Annex 1

GAR

Global Assessment Report on Disaster Risk Reduction

2015

GAR GLOBAL RISK ASSESSMENT: DATA, METHODOLOGY, SOURCES AND USAGE

UNISDR
The United Nations Office for Disaster Risk Reduction

Contents

Introduction

Since 2011, UNISDR has spearheaded a multi-hazard Global Risk Assessment in partnership with leading scientific and technical organizations. The objective is to provide comparable open-access disaster risk metrics across countries and hazard categories with a relatively coarse-grain resolution as a means of raising risk awareness. This fills a major gap in understanding risk. Most probabilistic risk assessments have been developed commercially for the insurance industry and cover specific risks, mainly in higher-income countries. However, they are rarely accessible and are based on proprietary models. While more and more public-domain risk models are now being developed, the use of different methodologies and data sets makes comparison difficult.

The GAR global risk assessment is based on original research carried out by different UNISDR partner institutions, including Arab Centre for the Studies of Arid Zones and Drylands (ACSAD), Beijing Normal University, Centro Internazionale in Monitoraggio Ambientale (CIMA) Foundation, CIMNE and Associates, Famine Early Warning Systems Network (FEWS NET), Geoscience Australia, Global Volcano Model (GVM), Joint Research Center (JRC), Kokusai Kogyo, Norwegian Geolotechnical Institute (NGI), United Nations Environment Programme–Global Resource Information Database (UNEP-GRID), and the World Agency for Planetary Monitoring and Earthquake Risk Reduction (WAPMERR). From this research, new hazard models have been built and existing hazard and risk modelling tools have also been upgraded.

This document is an Annex to Global Assessment Report 2015 (GAR15) and acts as the linkage between the risk results presented throughout GAR specially in chapter 3, and all the technical background papers presenting in depth technical information about each component of the global risk assessment.

This Annex provides an overview of the models developed and used for the GAR global risk assessment, it recounts their starting point in GAR09, GAR11, and GAR13 and traces their current status in GAR15. The terminology and methodological descriptions included in this Annex have been shortened and simplified. For the full technical descriptions and full literature background of each method the reader should refer to the GAR background papers (see reference list).

Some terms that will be extensively used in this annex are defined in the Box 1, mainly following the terminologies adopted for the Global Assessment Report.

Box 1: Risk terminology

Risk: The combination of the probability of an event and its negative consequences.

Disaster Risk: A function of hazard, exposure and vulnerability that provides an estimate of potential disaster losses in physical, social, or environmental assets, etