. Then a regional breakdown is presented, to identify which regions of the world are more prone to a specific hazard. For some hazards, a breakdown by income group⁹ is also reported.

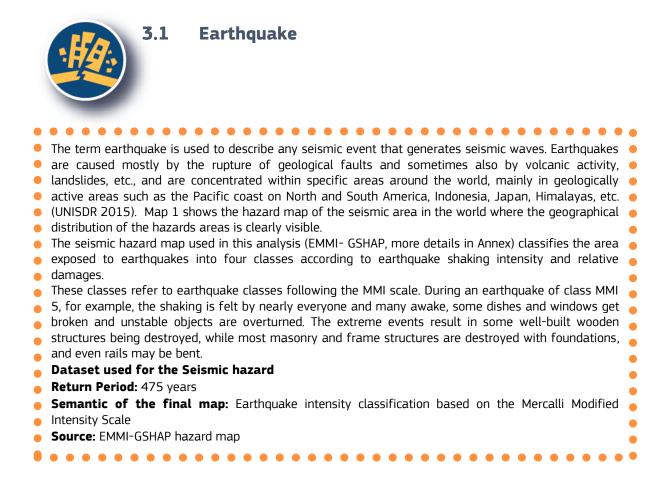
A specific level of income could be used as input to estimate the vulnerability: economic capacity of a community is in fact one of the components to be considered in vulnerability evaluation.

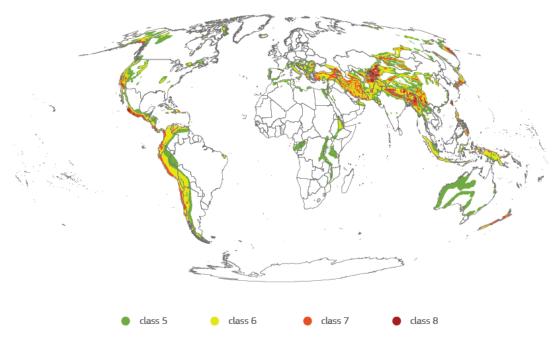
Finally, two lists are illustrated and commented: the first is the list of top ten countries ranked by the number of people potentially exposed to that specific hazard in 2015; the second is the list of top ten countries with the highest amount of builtup surface potentially exposed in 2015

⁸ For the regional grouping see Geographical classification

⁹ For the income grouping see Income







Map 1 Earthquake Hazards Map – Classes defined for the analysis

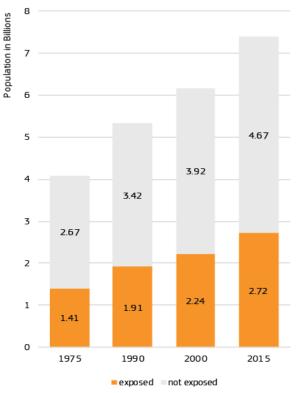


Figure 1 Global population potentially exposed to seismic hazard of class from 5 to 8, 475 years RP (1975-1990-2000-2015)

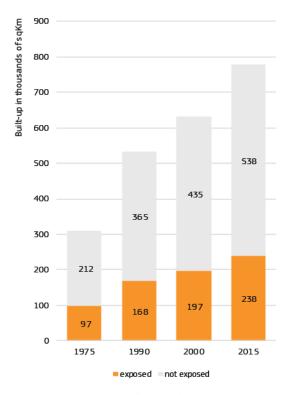


Figure 2 Global Built-up potentially exposed to seismic hazard of class from 5 to 8, 475 years RP (1975-1990-2000-2015)

The population potentially exposed to earthquakes has increased from 1.4 to 2.7 billion in the last 40 years (increment of 93%) (Figure 1), considering 475 years RP and any earthquake of class five or higher, i.e., from moderate to extreme event (see annex). In 2015, the total number of people living in hazard areas in 145 countries was 37% of the global population, concentrated in Asia, Pacific Islands, Middle East Asia, and Eastern Europe and on the western part of the If the population potentially Americas (Map 1). exposed to earthquakes doubled in the last 40 years, the built-up surface increased by 145% during the same period, from 97,000 to 238,000 km², corresponding to 31% of the global built-up surface (Figure 2).

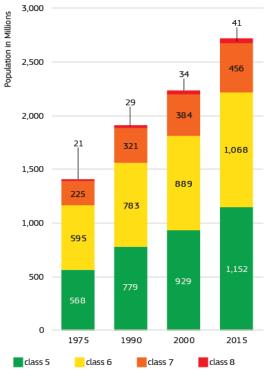


Figure 4 Population potentially exposed to seismic hazard by hazard class, 475 years RP (1975-1990-2000-2015)

Figure 4 illustrates the distribution of potentially exposed population living in the different class of hazard areas over time (475 years RP). Half billion people, one fourth of the potentially exposed population in 2015, lives in areas falling within the most dangerous classes (class 7 and 8).

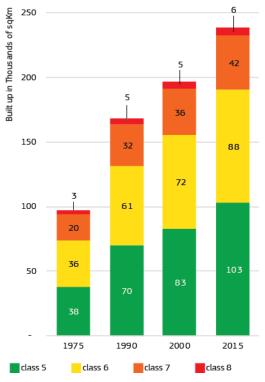
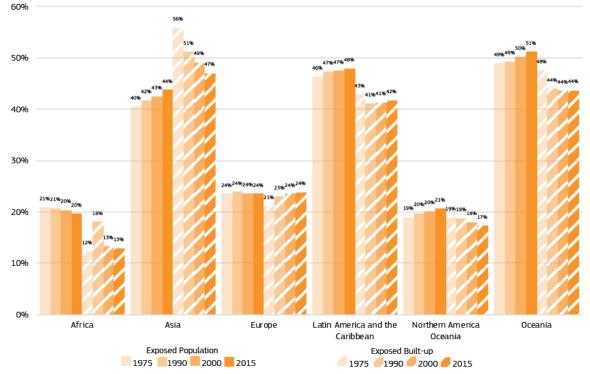


Figure 3 Built-up potentially exposed to seismic hazard by hazard class, 475 years RP (1975-1990-2000-2015)

A similar proportion can be found also in the share of built-up surface exposed, about 48,000 km² of the 230,000 km² potentially exposed to earthquake are in hazard zones falling within class 7 and 8 (Figure 3). The amount of built-up surface in hazard zones has more than doubled in the last 40 years, similarly to the exposed population.



Elever C. Change of Deputation a	and Duilt un natantially	a supported the second particular business in a	475 DD (1075 1000 2000	2015
Figure 5 Share of Population a	ina Built-up potentially	exposed to earthquake by region,	4/5 years RP (19/5-1990-2000	-2015)

Table 2 Population and Built-u	o surface potential	ly exposed to earthquake by region,	475 years RP (1975-1990-2000-2015)
--------------------------------	---------------------	-------------------------------------	------------------------------------

		Africa	Asia	Europe	Latin America and the Caribbean	Northern America	Oceania	N\A	total
r (S	1975	86,684,308	955,772,881	159,251,310	151,012,600	45,885,420	10,478,829	205,129	1,409,290,477
sed atio tant	1900	130,835,883	1,328,541,996	172,206,826	211,507,247	55,277,532	13,265,922	270,280	1,911,905,686
Exposed Population (inhabitants)	2000	165,500,872	1,569,470,634	171,767,285	250,151,172	62,948,799	15,558,069	334,362	2,235,731,194
	2015	233,325,052	1,912,205,773	173,475,388	304,362,164	73,971,099	20,080,067	408,209	2,717,827,753
נ <u>ז</u>	1975	2,794	44,464	19,360	12,511	14,758	3,400	18	97,306
Sed (Km)	1900	6,212	81,652	34,739	18,391	22,588	4,721	4	168,308
Exposed Built-up face (Km	2000	7,877	96,600	39,885	21,734	25,099	5,240	73	196,508
	2015	11,102	121,814	46,257	25,167	27,895	5,888	83	238,207

The region with the highest number of people exposed to earthquake in 2015 is Asia. 1.9 billion Asians live in seismic areas, increasing from 40% of the regional population in 1975 to 44% in 2015. In the same period, the share of built-up surface exposed decreased from 56% to 47%, but the total amount has increased of about 3 times (Table 2). Latin America and the Caribbean is the one with the highest share of population potentially exposed to this hazard: In 2015, 300 million people are seismic hazard (Table 2). exposed to corresponding to 48% of the regional population (Figure 5). While the exposed population and

built-up surface doubled in the last 40 years in terms of absolute values in Latin America and the Caribbean, the share of exposed population increased while the share of exposed built-up surface has been slightly decreasing. **Exposure to earthquake in Africa is decreasing in relative terms and increased in absolute number faster than in other regions.** In Africa, the share of exposed population and built-up surfaces exposed to earthquakes decreased between 1975 and 2015, but in the absolute terms they have increased by a factor of 4 during the same period (Table 2).



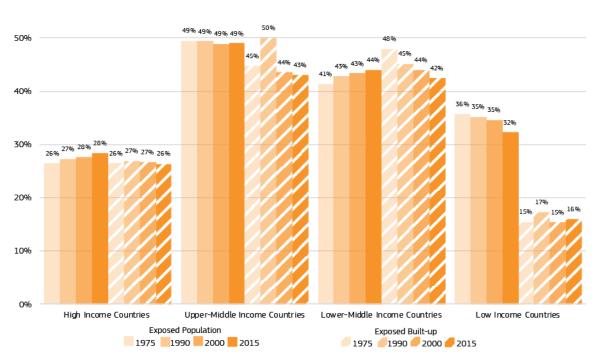


Figure 6 Share of Population and Built-up potentially exposed to earthquake by income group, 475 years RP (1975-1990-2000-2015)

Table 3 Population and Built-up :	surface potentially exposed to earth	nquake by income group, 475 years F	(1975-1990-2000-2015)

	Year	High Income Countries	Upper-Middle Income Countries	Lower- Middle Income Countries	Low Income Countries	Not Assigned	Total
т 5	1975	511,753,475	256,092,584	468,871,721	148,794,043	23,778,654	1,409,290,477
ati		629,022,532	351,983,759	684,864,929	216,320,685	29,713,781	1,911,905,686
Exposed Population	2000	690,050,716	403,786,543	833,336,178	275,858,974	32,698,783	2,235,731,194
" 2		771,467,002	483,103,954	1,056,255,081	370,695,235	36,306,481	2,717,827,753
p sed	1975	56,227	18,097	17,374	1,810	3,799	97,306
2 7 Y ~		94,915	33,251	31,534	3,718	4,889	168,308
n2Exp Built- surfa (Km	2000	108,639	39,355	37,807	4,976	5,731	196,508
Ĕ B s		128,173	47,385	48,098	8,106	6,445	238,207

Figure 6 shows potentially population and built-up surface exposed to earthquake by income groups over time (475 years RP). Exposed population increased in countries of all groups in the last 40 years. The one billion of people that live in hazard areas in Low Income Countries (LMC) representing 42% of the total population living in those countries (Figure 6). In Upper-Middle Income Countries (UMC) 43% of population is also living in hazards areas corresponding to almost half billion of people (Table 3). In Low Income Countries, the share of population potentially exposed over the total population is slightly decreasing in the last forty years (Figure 6). The built-up surface potentially exposed to earthquake in High Income Countries (128.000 km² in 2015), has more than doubled between 1975 and 2016 (Table 3), and its share increased from 26% to

28% in the same period (Figure 6). In the last forty years, the built-up surface potentially exposed increased by 128%, while the population increased by 51%. Looking at the share of built-up surface potentially exposed over total built-up surface, it can be observed that in Upper-Middle and Lower Middle Income Countries this share is significantly higher than in High Income Countries (42-43% and 26% in 2015). In fact, in UMCs and LMCs built-up surface in hazard areas are similar, about 47.000 km² and they increased in the last forty years respectively by 162% and 177%. Despite the fact that the amount of built-up surface potentially exposed in Low Income Countries is relatively small (8.000 km² and about 16% of the total in 2015), it is important to highlight that it increased by 348% in the last forty years.

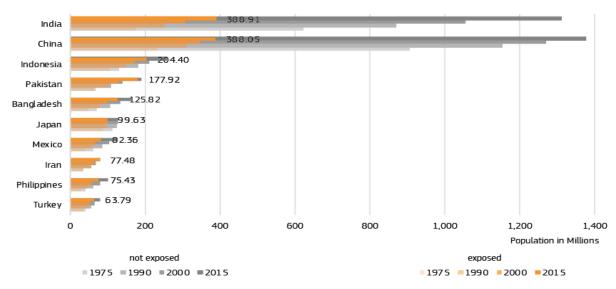


Figure 7 Ten countries with the highest number of people potentially exposed to seismic hazard in 2015, compared to total population, 475 years RP (1975-1990-2000-2015)

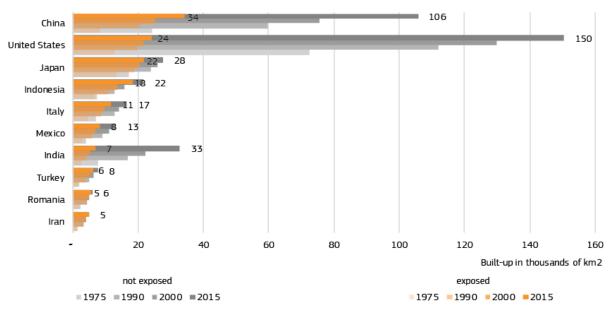


Figure 8 Ten countries with the highest amount of built-up potentially exposed to seismic hazard in 2015, compared to total built-up, 475 years RP (1975-1990-2000-2015)

In Figure 7, the 10 countries with the highest number of people living in hazard areas in 2015 are ranked by exposed population. **India and China have both more than 380 million of people potentially exposed to earthquakes** (475 years RP); Indonesia has more than 200 million people in the same condition, Pakistan and Bangladesh, and Japan follow in the ranking with more than 100 million each. Apart from India and China, all other countries in this ranking have more than 2/3 of the country population potentially exposed to earthquake hazard. In the case of Pakistan and Iran, this share is more than 95%. All of those countries are in Asia, apart from Mexico. Only China and Japan are High Income Countries (HIC)¹⁰. In Figure 8 the 10 countries with the highest amount of built-up surface potentially exposed to seismic hazard are ranked. Only three of them are HIC, while the others are LMC or UMC. In this top ten list, two European countries appear: Italy and Romania with respectively 84% and 92% of built-up surfaces in hazard zones. **Turkey, Romania, and Iran have very high share of exposed population over total population in all four periods having with most of the land mapped in the hazard areas.**

¹⁰ See Income Grouping pg.91

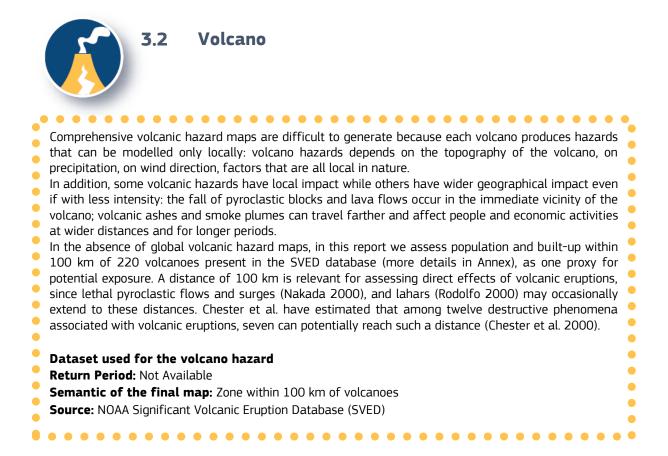
32

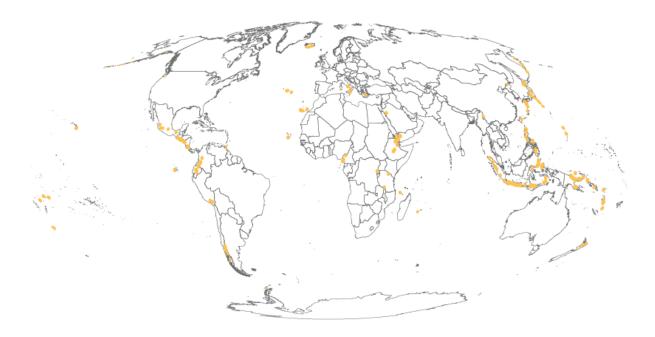
RUTA DE EVACUACIÓN

1)(((

/olcano

Ometepec, Nicaragua, 2014





Location of the active volcanos considered in the analysis

Map 2 Exposure analysis within 100 km radial distance from the 220 volcanoes included in the study

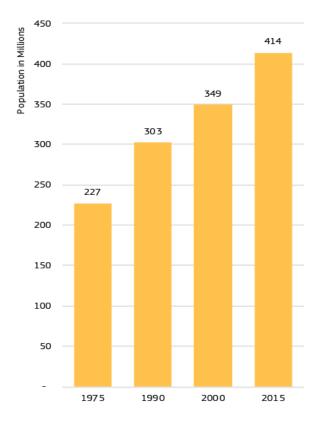


Figure 9 Population within 100 km of volcanoes (1975-1990-2000-2015)

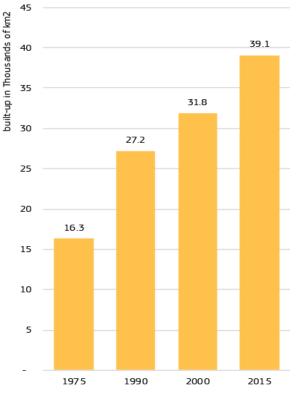


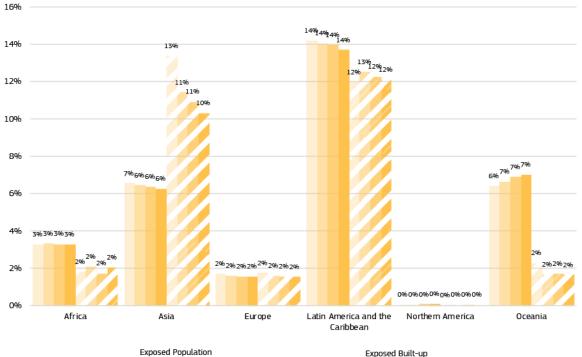
Figure 10 Area of built-up within 100 km of volcanoes (1975-1990-2000-2015)

Figure 9 shows evolution of total population within a range of 100 km from the 220 volcanoes in the SVED database (see Annexes). According to these results, **the proportion of the global population living within 100 km has remained relatively stable from 1975 to 2015 (at around 5.5%), although absolute values have increased by 82% in this period to a total 414 million people**, following the rate of global population growth (Table 4). This translates into additional 186 million potentially exposed since 1975.

Figure 10 shows evolution of **total area of builtup surface within 100 km of the 220 volcanoes in the SVED database**. According to these results, the amount of built-up surface in proximity of these volcanoes has been considerably increasing, reaching 39,000 km² in 2015. This represents an **increase of 139% since 1975** and of 23% between 2000 and 2015. However, increase rates were significantly higher from 1975 to 1990 (4.4% mean annual growth) compared to later periods (1.7 and 1.5% in 1990-2000 and 2000-2015 respectively). Still this increase has been in line with global increase in built-up surface in these periods, keeping the proportion of the global builtup surface potentially exposed stable at around 5%.

Table 4 Population	and	Built-up	surface	potentially	exposed	to	volcano
hazard (1975-1990-	200)-2015)					

	Exposed Population Share of exposed population over total		Exposed Built-up surface (km²)	Share of exposed Built-up surface over total	
1975	227,483,973	5.6%	16,312	5.3%	
1990	302,524,355	5.7%	27,167	5.1%	
2000	348,945,818	5.7%	31,837	5.0%	
2015	413,616,012	5.6%	39,063	5.0%	
increment 1975- 2015	82%		139%		



Exposed Population

1975 1990 2000 2015

Figure 11 Share of Built-up and Population potentially exposed to volcano hazards by region (1975-1990-2000-2015)

		Africa	Asia	Europe	Latin America and the Caribbean	Northern America	Oceania
- 5	1975	13,620,897	154,429,010	11,475,989	46,186,646	108,518	1,372,174
Exposed Population	1990	20,930,719	205,011,711	11,551,298	62,712,143	152,654	1,782,165
opul	2000	26,820,637	234,452,573	11,371,037	73,519,785	192,383	2,136,493
	2015	38,754,783	273,066,505	11,571,822	86,686,733	259,073	2,752,380
12	1975	412	10,623	1,592	3,485	13	162
bsed t-up e (kn	1990	714	18,200	2,407	5,594	47	177
Expo Buil face	2000	1,016	21,441	2,640	6,441	62	205
<u>.</u>	2015	1.758	26.716	2,969	7.290	75	221

1975 41990 42000 42015

Table 5 Built-up surface and Population potentially exposed to volcano hazards by region (1975-1990-2000-2015)

Figure 11 and Table 5 show the evolution over time of total population and built-up surface within 100 km of the 220 volcanoes in the SVED database, by continental region. Results show that Asia concentrates most of the potentially exposed population, in all epochs, followed by Latin America and the Caribbean which is the region with the highest share of exposed over total population. Those are also the regions with the highest share of built-up surface potentially exposed in all four epochs analysed.

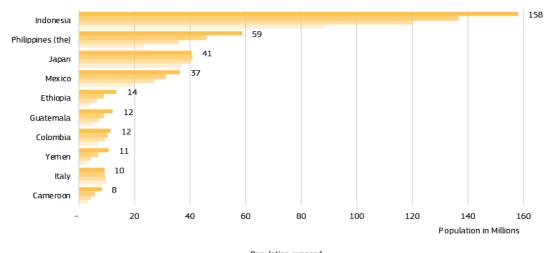
In 2015, these two regions the share of global exposure compared to their share of global population are significantly different (namely 66%)

exposed vs 59% of global population and 21% exposed vs 9% of global population, respectively). Potential exposure of people is much lower in other regions, but still amounting to 38.7 million in Africa and 11.5 million in Europe in 2015.

Concerning the temporal trends, potential exposure for both built-up surface and population has not increased since 1975 in Europe (about 2%), whereas it has increased significantly in the other regions, especially in Africa and Northern America. From 1975 to 2015, potential exposed population almost tripled in Africa (+185%) to 38.7 million and in Northern America, where it more than doubled, although totalling only 259,000 in 2015. Results in Figure 11 and Table 5 also highlight the concentration in **Asia of most of the potentially exposed built-up surface**, in all epochs, followed by Latin America and the Caribbean, and Europe. In 2015 these two former regions still present a share of global exposure significantly different from their share of global built-up surface (namely 68% vs 33% and 19% vs 8%, respectively).

Potential exposure of built-up surface is much lower in other regions, and lower than their share of global built-up surface. This mismatch is especially significant in Europe, which in 2015 concentrates only 8% of global exposure while accounting for 25% of all built-up surface. There are also significant regional differences regarding the global share of exposure of built-up surface respect to population. While in Africa this share is much lower for builtup surface than for population (4% vs 9% in 2015), in Europe the opposite situation occurs, with exposure of built-up surfaces being much higher than population's (8% vs 3% in 2015).

Regarding the temporal trends, potential exposure of built-up surface has grown substantially in all regions except Oceania (37%), and above population exposure. Greatest increases were observed in Northern America (472%) and Africa (327%). In Europe the significant growth in exposed built-up surface occurring in all periods (overall rise of 86%) contrasts with unchanging population exposure between 1975 and 2015.



Population exposed
1975 = 1990 = 2000 = 2015

Figure 12 Ten countries with the highest number of people potentially exposed to volcano hazards (1975-1990-2000-2015)

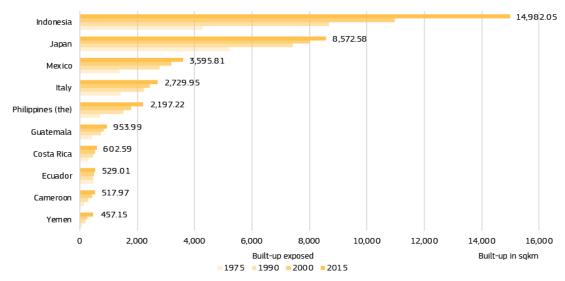


Figure 13 Ten countries with the highest amount of built-up potentially exposed to volcano hazards (1975-1990-2000-2015)

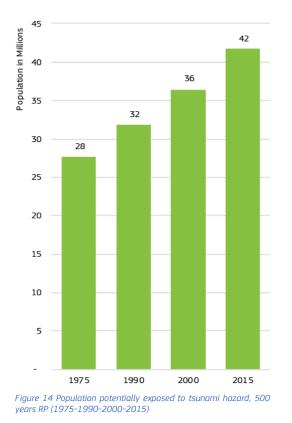
Figure 12 shows evolution of total population within a range of 100 km from the 220 volcanoes in the SVED database for the 10 countries with the overall highest exposure. These 10 countries have been accounting for 88% of the globally exposed population since 1975, or 361 million in 2015. Results show that the three countries with highest overall potential exposure are located in Asia, followed by countries in Latin America and Africa. Indonesia clearly leads the ranking, with 38% of the globally exposed population in 2015. Currently, Indonesia and the Philippines account for 52% of total exposed world population (217 million). In Europe, Italy has by far the highest potential exposure, with close to 10 million people. Concerning the temporal trends, potential exposure has not had the same behaviour in all countries due to differing population growth rates and tendencies. While exposure in Italy and Japan have decreased from 2000 to 2015 (in Italy also in all other epochs), in all other countries highlighted in Figure 12 it has increased significantly. In Yemen and Ethiopia, it has increased by more than 50% between 1975 and 1990 and between 2000 and 2015.

Figure 13 depicts the evolution of total area of built-up surface within 100 km of the 220 volcanoes in the SVED database, for the ten countries with the overall highest such exposure. These 10 countries have been accounting for about 90% of the globally exposed built-up surface since 1975, or 35 thousand km² in 2015 (out of 39 thousand). Results show that the rank of potentially exposed built-up surface is different from that regarding population (Figure 12). **Two Asian countries, Indonesia and Japan, clearly lead the built-up surface ranking and together comprise about 60% of the global exposure**. Japan and Italy concentrate a much larger share of global exposed built-up surface respect to population, while Philippines is in the opposite situation (6% vs 14% in 2015). Indonesia has been leading the ranking since 1990, whereas in 1975 it was led by Japan (with 32% of globally exposed built-up surface). Italy has the highest potential exposure in Europe, but changes regarding built-up surface and population are decoupled: while population exposure has been decreasing since 1975, built-up surface exposure has continued to increase, by significant rates (12% in period 2000-2015). In last 40 years, potentially exposed built-up surface has been increasing significantly in all countries considered, and it has grown above population growth (143% vs 80%).





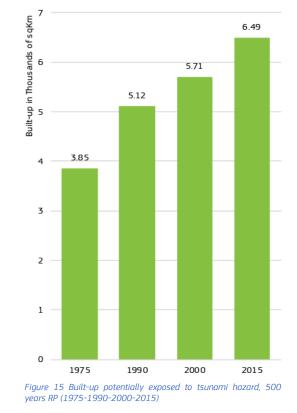
Tsunamis are waves set in motion by large and sudden forced displacements of the characteristics intermediate between tides and swell waves. Although tsunamis are i 10 events reported globally pr. year), they do represent a serious threat to the coase many areas. (UNISDR 2015)	nfrequent (ca. 5-
The frequency of tsunamis is linked to seismic activity, and areas historically affected is the ring of fire of the Pacific Rim both in Asia and in the Americas and Indonesia, Mediterranean costs have been hit by tsunamis in past times. As coastline is a prefe and to conduct human activities and tsunamis mainly hit coastal zones, this haza impact on global exposure, especially with growing world population and built-up s areas. For the purpose of this report, the hazard map for tsunami produced for the last Gl	even though also erred place to live and as a relevant urface in coastal
 Report on Disaster Risk Reduction with the 500 years return period has been used. Dataset used for the Tsunami hazard Return Period: 500 years Semantic of the final map: Area flooded by tsunami run-up Source: Tsunami Run-up hazard map (GAR 2015) 	



In 2015, 116 countries in the world have area exposed to tsunami hazard. According to the analysis done combining GHSL data and hazard maps, **in 2015 42 million people were potentially exposed to this natural hazard**, considering a 500 year return period. In 1975, there were 28 million, meaning that the global exposed population has increased by 51% in forty years (Figure 14).

Built-up surface potentially exposed to tsunami had increased more rapidly than population, by 68% between 1975 and 2015. In 1975, 3,850 square kilometres of built-up surfaces were exposed in the world. In 2015, this value reached 6,490 square kilometres (Figure 15).

EXPOSURE TO NATURAL HAZARDS



	EXPOSED POPULATION (inhabitants)					EXPOSED BUILT-UP SURFACE (km2)			
	1975	1990	2000	2015	1975	1990	2000	2015	
Africa	106,752	132,164	181,980	266,534	12	24	32	37	
Asia	25,499,171	29,143,289	33,302,269	37,920,629	3,321	4,396	4,893	5,541	
Europe	357,834	348,098	351,052	345,568	55	88	100	110	
Latin America and the Caribbean	1,354,945	1,894,868	2,257,014	2,737,349	148	192	225	264	
Northern America	214,982	249,646	276,136	311,798	299	395	436	508	
Oceania	65,119	74,943	85,522	107,124	16	21	24	28	
N\A	118	265	586	118	0.2	1	1	2	
TOTAL	27,598,921	31,843,274	36,454,560	41,689,119	3,851	5,116	5,711	6,488	

Table 6 Population and built-up surface exposed to tsunami hazard by region, 500 years RP (1975-1990-2000-2015)

Table 6 shows the trends of population and builtup surface potentially exposed to tsunami by region between 1975 and 2015. The region with the highest number of people potentially exposed is Asia (37.99 million), followed by Latin America and the Caribbean (2.77 million). Concerning temporal changes, exposed population has been especially increasing in Asia (from 26 million to almost 38 million) in Latin America and the Caribbean (from 1.3 to 2.7 million). This figure also shows that Asia is the most exposed region in terms of built-up surface assets (5.540 km² in 2015), followed by Northern America (500 km²) or 7.82% share over total built-up surface, while the share of population potentially exposed to tsunami in 2015 (500 years RP) was 0.75%.

Figure 16 illustrates the regional distribution of exposure to tsunamis in 2015. Asia concentrates almost 91% of the world's exposed population, with Africa, Europe, and Northern America representing less than 1% of total each. Differences emerge when comparing the shares of built-up surface and population. Only 0.75% of the world population exposed to tsunamis live in Northern America¹¹, but 7.82% of the total built-up surface exposed to the same hazard is located in the that region. Significant differences can be highlighted also in Europe (0.83% vs 1.69) and in Oceania (0.26% vs 0.43%). The opposite case is represented by Latin America and the Caribbean where the share of built-up surface exposed is lower than the share of exposed population (6.57% vs 4.07%).

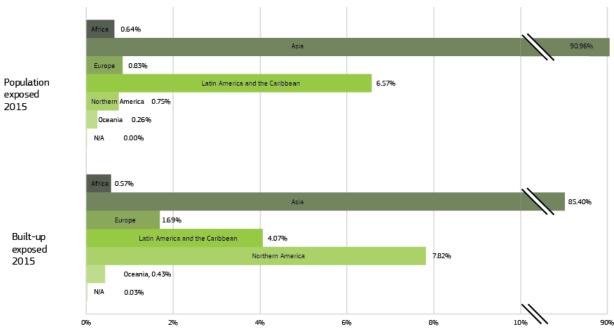
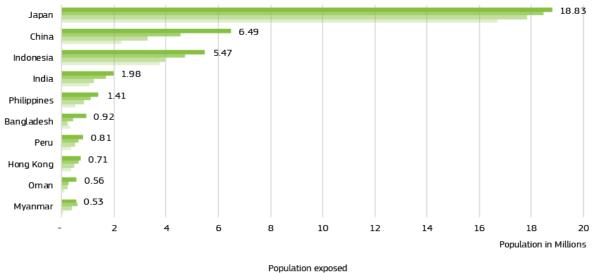


Figure 16 Share of Population and built-up exposed to tsunami hazard by region, 500 years RP (2015)

¹¹ Note than in this regional grouping, Northern America includes the United States and Canada.



Population exposed = 1975 = 1990 = 2000 = 2015

Figure 17 Ten countries with the highest number of people potentially exposed to tsunami hazard in 2015, 500 years RP (1975-1990-2000-2015)

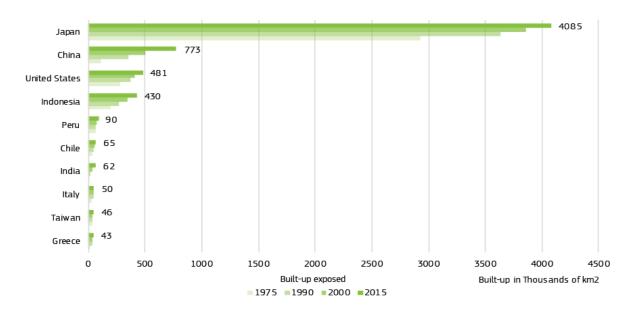


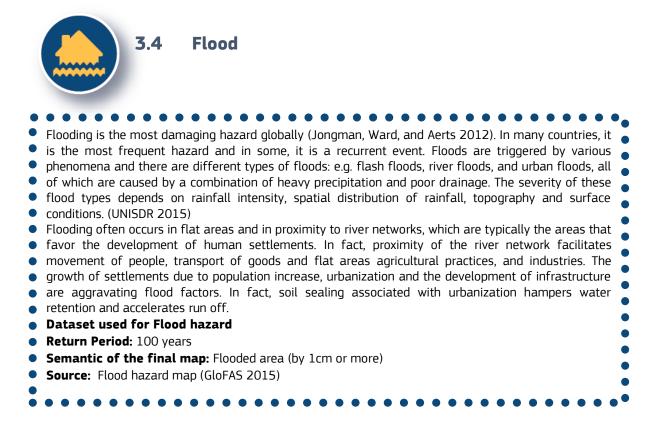
Figure 18 Ten countries with the highest built-up area potentially exposed to tsunami hazard in 2015, 500 years RP (1975-1990-2000-2015)

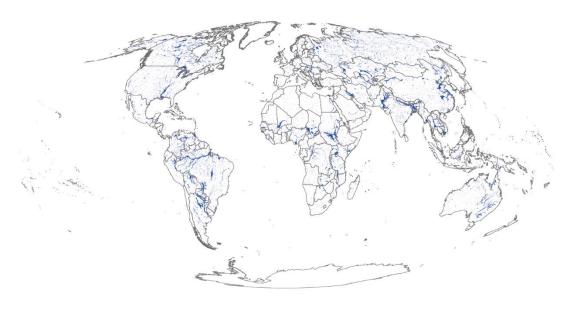
According to data obtained combined the GHSL and the hazard map, **Japan is the country with the highest number of people potentially exposed to tsunami in 2015** for 500 years RP (Figure 17). The exposed population increased from about 16 million in 1975 to almost 19 million in 2015.

Having experienced a big increment in population in coastal areas in the last decades, **China has** seen also the number of population exposed to tsunami become bigger, from 2 to 6.5 **million**. Peru is the only non-Asian country in the top 10 of the most exposed countries, among them Indonesia, India, Philippines, Bangladesh, Hong Kong, Oman and Myanmar. Japan, along with China and Indonesia concentrate 74% of the total population exposed. However, Japan is a major exposure hotspot for tsunamis, concentrating 45% of global exposure in 2015. This share has been decreasing since 1975 when it was accounting for 61% of global exposure.

Figure 18 shows the ten countries with the highest amount of built-up surface potentially exposed to tsunami with 500 years RP. These ten countries account for 94% of global built-up surface exposure in 2015, and this share has been only slightly decreasing since 1975 (when it was amounting to 96%). The figure also shows that Japan has by far the highest amount of built-up surface exposed in 2015 (4,000 km² of built-up surface), or 63% of total global **exposure**, followed by China. Together these two countries concentrate 75% of the total global exposure. The United States of America, which were not included in the top ten by population, are third with 7% of total. Two European countries appear in this rank, Italy and Greece (50 and 42 thousand square kilometres respectively). This happens because these countries have a significant amount of built-up surfaces potentially exposed to tsunami, but these areas have lower population densities than those of other countries in Figure 17. Exposure has been increasing in all countries from 1975 to 2015, with highest rates observed in India, China, and Indonesia.







Areas exposed to floods

Map 3 Global map of the areas exposed to flood

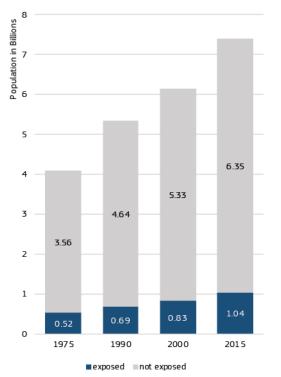


Figure 19 Population potentially exposed to flood hazard, 100 years RP (1975-1990-2000-2015)

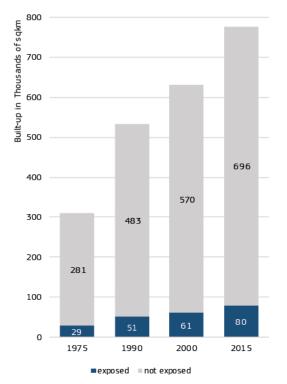
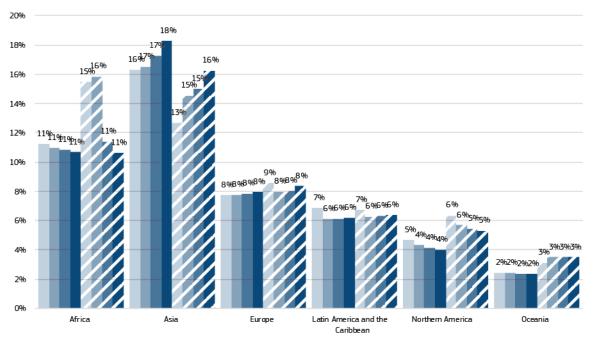


Figure 20 Built-up potentially exposed to flood hazard, 100 years RP (1975-1990-2000-2015)

More than 1 billion people globally were potentially exposed to a hundred year RP floods in 2015. That is more than 14% of the global population. The figure doubled compared to 1975 (Figure 19). In the same period, the area of built-up surface potentially exposed to a hundred year flood almost triplicated from 28,677 km² to 80,483 km² (Figure 20). Similar differences in growth rate of population and built-up surface are also observed at global level. In the last forty years the population increased by a factor of 1.8, while the built-up surface increased by a factor of 2.5 (Martino Pesaresi, Melchiorri, et al. 2016, 35). However, with factors of 2 for population and 2.8 for the built-up surface the increase is stronger in potentially exposed areas.

Although significantly less people are potentially exposed to a hundred year RP floods compared to earthquakes [see 3.1], exposure to this hazard is significantly relevant because flooding is the most frequent natural disaster. According to the CRED/EMDAT/UNISDR report '*The human cost of weather related disasters*', between 1995-2015 floods were by far the most occurring disaster with 43% (CRED and UNISDR 2015).



Exposed Population 1975 1990 2000 2015 Exposed Built-up 1975 1990 2000 2015

Figure 21 Share of Built-up and Population potentially exposed to floods by region, 100 years RP (1975-1990-2000-2015) Table 6 Built-up surface and Population potentially exposed to floods by region, 100 years RP (1975-1990-2000-2015)

	Year	Africa	Asia	Europe	Latin America and the Caribbean	Northern America	Oceania
- 5	1975	46,809,067	384,765,697	52,299,761	22,320,393	11,285,911	524,067
Exposed Population	1990	69,325,866	525,072,781	55,884,148	27,333,928	12,085,131	654,176
pul	2000	88,143,275	637,094,193	56,927,008	32,360,381	12,972,284	722,268
- č	2015	126,566,129	797,601,275	58,693,079	39,188,090	14,286,300	913,088
ed up (Km²)	1975	3,514	10,072	7,884	1,962	4,951	223
	1990	5,457	23,222	12,069	2,807	6,843	375
Exposed Built-up surface (Ki	2000	6,747	29,496	13,601	3,332	7,609	419
sul	2015	9,135	42,123	16,224	3,843	8,556	470

In 2015, people in potentially exposed areas were living in 155 countries (out of 251). Although these areas are distributed in all continents (Map 3), **flood exposed areas potentially affect people in Asia and Africa more than other continents** (Table 6). The regional distribution of potentially exposed population and built-up surface shows significant differences. The majority of the population potentially exposed to floods, almost 800 million people, live in Asian countries, followed by Africa with 126 million. Figure 21 illustrates the different share of built-up surface and population potentially exposed to floods by region over time. In Asia 18% of the population in exposed, as well of 16% of the built-up surface (both shares increased since 1975). The other regions have smaller share of exposed population. Table 6 illustrated also the built-up surface exposed over time. **Asia is still the region with the highest amount of built-up surface potentially exposed to floods** in 2015 (42,120 km² corresponding to 16% of the total built-up surface), followed by Europe (16,220 km²) and by Africa (9,140 km²). In all regions, these values have been increasing between 1975 and 2015, mostly in Asia with an increase of 4.2 times more than the global average).

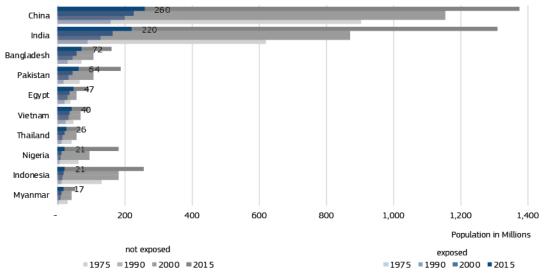


Figure 22 Ten countries with the highest number of people potentially exposed to floods in 2015, compared to total population, 100 years RP (1975-1990-2000-2015)

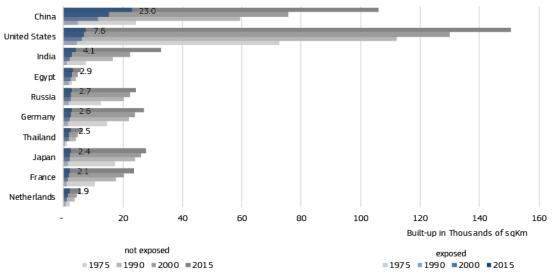


Figure 23 Ten countries with the highest amount of built-up potentially exposed to floods in 2015, compared to total built-up, 100 years RP (1975-1990-2000-2015)

Figure 22 illustrates the ten countries with the highest number of people exposed to floods in 2015, compared to total population over time. China has the highest number of people exposed to floods. 260 million (19% of the country population), followed by India with 220 million (16.8%), and by the Bangladesh with 71 million (44.6%). In 2015, sixteen countries had more than one quarter of the population exposed to floods. Of these countries only the Netherlands is in High Income Countries; Suriname, Turkmenistan, Irag, and Thailand are Upper-Middle Income Countries; Egypt, Pakistan, and Vietnam are Lower-Middle Income Countries; Bangladesh, Cambodia, Chad, Laos, Myanmar, South Sudan, Sudan are Low Income and Less

Developed countries¹². In countries such as Pakistan, Thailand and Nigeria the increment of population in hazard areas is bigger than the increment of the national population (242% against 183% in Pakistan, 140% against 61% in Thailand, and 239% against 187% in Nigeria), suggesting that population is increasing more in coastal and riverside areas, typically more exposed to flood hazard.

In Figure 23 the ten countries with the highest amount of built-up surface potentially exposed to floods in 2015 are ranked, compared to total builtup surface over time. **China is by far the**

¹² French Guiana is not listed under any income group but it has 33.2% of the 2015 population potentially exposed to flood.

country with the highest amount of built-up surface exposed to floods in 2015 (23,000 of km²), followed by the United States with 7,600 km² (not included in the list of the countries with the highest number of people exposed) **and by India with 4,100** km². In all the countries included in this list, the built-up surface exposed to floods increased in the last 40 years. In China and Thailand, the exposed built-up surface has increased by factors of 5 and 4 respectively between 1975 and 2015.

Figure 24 shows the EU countries with more than 50,000 people potentially exposed to floods ranked by exposed population in 2015. Germany is the EU country with the highest number of people exposed to floods, about 8 million (10% of the national population), followed by France with 5.7 million (9%).

The Netherlands, third in this ranking, has an exposed population of 5.3 million that is one third of the national population. In this country, the exposed population increased to 44% between 1975 and 2015, while the national population increased to 13% (Table 7). In the same period, in Italy the exposed population increased by 28%. compared to national population increment of 5% only. In Hungary and Romania, while the national population decreased between 1975 and 2015, the exposed population has been increasing. In some EU countries, such as Italy, Poland, United Kingdom, Slovakia, and Greece, while national populations register slight increment between 1975 and 2015, figures indicates that the population exposed to floods is increasing significantly from 20 to 44% (Table 7). Countries as Hungary, Austria, Slovakia, and Latvia register high shares of population exposed over the total population in 2015, between 15% and 19%.

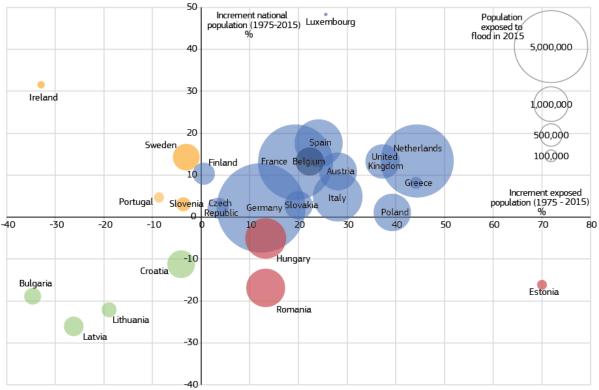


Figure 24 EU countries with more than 50,000 people potentially exposed to flood in 2015, 100 years RP (1975-1990-2000-2015)

Country	Population exposed to floods (2015)	National population (2015)	Increment of exposed population between 1975 and 2015	Increment of national population between 1975 and 2015	Share of exposed population over national population (2015)
Germany	8,012,900	80,746,785	12%	2%	10%
France	5,727,264	64,378,728	19%	13%	9%
Netherlands	5,396,798	16,908,820	44%	13%	32%
Italy	2,477,981	59,762,191	28%	5%	4%
Spain	2,312,117	46,085,657	24%	18%	5%
Hungary	1,666,455	9,855,867	13%	-5%	17%
Romania	1,495,473	19,514,874	13%	-17%	8%
Austria	1,445,487	8,541,414	28%	11%	17%
Poland	1,422,384	38,591,013	39%	1%	4%
United Kingdom	1,190,047	64,662,475	37%	13%	2%
Belgium	798,834	11,300,151	22%	13%	7%
Slovakia	790,427	5,426,123	20%	3%	15%
Croatia	750,374	4,237,095	-4%	-11%	18%
Sweden	717,462	9,756,555	-3%	14%	7%
Finland	478,649	5,446,337	1%	10%	9%
Czech Republic	439,759	10,544,758	3%	2%	4%
Latvia	379,525	1,969,769	-26%	-26%	19%
Bulgaria	282,390	7,123,263	-35%	-19%	4%
Lithuania	221,022	2,878,296	-19%	-22%	8%
Slovenia	191,166	2,067,334	-4%	3%	9%
Greece	145,006	10,946,801	44%	8%	1%
Portugal	101,591	10,354,470	-9%	5%	1%
Ireland	52,450	4,691,951	-33%	32%	1%
Luxembourg	8,548	566,219	26%	48%	2%

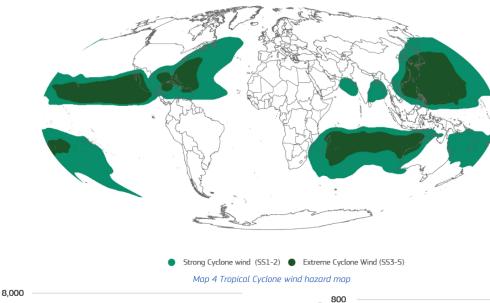
Table 7 Comparison between national and population exposed to floods in EU countries, 100 years RP (ranked by exposed population in 2015)

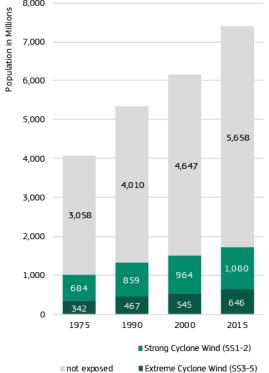
Tropical Cylcone Wind

Australia, 2016



Tropical cyclones are unevenly spread around the globe as their development depends on specific • climatic and oceanic conditions. A tropical cyclone has multiple impacts on the affected areas, including: extremely powerful winds; torrential rains leading to floods and/or landslides; high waves and damaging storm surge, leading to extensive coastal flooding. The complexity of the multiple forms of impact triggered by tropical cyclones would call for integrated modelling of wind, rain, storm surge and landslides. However, given the limited time available for the present study, priority was given to modelling the winds and storm surge. (UNISDR 2015) Tropical cyclones form with a combination of oceanic and atmospheric processes. The processes include warm sea surface temperature, vortices at tropical latitudes induced by Earth's rotation, rising air converted over a large area, and high air pressure. A wide range of scientific evidences points to an increase of frequency and intensity of cyclone occurrence due to the climate change (IPPC 2007). Cyclones damages are caused by heavy rain fall, strong winds and sea level surge. Despite the fact that heavy rains can cause landslides and flooding, the most damaging effect of cyclone hazard are wind and storm surge. Exposure to tropical cyclone wind is illustrated in this paragraph, storm in the following one (3.6). In order to analyse exposure to cyclone wind, the Saffir-Simpson Hurricane Wind Scale used in the GAR 2015 has been adopted. The Saffir-Simpson (SS) Hurricane Wind Scale is a 1 to 5 rating based on a hurricane's sustained wind speed. This scale estimates potential property damage. Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and damage. For the purpose of this analysis, the cyclone wind hazard is presented in two categories: SS1-2 and SS3-5 from the Saffir-Simpson Scale. Strong Cyclone Wind (category SS1-2) are very dangerous. They reach up to 177 km/h and produce some damage: for example, well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters; large branches of trees will snap and shallowly rooted trees may be toppled; extensive damage to power lines and poles likely will result in power outages that could last a few to several days. Extreme Cyclone Winds (category SS3-5) exceed 178 km/h and cause devastating damage: well-built framed homes may incur major damage or removal of roof decking and gable ends; many trees will be snapped or uprooted, blocking numerous roads; electricity and water will be unavailable for several days to weeks after the storm passes. Above category SS3-5 the damage is catastrophic leaving most of the impacted area uninhabitable for weeks or months. Dataset used to Tropical Cyclone wind Hazard Return Period: 250 years **Semantic of the final map:** Area affected by cyclone wind of Saffir-Simpson category 1 or higher Source: Cyclone wind hazard map (GAR 2015)







The global trend of population potentially exposed to tropical cyclone wind is shown in Figure 25. This hazard threats 89 countries in the world, of which 45 are exposed to also the devastating hurricanes (both SS1-2 and SS3-5). **Both, the total population potentially exposed to categories SS1-2 and to categories SS3-5** increased in the last 40 years: from 1 billion in 1975 up to 1.6 billion in 2015 (one billion in class SS1-2 and 640 million in SS3-5), which represents about the 24% of the world population.

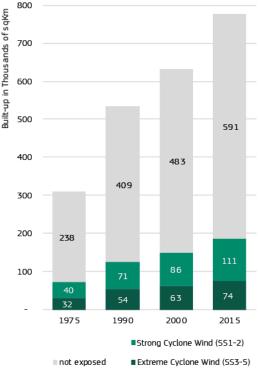


Figure 26 Built-up potentially exposed to Tropical cyclone wind, compared to total, 250 years RP (1975-1990-2000-2015)

In Figure 26 the global trend of **built-up surface potentially exposed to tropical cyclone wind** is presented. Both built-up surface potentially exposed to categories SS1-2 and to categories SS3-5 increased in the last 40 years, from 72.000 km² in 1975 to 185.000 km² which represents about the 24% of the global built-up surface stock. The built-up surface in SS3-5 increased from 32.000 to 74.000 km² (increment 131% from 1975 to 2015), while built-up surface in SS1-2 increased from 40.000 in 1975 to 111.000 km²in 2015 with an **increment of 177% in the last 40 years**.

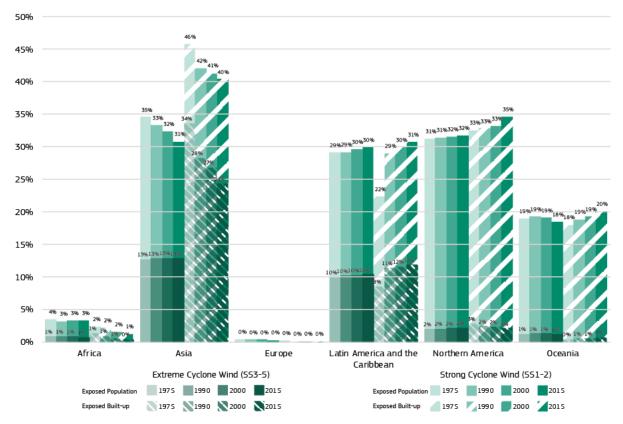


Figure 27 Share of Built-up and Population potentially exposed to tropical cyclone wind SS1 and SS3 by region, 250 years RP (1975-1990-2000-2015)

	1 5	Africa	Asia	Europe	Latin America and the Caribbean	Northern America	Oceania	N\A				
			Strong Tropical Cyclone Wind									
_ =	1975	14,697,187	816,648,698	2,819,200	94,964,371	75,779,017	4,059,133	16,278,945				
atio	1990	20,338,839	1,059,183,769	2,911,723	130,479,067	88,148,763	5,184,770	20,200,422				
Exposed Population	2000	26,996,934	1,194,974,452	2,721,071	155,794,498	98,859,034	5,932,066	22,846,971				
" č	2015	39,858,377	1,348,043,284	2,404,450	189,893,623	113,644,071	7,258,941	25,171,005				
" "	1975	552	36,486	195	6,512	25,418	1,288	1,148				
Exposed Built-up surface (km²)	1990	760	67,264	264	12,959	39,545	2,019	1,504				
Expo Built face	2000	916	81,257	280	15,721	46,308	2,317	1,639				
n ns	2015	1,102	104,722	308	18,557	55,851	2,715	1,852				
			-	Extrem	ne Tropical Cyclone W	/ind	_	_				
_ =	1975	3,683,521	300,394,511	-	32,628,663	4,755,179	262,213	10,740				
atio	1990	5,286,904	410,024,651	-	45,698,450	5,817,091	348,744	23,252,080				
Exposed Population	2000	6,888,062	476,215,615	-	54,396,343	6,677,242	410,111	24,877,828				
	2015	9,535,065	562,215,490	-	66,166,353	7,773,321	444,251	30,432				
n²)	1975	306	26,803	-	2,479	2,184	33	3				
sed t-up e (kr	1990	332	45,195	-	5,108	2,951	58	7				
Exposed Built-up surface (km²)	2000	338	52,784	-	6,107	3,222	70	10				
- ns	2015	379	63,090	-	7,146	3,419	102	15				

Table 8 Built-up surface and Population potentially exposed to tropical cyclone wind SS1 and SS3 by region, 250 years RP (1975-1990-2000-2015)

The majority of people potentially exposed to tropical cyclone winds lives in Asia (1.3 billion in 2015) which is by far the most potentially exposed region. More than half billion of people is potentially exposed to tropical cyclone wind of categories SS3-5 (Table 8). The second most exposed region is Latin America and the Caribbean in which the population potentially exposed to tropical cyclone wind increased from 95 million to 190 million between 1975 and 2015. While population potentially exposed to tropical cyclone winds in Asia is evident from the previous figure, a great amount of built-up potentially exposed to this hazard is also located in other regions. Figure 27 also provides a similar regional distribution for the built-up surface potentially exposed to tropical cyclone wind of categories SS1-2 and categories SS3-5. Asia is by far the region with the highest amount of built-up surface potentially exposed to both classes, while Northern America has a very high amount of built-up surface exposed but mostly in categories SS1-2.

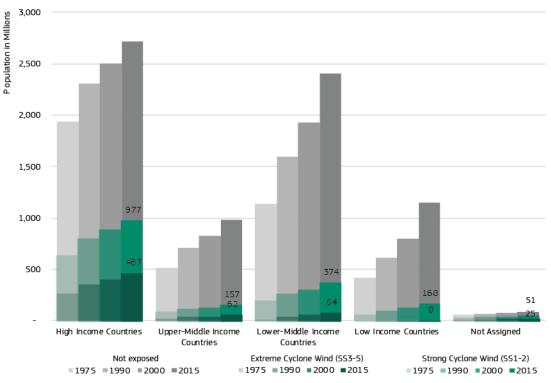


Figure 28 Population potentially exposed to tropical cyclone winds SS1 and SS3 by income group, compared to total population, 250 years RP (1975-1990-2000-2015)

In Figure 28 population potentially exposed to tropical cyclone wind by income groups is reported for the four analysed epochs. Also in this case, trends show that in both categories SS1-2 and categories SS3-5 the population is increasing. The group of high-income countries (which includes USA, China, Japan, and Australia, among

others) is the one with the highest number and share of population exposed, almost one billion in 2015, representing 36% of the total population of the same group. In the other groups, the share of exposed population over total population is around 15%.

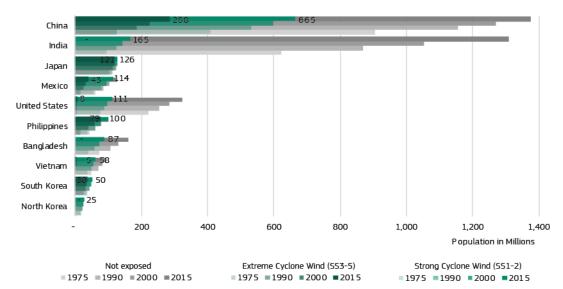


Figure 30 Ten countries with the highest number of people potentially exposed to tropical cyclone winds SS1 in 2015, compared to total population, 250 years RP (1975-1990-2000-2015)

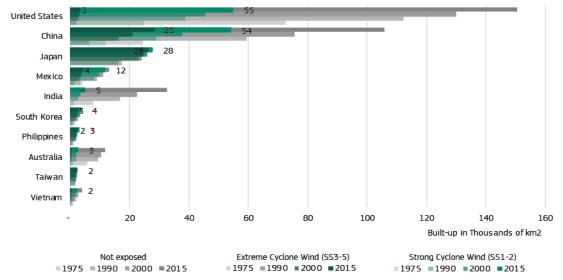


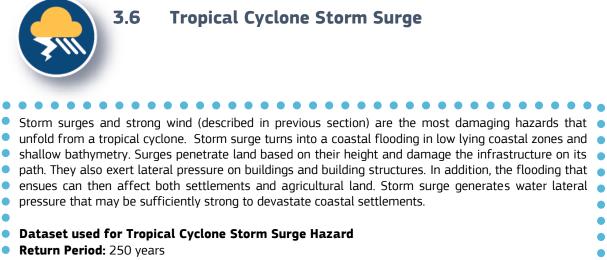
Figure 29 Ten countries with the highest amount of built-up potentially exposed to tropical cyclone winds SS1 in 2015, compared to total built-up, 250 years RP (1975-1990-2000-2015)

Figure 30 reports the 10 countries with the highest number of population potentially exposed to tropical cyclone wind of class SS1 and SS3 in 2015 compared with the total population of the country. The ranking shows that China is in first position both for SS1 and SS3, followed by India for SS3 and Japan, in which 95% of population is exposed to tropical cyclone winds in class SS3 and the remaining 5% only to SS1. Also in the Philippines almost all population is potentially exposed to tropical cyclone wind (99%) of which 79% to the most dangerous class of hazard. All population of North Korea is potentially exposed to SS1, while in South Korea 75% of the population is exposed to tropical cyclone wind SS1 and 25% at SS3. Almost half of

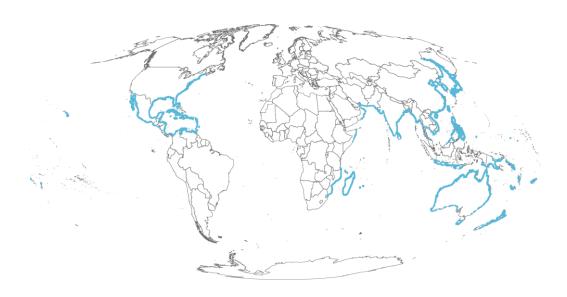
Chinese population (664 million) and more than one third of the Mexican population (113 million) live in hazard areas of class SS1. In the same countries, 287 million and 42 million are potentially exposed to class SS3. Figure 29 reports the ten countries with the highest amount of built-up surface potentially exposed to class SS1 and SS3 in 2015 compared to the total builtup surface. The United States of America are the country with the highest amount in SS1, 55.000 km² corresponding to 37% of the total built-up surface, but China and Japan are the ones with the highest amount of built-up surface in class SS3 (28.000 km^2 and 26.000 km^2 respectively). In Japan, in fact 95% of the built-up surface is in hazard areas of class SS3 and only 5% only in class SS1.

Tropical Cyclone Storm Surge

Havana,, Cuba, 2016



- **Semantic of the final map:** Inundated area (area affected by storm surge)
- **Source:** Storm Surge hazard map (GAR 2015)



Tropical Cyclone Storm Surge Hazard Map (elaborated by JRC)

Map 5 Tropical Cyclone Storm Surge hazard map

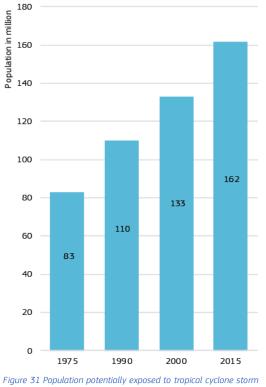


Figure 31 Population potentially exposed to tropical cyclone storm surge, 250 years RP (1975-1990-2000-2015)

In 2015, 162 million of people in the world were exposed to tropical cyclone storm surge in 79 countries (Figure 31). **The population potentially exposed to tropical cyclone storm surge doubled in the last forty year,** it was 83 million in 1975.

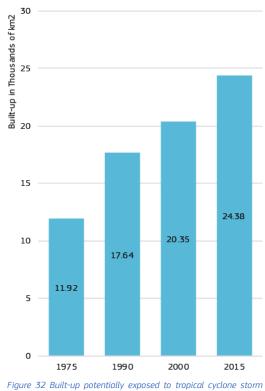


Figure 32 Built-up potentially exposed to tropical cyclone storm surge, 250 years RP (1975-1990-2000-2015)

The built-up surface in hazard areas also increased with by 104% with respect to 1975, (from 12 to 24 thousand km²) (Figure 32). Both these figures, as all the ones contained in this paragraphs, have been produced considering a 250 year return period.

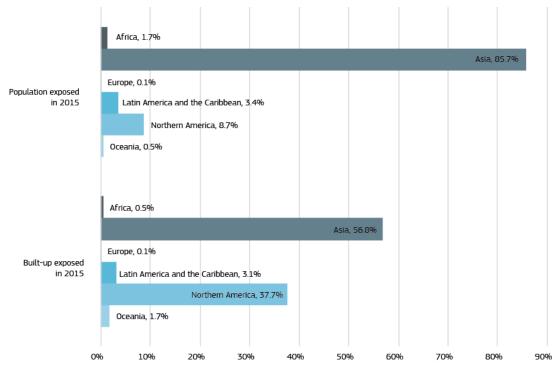


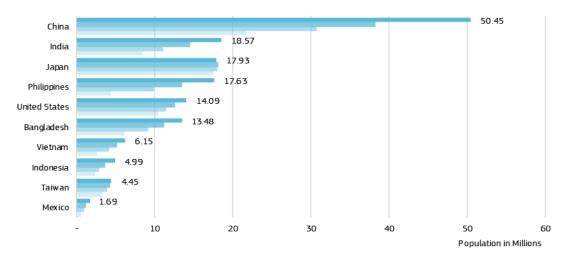
Figure 33 Share of Population and built-up surface exposed to tropical cyclone storm surge by region over total exposed population and builtup surface, 250 years RP (2015)

Table 9 Population and built-up surface exposed to tropical cyclone storm surge by region over time, 250 years RP (1975-1900-200-2015)

		Africa	Asia	Europe	Latin America and the Caribbean	Northern America	Oceania	N\A	Total
	1975	879,180	68,247,894	92,330	2,550,298	10,415,126	395,336	186,243	82,766,407
Population	1990	1,120,275	93,203,252	101,334	3,368,884	11,445,015	495,678	4,999,277	114,733,716
exposed	2000	1,548,971	113,359,870	96,018	4,409,197	12,564,833	588,383	5,322,027	137,889,300
	2015	2,231,988	138,764,515	93,490	5,540,910	14,092,042	756,330	353,438	161,832,715
Built-up	1975	28	6,116	8	377	5,193	177	19	11,918
surface	1990	61	9,463	11	545	7,237	296	539	18,153
exposed	2000	103	11,112	12	659	8,086	352	641	20,964
(km²)	2015	121	13,859	15	752	9,185	419	33	24,382

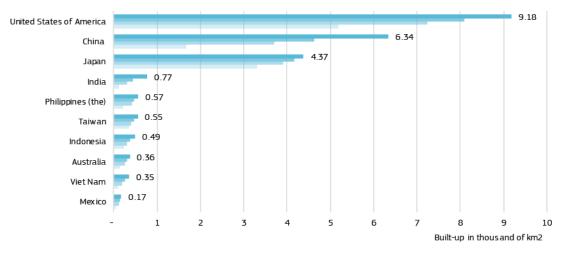
Figure 33 illustrates the geographical distribution of people and built-up surface potentially exposed to tropical cyclone storm surge in 2015. Asia is by far the region with the highest number of people potentially exposed to tropical cyclone storm surge: **almost 86% of the total exposed world population live in Asia (139 million), and 8.7% in Northern America (14 million).** The exposed population in Asia increased in the last forty years of 70 million, doubling between 1975 and 2015 (Table 9). The geographic distribution of the built-up surface potentially exposed to tropical cyclone storm surge is significantly different from the one of the population. Almost 14,000 km² of built-up surface exposed are in Asia and more than 9,000 km² in Northern America¹³. In fact, **despite the relatively small share of exposed population living in Northern America, almost 38% of the share of global built-up surface potentially exposed to tropical cyclone storm surge (250 year RP) is located in this region**.

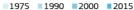
¹³ Please note that Asia includes 51 countries; Northern America includes Canada and the United States of America (see Geographical classification)



1975 1990 2000 2015

Figure 34 Ten countries with the highest number of people potentially exposed to cyclone surge in 2015, 250 years RP (1975-1990-2000-2015)







China is by far the country with the highest number of people potentially exposed to cyclone storm surge (Figure 34). **50 million of Chinese live in coastal areas prone to tropical cyclone storm surge**. Their number increased by 1.5 times in the last forty years. This is not surprising if we consider the growth of Chinese population since 1975 and the urbanization rate in this country (88.2% in 2015). India, Japan and the Philippines have similar population potentially exposed (about 18 million each), followed by the United States and Bangladesh (13-14 million). In Figure 35, the ten countries with the highest amount of built-up surface potentially exposed to tropical cyclone storm surge in 2015 are ranked and the increment over time of this value is reported. The United States of America have the highest amount (9,000 km²), followed by China and Japan (6,000 and 4,000 respectively in 2015). The other countries have all less than 1,000 km² of built-up surface potentially exposed (India, the Philippines, Taiwan, Indonesia, Australia, Vietnam and Mexico). All countries report an increment of built-up surface in the last forty years: in 2015 in China it is four times the amount of 1975.

4. CONCLUSIONS

Population growth, urbanization, and socioeconomic development drive the evolution of exposure, and have been the primary factor of disaster losses in recent decades (GFDRR 2016). The effect of exposure on increasing disaster losses is strong, and has been established with much more confidence than the effect of hazard and vulnerability (Visser, Petersen, and Ligtvoet 2014). In order to achieve the goal set by the Sendai Framework to avoid the construction of "new risk" and reducing the existing one (UNISDR 2015c), global multi-temporal analysis of exposure is essential for a better understanding of the spatial and temporal patterns of disaster risk drivers and for identifying effective policy actions for more resilient communities.

This Atlas sheds light on the spatiotemporal changes in exposure to natural hazards in the last four decades. The analysis is based on datasets produced for the whole globe from a single data source – remote sensing data – with a consistent methodology that enables a systematic quantification of exposure and its changes over time.

The findings presented in the Atlas were in part expected and anticipated by other global analysis, such as the GAR (UNISDR 2013, 2015b), or the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2014), among others. However, some new aspects of exposure of human settlements to natural hazards were unveiled through the analysis of the Global Human Settlements data in combination with maps of natural hazards with a worldwide coverage:

- In built-up surface and population increased in all regions and results show that the increase of exposure is in line with the
- Global exposure, both for population and built-up surface, has doubled for all hazards between 1975 and 2015.
- Flood, the most frequent natural disaster, potentially affects more people in Asia (76.9% of the global population exposed) and Africa (12.2%) than in other regions.

- Tropical cyclone winds threaten 89 countries in the world and the population exposed to cyclones increased from 1 billion in 1975 up to 1.6 billion in 2015.
- The country most at risk to Tsunamis is Japan whose population is potentially 4 times more exposed than the second potentially affected country.
- Sea level surge affects the countries across the tropical region and China has the largest increase of population over the last four decades.

The value of the GHSL layers used to generate the figures in this Atlas is that the data are available at fine scale and with a wall-to-wall coverage. Researchers and policy makers are now able to aggregate exposure information at all geographical scales of analysis from the city level to the region, continent and global. As start, this Atlas produces new information on exposure to natural disaster at country level only. We also provide continental aggregations and a grouping of countries according to the economic classification of the UN statistical Division. However, disaster risk practitioners and scientist can generate statistics also at local or regional level to assess exposure to natural hazards. In order fully exploit the potential of the resolution of the GSHL, institutions involved in disaster risk reduction are invited to produce hazard maps at local scale.

The present study is a first attempt to quantify global exposure and it can be improved in a number of ways. First, exposure is calculated for each hazard separately and based on one single return period. We relied on the available open hazard data for this. The return periods are different for each hazard and that prevented us to generate a multi-hazard exposure map. Secondly, the Atlas 2017 focuses on two variables only, population and built-up surface. Other exposed assets including agricultural land, infrastructure, pasture land, water resources, and ecosystem services should be included in future analysis. Other emerging hazards such as slow onset disasters (droughts, desertification, etc.) might as well be included.

The exposure information illustrated in the Atlas 2017 reports on built-up surface and population. This information should eventually be complemented with information on socioeconomic characteristics of population including group, fertility, and built-up surface age characteristics such as infrastructure typologies, building taxonomy, structural characteristics, and replacement values. All those information would support a proper definition of the vulnerability of the assets at risk.

The measure of the built-up surface and population itself can be greatly improved. That improvement already started. The new GHSL Built-up surface layers that will be available in 2018 are computed using Sentinel-1 and Sentinel-2 data, which improve the resolution of the product. In addition, the provision of open data such as Sentinel data allows generating continuous update of the GHSL baseline data. The new GHSL datasets will allow improving the capacity to measure exposure also at local level. Researchers and policy makers may thus take advantage to generated exposure and risk analysis at the geographical scale they are operating whether at local, regional, national, continent or global level.

5. REFERENCES

- Alfieri, L., B. Bisselink, F. Dottori, G. Naumann, A. de Roo, P. Salamon, K. Wyser, and L. Feyen. 2017. "Global Projections of River Flood Risk in a Warmer World." *Earth's Future*, no. 5: 171–82. doi:10.1002/2016EF000485.
- Bouziani, Mourad, Kalifa Goïta, and Dong-Chen He. 2010. "Automatic Change Detection of Buildings in Urban Environment from Very High Spatial Resolution Images Using Existing Geodatabase and Prior Knowledge." *ISPRS Journal of Photogrammetry and Remote Sensing* 65 (1): 143–153.
- Chester, David K., Martin Degg, Angus M. Duncan, and J. E. Guest. 2000. "The Increasing Exposure of Cities to the Effects of Volcanic Eruptions: A Global Survey." *Global Environmental Change Part B: Environmental Hazards* 2 (3): 89–103.
- CIMNE, and INGENIAR Ltda. 2015. "Update on the Probabilistic Modelling of Natural Risks at Global Level: Global Risk Model - UNISDR." https://www.unisdr.org/we/inform/publications/49730.
- CRED and UNISDR. 2015. "The Cost of Weather Related Disasters 1995-2015." Centre for Research on the Epidemiology of Disasters Institute of Health and Society and UNISDR. http://cred.be/sites/default/files/HCWRD_2015.pdf.
- De Groeve, Tom, Luca Vernaccini, and Karmen Poljansek. 2015. "Index for Risk Management INFORM. Concept and Methodology Version 2016." EUR - Scientific and Technical Research Reports. Publications Office of the European Union. JRC98090. http://publications.jrc.ec.europa.eu/repository/handle/11111111/38453.
- Deichmann, U, D Ehrlich, C Small, and G Zeug. 2011. Using High Resolution Satellite Data for the Identification of Urban Natural Disaster Risk.
- Dell'Acqua, F., P. Gamba, and K. Jaiswal. 2013. "Spatial Aspects of Building and Population Exposure Data and Their Implications for Global Earthquake Exposure Modeling." *Natural Hazards* 68 (3): 1291–1309.
- Dottori, Francesco, Peter Salamon, Alessandra Bianchi, Lorenzo Alfieri, Feyera Aga Hirpa, and Luc Feyen. 2016. "Development and Evaluation of a Framework for Global Flood Hazard Mapping." *Advances in Water Resources* 94: 87–102.
- Ehrlich, Daniele, and Patrizia Tenerelli. 2013. "Optical Satellite Imagery for Quantifying Spatio-Temporal Dimension of Physical Exposure in Disaster Risk Assessments." *Natural Hazards* 68 (3): 1271–1289.
- "Eurocode 8: Seismic Design of Buildings Worked Examples." 2012. EUR 25204 EN-2012. Luxembourg: Publications Office of the European Union.
- European Parliament and the Council of the European Union. 2007. *DIRECTIVE 2007/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2007 on the Assessment and Management of Flood Risks (Text with EEA Relevance)*. http://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=celex%3A32007L0060.
- Freire Sergio, MacManus, Kytt, Pesaresi, Martino, Doxsey-Whitfield, Erin, and Mills, Jane. 2016. "Development of New Open and Free Multi Temporal Global Population Grids at 250 M Resolution." In *Geospatial Data in a Changing World*. Helsinki, Finland.
- GFDRR. 2016. "The Making of a Riskier Future: How Our Decisions Are Shaping Future Disaster Risk." Washington, USA: Global Facility for Disaster Reduction and Recovery.
- Hoque, Mozzammel M.A., and Shan Alam M. Khan. 1997. "Storm Surge Flooding in Chittagong City and Associated Risks." In . Vol. 239. Anaheim, California: IAHS.
- IPCC. 2012. "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change." Cambridge, UK, and New York, NY, USA: Cambridge University Press.
- ———. 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Jarvis, A., H.I. Reuter, and E Guevara. 2008. "Hole-Filled SRTM for the Globe Version 4, Available from the CGIAR-CSI SRTM 90m Database (Http://srtm.csi.cgiar.org)."
- Jongman, Brenden, Philip J. Ward, and Jeroen C.J.H. Aerts. 2012. "Global Exposure to River and Coastal Flooding: Long Term Trends and Changes." *Global Environmental Change* 22 (4): 823–35. doi:10.1016/j.gloenvcha.2012.07.004.
- Nakada, Setsuya. 2000. "Hazards from Pyroclastic Flows and Surges." *Encyclopedia of Volcanoes, Editado Por Haraldur Sigurdsson*, 945–956.

- Pesaresi, M, Daniele Ehrlich, Stefano Ferri, Aneta J. Florczyk, Sergio Freire, Matina Halkia, Andreea Julea, Thomas Kemper, Pierre Soille, and Vasileios Syrris. 2016. "Operating Procedures for the Production of the Global Human Settlment Layer from Landsat Data of the Epochs 1975, 1990, 20000, and 2014." Joint Research Centre.
- Pesaresi, Martino, Daniele Ehrlich, Stefano Ferri, Aneta Florczyk, Sergio Freire, Matina Halkia, Andreea Julea, Thomas Kemper, Pierre Soille, and Vasileios Syrris. 2016. "Operating Procedure for the Production of the Global Human Settlement Layer from Landsat Data of the Epochs 1975, 1990, 2000, and 2014." JRC Technical Report EUR 27741 EN. Ispra, Italy: Publications Office of the European Union. http://publications.jrc.ec.europa.eu/repository/handle/JRC97705.
- Pesaresi, Martino, Guo Huadong, Xavier Blaes, Daniele Ehrlich, Stefano Ferri, Lionel Gueguen, Matina Halkia, et al. 2013. "A Global Human Settlement Layer From Optical HR/VHR RS Data: Concept and First Results." *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 6 (5): 2102–31. doi:10.1109/JSTARS.2013.2271445.
- Pesaresi, Martino, Michele Melchiorri, Alice Siragusa, and Thomas Kemper. 2016. "Atlas of the Human Planet 2016. Mapping Human Presence on Earth with the Global Human Settlement Layer." EUR 28116 EN. Luxembourg: Publications Office of the European Union.
- Potere, David, and Annemarie Schneider. 2007. "A Critical Look at Representations of Urban Areas in Global Maps." *GeoJournal* 69 (1–2): 55–80. doi:10.1007/s10708-007-9102-z.
- Preparatory Committee for the United Nations Conference on Housing and Sustainable Urban Development (Habitat III). 2016. "Policy Paper 6: Urban Spatial Strategies: Land Market and Segregation." A/CONF.226/PC.3/19.
- Rodolfo, Kelvin S. 2000. "The Hazard from Lahars and Jökulhlaups." *Encyclopedia of Volcanoes. Academic Press, San Diego*, 973–995.
- Schneider, Annemarie, Mark A. Friedl, and David Potere. 2010. "Mapping Global Urban Areas Using MODIS 500-M Data: New Methods and Datasets Based on 'urban Ecoregions." *Remote Sensing of Environment* 114 (8): 1733–46. doi:10.1016/j.rse.2010.03.003.
- Stevens, A. J., D. Clarke, R. J. Nicholls, and M. P. Wadey. 2015. "Estimating the Long-Term Historic Evolution of Exposure to Flooding of Coastal Populations." Natural Hazards and Earth System Sciences Discussions 3 (2): 1681–1715.
- UNISDR. 2013. "From Shared Risk to Shared Value –The Business Case for Disaster Risk Reduction. Global Assessment Report on Disaster Risk Reduction." Geneva, Switzerland: United Nations Office for Disaster Risk Reduction (UNISDR).
- ———. 2014. "Tsunami Methodology and Result Overview." Norwegian Geolotechnical Institute (NGI) and Geoscience Australia (GA).
- -----. 2015a. "Global Assessment Report 2015." Geneva: United Nations. http://www.preventionweb.net/english/hyogo/gar/2015/en/gar-pdf/GAR2015_EN.pdf.
- ———. 2015b. "Making Development Sustainable: The Future of Disaster Risk Management. Global Assessment Report on Disaster Risk Reduction." Geneva, Switzerland: United Nations Office for Disaster Risk Reduction (UNISDR).
- ———. 2015c. "Sendai Framework for Disaster Risk Reduction 2015-2030." United Nations International Strategy for Disaster Risk Reduction. http://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf.
- United Nations. 2015. "Sendai Framework for Disaster Risk Reduction 2015–2030. In: UN World Conference on Disaster Risk Reduction, 2015 March 14–18, Sendai, Japan. Geneva: United Nations Office for Disaster Risk Reduction; 2015. Available from: http://www.wcdrr.org/uploads/Sendai_Framework_for_Disaster_Risk_Reduction_2015-2030.pdf [Cited 2015 May 11]." http://www.wcdrr.org/uploads/Sendai_Framework_for_Disaster_Risk_Reduction_2015-2030.pdf [cited 2015 May 11].
- United Nations, General Assembly. 2015. "Transforming Our World: The 2030 Agenda for Sustainable Development." http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E.
- United Nations General Assembly. 2016. "Open-Ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction."
- Visser, Hans, Arthur C. Petersen, and Willem Ligtvoet. 2014. "On the Relation between Weather-Related Disaster Impacts, Vulnerability and Climate Change." *Climatic Change* 125 (3–4): 461–77. doi:10.1007/s10584-014-1179-z.
- Wald, David J., Vincent Quitoriano, Thomas H. Heaton, and Hiroo Kanamori. 1999. "Relationships between Peak Ground Acceleration, Peak Ground Velocity, and Modified Mercalli Intensity in California." *Earthquake Spectra* 15 (3): 557–564.

World Bank, GFDRR. 2014. "UNDERSTANDING RISK IN AN EVOLVING WORLD." http://wwwwds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2014/10/30/000470435_2014103 0131730/Rendered/PDF/921680PN0Box3800World0Policy0Note00.pdf.

6. ANNEXES

6.1 Methodology and input data

The potential human and physical exposure has been estimated per each hazard separately and then aggregated at country level. The human exposure is based on the estimated number of people exposed to given hazard. It results from the combination of the hazard zones and the total population living in the spatial unit. It thus indicates the expected number of people exposed in the hazard zone. Similarly, the physical exposure is based on the estimated total built-up surface exposed to given hazard. It results from the combination of the total built-up surface in the spatial unit. It thus indicates the expected number of people exposed to given hazard. It results from the combination of the hazard zones and the total built-up surface in the spatial unit. It thus indicates the expected number of built-up surface in the spatial unit. It thus indicates the expected number of built-up surface exposed in the hazard zone.

The dataset on hazard zones used in this work vary in data type and formats. Therefore, a common working grid has been selected. All analysis has been performed using a global grid at 250 m resolution in World Mollweide projection, which is one of the global area-equal projections.

6.1.1 Exposure data

The physical and human exposure has been analysed using built-up surface and population grids, respectively. The built-up surface density maps have been aggregated from a 38 x 38 m (approx.) multi-temporal classification of built-up surface presence (GHS_BUILT_LDSMT_GLOBE_R2015B) derived from four Landsat image collections. The population data (GHS_POP_GPW4_GLOBE_R2015A) have been produced by disaggregating census information into built-up surface maps respecting the targeted nominal temporal signature (Freire Sergio et al. 2016). The table below presents the technical details of the exposure maps used. The datasets are available in the working grid.

Exposure data	Dataset ID	Product ID	Resolution /	Temporal
Exposure auta	Dataset ID	Froduct ID	Projection	characteristic
Built-up surface	GHS_BUILT_LDS1975_GLOBE		250 m / World	1075
1975	_R2016A_54009_250_v1_0	GHS_BUILT_LDSMT_GLOBE_R2015B	Mollweide	1975
Population 1975	GHS_POP_GPW41975_GLOBE	GHS_POP_GPW4_GLOBE_R2015A	250 m / World	1975
Population 1975	_R2015A_54009_250_v1_0		Mollweide	1973
Built-up surface	GHS_BUILT_LDS1990_GLOBE	GHS_BUILT_LDSMT_GLOBE_R2015B	250 m / World	1990
1990	_R2016A_54009_250_v1_0		Mollweide	1990
Population 1990	GHS_POP_GPW41990_GLOBE	GHS POP GPW4 GLOBE R2015A	250 m / World	1990
	_R2015A_54009_250_v1_0		Mollweide	1550
Built-up surface	GHS_BUILT_LDS2000_GLOBE	GHS_BUILT_LDSMT_GLOBE_R2015B	250 m / World	2000
2000	_R2016A_54009_250_v1_0		Mollweide	2000
Population 2000	GHS_POP_GPW42000_GLOBE	GHS POP GPW4 GLOBE R2015A	250 m / World	2000
	_R2015A_54009_250_v1_0		Mollweide	2000
Built-up surface	GHS_BUILT_LDS2014_GLOBE		250 m / World	2014
2015	_R2016A_54009_250_v1_0	GHS_BUILT_LDSMT_GLOBE_R2015B	Mollweide	2014
Population 2015	GHS_POP_GPW42015_GLOBE	GHS POP GPW4 GLOBE R2015A	250 m / World	2015
ropulation 2015	_R2015A_54009_250_v1_0		Mollweide	2013

Table 10 The exposure grids used in this work.

6.1.2 Hazard data

One hazard map has been created per each natural hazard. For the purpose of the analysis, all maps have been produced as grids at 250 m in World Mollweide projection. Table below summarises the details of the hazard maps, and their production is explained in more details in this Annex.

Table 11 The natural hazard maps used in this work (RP: return period)

Natural Hazard	Dataset	Source	Data type	Selected RP
Earthquake	EMMI-GSHAP (multiclass)	GAR 2013	Raster, 11km (approx.) WGS-84	475 RP
Volcano	JRC-SVED	NOAA SVED, adapted byJRC	Vector (point), WGS-84	NA
Tsunami	Tsunamis Run-up	GAR 2015	Raster, 80 m (approx.) WGS-84	500 RP
Flood	Flood map	JRC GloFAS	Raster, 1 km (approx.) WGS-84	100 RP
Cyclone Wind	Wind JRC-GAR, wind category (multiclass) GAR 2015, adapted by JR		Raster, 1 km (approx.) WGS-84	250 RP
Cyclone Storm Surge	JRC-GAR, inundated area	GAR 2015, adapted by JRC	Vector (point), WGS-84	250 RP

Earthquake

The information on seismic hazard used in this work is based on the Earthquakes Modified Mercalli Intensity (EMMI) dataset produced by CIESIN Columbia University for the GAR 2013¹⁴. This simulation-based dataset is derived from Global Seismic Hazard Assessment Program (GSHAP) dataset that was converted to MMI scales based on the methodology described by Wald et al. (1999). The GSHAP project (1992-1999) depicts Peak-Ground-Acceleration (PGA) with 10% chance of exceedance in 50 years, corresponding to a return period of 475 years. This EMMI-GSHAP grid is provided at 11x11km grid cells (approx.) in WGS-84, and it has been brought into the final seismic hazard map in the working grid (250 m, World Mollweide projection).

The EMMI scale classifies the area exposed to earthquakes into ten classes¹⁵ according to earthquake shaking intensity and relative damages (see Table below). The lower numbers of the intensity scale generally deal with the manner in which the earthquake is felt by people. The higher numbers of the scale are based on observed structural damage. Structural engineers usually contribute information for assigning intensity values of VIII or above.

Table 12 Earthquakes Modified Mercalli Intensity scale and produced damage

Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favourable conditions.
II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
ш	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

In this analysis the multi-temporal exposure estimates have been calculated using four hazard zones: class 5, class 6, class 7, and class 8. Table below outlines how this schema can be mapped into MMI scale, and Map 1 (pg.26) shows the geographical extent of these hazard zones.

Table 13 Mapping between classes of the hazard zone map and MMI scale

Earthquake hazard map encoding	MMI class
Class 5	V-VI-VII
Class 6	VII-VIII
Class 7	VIII-IX
Class 8	Х

¹⁴ http://preview.grid.unep.ch/index.php?preview=data&events=earthquakes&evcat=3&lang=eng

¹⁵ https://earthquake.usgs.gov/learn/topics/mercalli.php

Volcano

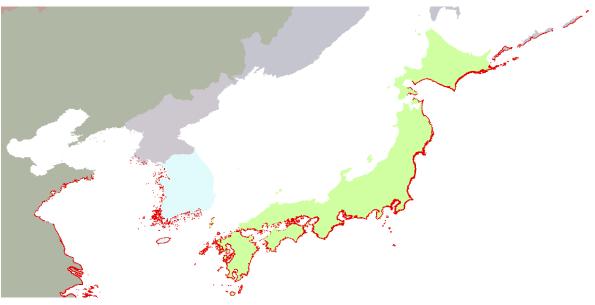
The hazard map of volcanoes is based on the NOAA Significant Volcanic Eruption Database¹⁶ (SVED), a global listing of over 500 significant eruptions. In this data, a significant eruption is classified as one that meets at least one of the following criteria: caused fatalities, caused moderate damage (approximately USD \$1 million or more), with a Volcanic Explosivity Index (VEI) of 6 or higher, caused a tsunami, or was associated with a major earthquake.

In this work, the volcano hazard map is understood as the potentially affected area within the distance of 100 km or closer to any potentially dangerous volcano. The volcano hazard map has been produced as follows. First, a unique list of volcanoes has been derived from the SVED. The underwater volcanoes have been excluded because it is assumed that they mainly cause tsunamis (which is analysed using a dedicated hazard map which does not consider volcanogenic tsunamis). The final SVED volcano list contains 220 volcanoes of which only less than ten had the last know eruption in BCE (the oldest event around -4360 BCE). Then, a buffer of 100km was constructed per each volcano from the SVED list. Finally, the resulted buffered point layer was converted into the working grid (i.e., 250 m, World Mollweide projection).

¹⁶ https://www.ngdc.noaa.gov/hazard/volcano.shtml

Tsunami

The tsunami hazard map has been derived from the GAR 2015 tsunami map¹⁷ that depicts the estimate of tsunami Run-up. The applied tsunami hazard model uses a Probabilistic Tsunami Hazard Assessment (PTHA) methodology, which quantifies the probability of the tsunami run-up height in various areas, combined with the method of amplification factor to estimate maximum shoreline water elevations. This dataset was modelled using global data, and is based on two a comprehensive list of reports and scientific papers compiled and utilized in producing tsunami hazard maps as well as finding return periods of future events. In this map, each cell (of 80 m approx.) represents a tsunami run-up over a minimum return period of 500 years.



Map 6 Tsunami Run-up (GAR 2015) on example of Japan

The hazard map used in this work is the result of the transformation of the GAR 2015 tsunami frequency map into the working grid, i.e. 250 m in World Mollweide projection.

¹⁷ http://preview.grid.unep.ch/index.php?preview=data&events=tsunamis&evcat=2&lang=eng

Flood

The hazard data for flood exposure are derived from the Flood hazard map of the World (GloFAS 2015)¹⁸ (Dottori et al. 2016). These flood hazard maps are based on streamflow data from the European and Global Flood Awareness System (EFAS and GloFAS) and have been computed using two-dimensional hydrodynamic models. There are several hazards maps, according to the return period used to derive the data, i.e, 10, 20, 50, 100, 200 and 500 years. These maps can be used to assess flood exposure and risk of population and assets. However, this dataset is based on JRC elaborations and is not an official flood hazard map.

For purpose of this analysis, the 100-RP map has been used, which depicts flood prone areas at global scale for flood events with 100-year return period: this is usually adopted in national flood risk assessment documents and maps as a reference for rare and severe flood events

Resolution is 30 arcseconds (approx. 1km). Cell values indicate water depth (in m). The derived hazard map represents areas flooded with 1cm or more (that includes all affected area, independently by the height of water), per each cell of 250m grid in World Mollweide projection.

The limit of the minimum water depth in the flood map was set at 1cm as it was in other previous experiments (Alfieri et al. 2017).

¹⁸ [Dataset] PID: http://data.europa.eu/89h/jrc-floods-floodmapgl_rp100y-tif

Tropical Cyclone Wind

The cyclone wind hazard map used in this analysis, has been derived from the GAR map on Tropical Cyclonic Wind. The tropical cyclonic strong wind and storm surge model use information from 2594 historical tropical cyclones, topography, terrain roughness, and bathymetry (CIMNE and INGENIAR Ltda 2015). There are several maps offered at 30 arc-seconds resolution (approx. 1km) for different return periods, i.e. 50, 100, 250, 500, and 1000 years.

In this work, the 250-RP map has been used. The GAR cyclone wind hazard data represents the gasp wind speed per cell. This map has been reclassified to express the Saffir-Simpson Hurricane Wind Scale¹⁹, a 1 to 5 hurricane rating based on a sustained wind speed²⁰. This scale estimates potential property damage. Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and damage, while category 1 and 2 storms are still dangerous and require preventative measures. The exposure has been estimated per each category (i.e., SS class), and the values have been aggregated into two classes for the analysis (SS1-2 and SS3-5).

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
1	119-153 km/h	Very dangerous winds will produce some damage: Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	154-177 km/h	Extremely dangerous winds will cause extensive damage: Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3	178-208 km/h	Devastating damage will occur: Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	209-251 km/h	Catastrophic damage will occur: Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (major)	252 km/h or higher	Catastrophic damage will occur: A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

Table 14 The Saffir-Simpson Hurricane Wind Scale is a 1 to 5 rating based on a hurricane's sustained wind speed. Source: NOAA

Table 15 Mapping between classes of the hazard zone map and the Saffir-Simpson Hurricane Wind Scale

Tropical cyclone wind hazard map encoding	SS classes
551-2	1, 2
SS3-5	3, 4, 5

¹⁹ http://www.nhc.noaa.gov/aboutsshws.php

²⁰ The re-classification rules consider that wind gasp speed is around 30% higher than sustained wind speed.

Tropical Cyclone Storm Surge

The baseline data used to create the storm surge hazard map is the global GAR 2015 dataset of the wave high. These data have been created by the tropical cyclonic strong wind and storm surge model, which uses information from 2594 historical tropical cyclones, topography, terrain roughness, and bathymetry (CIMNE et al., 2015a). GAR 2015 Storm Surge hazard maps are expressed in points, and are made available for different return periods, i.e. 50, 100, 250, 500, and 1000 years.



Map 7 SRTM tiles covering the terrestrial land masses. The land masses above 60-degree latitude North are not covered

The data used in this analysis has been produced for return period of 250 years. This dataset consists of more than 165,000 points along the coast representing the expected storm surge level. In order to estimate the inundated area affected by storm surge, a global elevation model have been used by applying method described in Hoque and Khan, 1997 (Hoque and Khan 1997) adopted by JRC INFORM. First, the point layer was converted in a raster. Then for each pixel the information of surge level was compared with the

terrain elevation. The pixels where the expected surge level is higher or equal than the Digital Elevation Model (DEM), define the hazard zone. The final hazard map represents the potentially inundated areas (see Map 5 Tropical Cyclone Storm Surge hazard map).

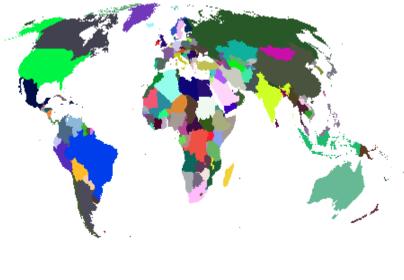
The DEM was taken from the Shuttle Radar Topography Mission (SRTM) v4.1 (Jarvis, Reuter, and Guevara 2008), which provides terrain elevation grids at a 90 meters resolution (approx.). The SRTM radar data were processed into a Digital Surface Model (DSM) and available as open source at 3 arc-seconds for the entire land masses between latitude 60 North and 50 South.

The storm surge impact calculated is an estimation that is affected by uncertainties in three variables at least, the surge model, the SRTM dataset (from which the elevation data are derived) and the exposure (population and built up). Despite the SRTM dataset limitations (e.g., the height measures include that of buildings, and vegetation canopy) this dataset was ultimately used because it is the one that best matches the resolution of the built up layers, and for its geographical scale, that covers most of the inhabited place of the earth. However, there are limitations and assumptions associated with the data that were taken into account during the analysis.

6.1.3 Geospatial aggregation for analysis

In this work, the potential exposure to natural hazards were analysed using several spatial aggregation of the world. The main layer was the country layer, and then geographical and income aggregation of the country data.

Country layer



The global data used in this work were analysed and aggregated at country level (i.e., 251 entities) using the Database of Global Administrative Areas (GADM $v2)^{21}$. This dataset is freely available for non-commercial use, which enables users to recreate the analysis.

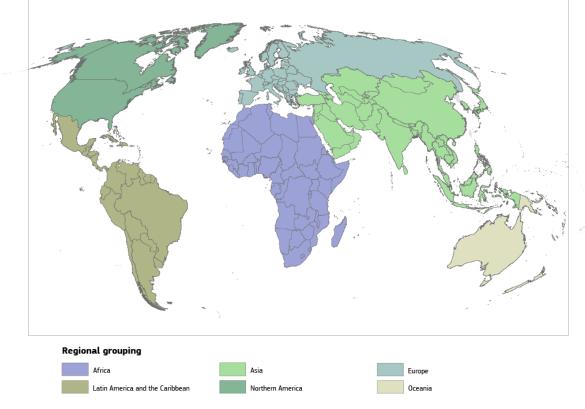
Although it is a public database, GADM has a higher spatial resolution than other free or commercial databases. The GADM project created the spatial data for many countries from spatial databases provided by

Map 8 Country layer used for the analysis

national governments, NGO, and/or from maps and lists of names available on the Internet (e.g. from Wikipedia).

²¹ Global administrative areas (boundaries). University of Berkeley, Museum of Vertebrate Zoology and the International Rice Research Institute (2012).

Geographical classification



Map 9 Country classification per regions of the world

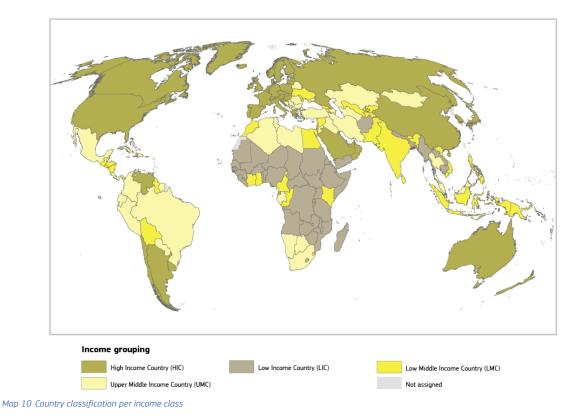
This report includes multi-temporal global data. Data are also presented in aggregated formats.

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.

The following countries are not listed under any group: French Southern Territories, Bouvet Island, Heard Island and McDonald Islands, British Indian Ocean Territory, Paracel Islands, North Korea, British Virgin Islands, Akrotiri and Dhekelia, Caspian Sea, Clipperton Island, Northern Cyprus, United States Minor Outlying Islands.

Income classification



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)²².

The following countries are not listed under any income group: Anguilla, Åland, French Southern Territories, Bonaire, Sint Eustatius and Saba, Saint-Barthélemy, Bouvet Island, Cocos Islands, Cook Islands (the), Christmas Island, Western Sahara, Falklands,Guernsey, Gibraltar, Guadeloupe, French Guiana, Heard Island and McDonald Islands, Isle of Man, British Indian Ocean Territory, Jersey,Saint-Martin, Montserrat, Martinique, Mayotte, New Caledonia, Norfolk Island, Niue, Nauru, Pitcairn Islands, Paracel Islands, North Korea, eunion,South Georgia and the South Sandwich Islands, Saint Helena, Svalbard and Jan Mayen, Spratly islands, Saint Pierre and Miquelon, Taiwan, Vatican City, British Virgin Islands, Wallis and Futuna Islands, Akrotiri and Dhekelia, Caspian Sea, Clipperton Island, Kosovo, Northern Cyprus, United States Minor Outlying Islands, Tokelau.

²² <u>https://esa.un.org/unpd/wpp/General/Files/Definition_of_Regions.pdf</u>

6.2 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.

The baseline data used to produce the *Atlas* have been organized in four epochs, namely 1975, 1990, 2000, 2015. Each epoch integrates satellite and census data that best approximate the nominal year: information about the exact dates of the satellite data and census data integrated in the product can be found at (M Pesaresi et al. 2016).

The empirical evidences about built-up surfaces 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 surfaces 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 surfaces quantities as estimated by GHSL are the best estimation available today using global open remote sensing data (Martino Pesaresi, Ehrlich, 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 (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, names, 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 surface, area of settlement, and detection of *Urban Centres*) or missing continuous values across time.

Use constraints

This Atlas was generated using a selection of open global datasets. The main purpose of this Atlas is to highlight the importance of the exposure factor in the global risk assessment, in support to international policy processes, and to broadly identify areas where more detailed data should be collected for local policy agendas. The Atlas is not intended to be used *as-it-is* for local-scale applications such as land use planning, in-situ planning, or emergency and life-saving operations. The European Commission - Joint Research Centre and collaborators should in no case be liable for misuse or misinterpretation of the presented results. The designations employed and the presentation of material on the maps do not imply the expression of any opinion whatsoever on the part of European Commission - Joint Research Centre concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries

LIST OF ABBREVIATIONS

CRED	Centre for Research on the Epidemiology of Disasters
DRR	Disaster Risk Reduction
ECHO	European Commission - Humanitarian Aid and Civil Protection
GAR	Global Assessment Report
GDACS	Global Disaster Alert and Coordination System
GloFAS	Global Flood Awareness System
GHSL	Global Human Settlement Layer
GSHAP	Global Seismic Hazard Assessment Program
HFA	Hyogo Framework for Action
INFORM	Index for Risk Management
MMI	Modified Mercalli Intensity Scale (I-XII)
NOAA	National Oceanic and Atmospheric Administration, the United States
OCHA	Office for the Coordination of Humanitarian Affairs
OECD	Organisation for Economic Co-operation and Development
PGA	Peak Ground Acceleration
RP	Return Period
SDG	Sustainable Development Goals
SFDRR	Sendai Framework for Disaster Risk Reduction
SS	Saffir-Simpson Hurricane Scale
SRTM	Shuttle Radar Topography Mission
UNEP	United Nations Environment Programme
UNISDR	United Nations Office for Disaster Risk Reduction

DEFINITIONS

Built-up surface per capita Ratio between area of built-up land and population

Built-up surface	Built up area is typically expressed with a continuous value representing the proportion of building footprint area within the total size of the cell. (Martino Pesaresi, Melchiorri, et al. 2016)
Disaster	A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts. (United Nations General Assembly 2016)
Exposure	The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas. (United Nations General Assembly 2016)
Geodata	An image that has geographic information embedded in the file, like GeoTIFF
Hazard	A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. (United Nations General Assembly 2016)
Land mass	Land mass is the total surface of continental land excluding inland water bodies (Martino Pesaresi, Melchiorri, et al. 2016)
Megacity	A megacity is an urban settlement hosting more than 10 million people
Natural hazard	Natural hazards are predominantly associated with natural processes and phenomena. (United Nations General Assembly 2016)
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
Return period	Average frequency with which a particular event is expected to occur. (UNISDR 2015a)
Disaster Risk	The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity. (United Nations General Assembly 2016)
Vulnerability	The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. (United Nations General Assembly 2016)

LIST OF FIGURES

Figure 1	Global population potentially exposed to seismic hazard of class from 5 to 8, 475 years RP (1975-1990-2000-2015)
Figure 2	Global Built-up potentially exposed to seismic hazard of class from 5 to 8, 475 years RP (1975-1990-2000-2015)
Figure 3	Built-up potentially exposed to seismic hazard by hazard class, 475 years RP (1975-1990-2000-2015)
Figure 4	Population potentially exposed to seismic hazard by hazard class, 475 years RP (1975-1990-2000-2015)
Figure 5	Share of Population and Built-up potentially exposed to earthquake by region, 475 years RP (1975-1990-2000-2015)
Figure 6	Share of Population and Built-up potentially exposed to earthquake by income group, 475 years RP (1975-1990-2000-2015)
Figure 7	Ten countries with the highest number of people potentially exposed to seismic hazard in 2015, compared to total population, 475 years RP (1975-1990-2000-2015)
Figure 8	Ten countries with the highest amount of built-up potentially exposed to seismic hazard in 2015, compared to total built-up, 475 years RP (1975-1990-2000-2015)
Figure 9	Population within 100 km of volcanoes (1975-1990-2000-2015)
Figure 1	0 Area of built-up within 100 km of volcanoes (1975-1990-2000-2015)
	1 Share of Built-up and Population potentially exposed to volcano hazards by region (1975-1990- 2000-2015)
Figure 1	2 Ten countries with the highest number of people potentially exposed to volcano hazards (1975- 1990-2000-2015)
Figure 1	3 Ten countries with the highest amount of built-up potentially exposed to volcano hazards (1975- 1990-2000-2015)
Figure 1	4 Population potentially exposed to tsunami hazard, 500 years RP (1975-1990-2000-2015)
Figure 1	5 Built-up potentially exposed to tsunami hazard, 500 years RP (1975-1990-2000-2015)
Figure 1	6 Share of Population and built-up exposed to tsunami hazard by region, 500 years RP (2015)
Figure 1	7 Ten countries with the highest number of people potentially exposed to tsunami hazard in 2015, 500 years RP (1975-1990-2000-2015)
Figure 1	8 Ten countries with the highest built-up area potentially exposed to tsunami hazard in 2015, 500 years RP (1975-1990-2000-2015)
Figure 1	9 Population potentially exposed to flood hazard, 100 years RP (1975-1990-2000-2015)
Figure 2	0 Built-up potentially exposed to flood hazard, 100 years RP (1975-1990-2000-2015)
Figure 2	1 Share of Built-up and Population potentially exposed to floods by region, 100 years RP (1975-
	1990-2000-2015)
Figure 2	2 Ten countries with the highest number of people potentially exposed to floods in 2015, compared to total population, 100 years RP (1975-1990-2000-2015)
Figure 2	3 Ten countries with the highest amount of built-up potentially exposed to floods in 2015, compared to total built-up, 100 years RP (1975-1990-2000-2015)
Figure 2	4 EU countries with more than 50,000 people potentially exposed to flood in 2015, 100 years RP (1975-1990-2000-2015)
Figure 2	5 Population potentially exposed to Tropical cyclone wind, compared to total, 250 years RP (1975- 1990-2000-2015)
Figure 2	6 Built-up potentially exposed to Tropical cyclone wind, compared to total, 250 years RP (1975- 1990-2000-2015)
Figure 2	7 Share of Built-up and Population potentially exposed to tropical cyclone wind SS1 and SS3 by
_ ·	region, 250 years RP (1975-1990-2000-2015)

Figure 28 Population potentially exposed to tropical cyclone winds SS1 and SS3 by income group, compare	ed
to total population, 250 years RP (1975-1990-2000-2015)	59
Figure 29 Ten countries with the highest amount of built-up potentially exposed to tropical cyclone winds	
SS1 in 2015, compared to total built-up, 250 years RP (1975-1990-2000-2015)	60
Figure 30 Ten countries with the highest number of people potentially exposed to tropical cyclone winds S	551
in 2015, compared to total population, 250 years RP (1975-1990-2000-2015)	60
Figure 31 Population potentially exposed to tropical cyclone storm surge, 250 years RP (1975-1990-2000)-
2015)	63
Figure 32 Built-up potentially exposed to tropical cyclone storm surge, 250 years RP (1975-1990-2000-	
2015)	63
Figure 33 Share of Population and built-up surface exposed to tropical cyclone storm surge by region over	r
total exposed population and built-up surface, 250 years RP (2015)	64
Figure 34 Ten countries with the highest number of people potentially exposed to cyclone surge in 2015, 2	250
years RP (1975-1990-2000-2015)	65
Figure 35 Ten countries with the highest amount of built-up potentially exposed to tropical cyclone storm	
surge in 2015, 250 years RP (1975-1990-2000-2015	65

LIST OF MAPS

Map 1 Earthquake Hazards Map – Classes defined for the analysis	26
Map 2 Exposure analysis within 100 km radial distance from the 220 volcanoes included in the study	34
Map 3 Global map of the areas exposed to flood	48
Map 4 Tropical Cyclone wind hazard map	57
Map 5 Tropical Cyclone Storm Surge hazard map	62
Map 6 Tsunami Run-up (GAR 2015) on example of Japan	75
Map 7 SRTM tiles covering the terrestrial land masses. The land masses above 60-degree latitude North	are
not covered	78
Map 8 Country layer used for the analysis	79
Map 9 Country classification per regions of the world	80
Map 10 Country classification per income class	81

LIST OF TABLES

3
9
0
5
-
5
C

Table 7 Comparison between national and population exposed to floods in EU countries, 100 years RP	
(ranked by exposed population in 2015)	53
Table 8 Built-up surface and Population potentially exposed to tropical cyclone wind SS1 and SS3 by re	gion,
250 years RP (1975-1990-2000-2015)	
Table 9 Population and built-up surface exposed to tropical cyclone storm surge by region over time, 2	50
years RP (1975-1900-200-2015)	64
Table 10 The exposure grids used in this work	71
Table 11 The natural hazard maps used in this work (RP: return period)	72
Table 12 Earthquakes Modified Mercalli Intensity scale and produced damage	73
Table 13 Mapping between classes of the hazard zone map and MMI scale	73
Table 14 The Saffir-Simpson Hurricane Wind Scale is a 1 to 5 rating based on a hurricane's sustained	wind
speed. Source: NOAA	77
Table 15 Mapping between classes of the hazard zone map and the Saffir-Simpson Hurricane Wind Sc	ale77

LIST OF BOXES

Box 1 Sendai Framework for Disaster Risk Reduction – UNISDR	.13
Box 2 INFORM – Index for Risk Management	.15
Box 3 GAR15 - Global Assessment Report 2015	.23

Europe Direct is a service to help you find answers to your questions about the European Union.

Freephone number (*):

00 800 6 7 8 9 10 11

(*) The information given is free, as are most calls (though some operators, phone boxes or hotels may charge you).

More information on the European Union is available on

HOW TO OBTAIN EU PUBLICATIONS

Free publications:

one copy:

via EU Bookshop (http://bookshop.europa.eu);

- more than one copy or posters/maps: from the European Union's representations (http://ec.europa.eu/represent_en.htm); from the delegations in non-EU countries (http://eeas.europa.eu/delegations/index_en.htm); by contacting the Europe Direct service (http://europa.eu/europedirect/index_en.htm) or
 - calling 00 800 6 7 8 9 10 11 (freephone number from anywhere in the EU) (*).

(*) The information given is free, as are most calls (though some operators, phone boxes or hotels may charge you).

Priced publications:

via EU Bookshop (http://bookshop.europa.eu).

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.



EU Science Hub ec.europa.eu/jrc

- 9 @EU_ScienceHub
- f EU Science Hub Joint Research Centre
- in Joint Research Centre
- EU Science Hub



doi: 10.2760/19837 ISBN 978-92-79-67959-9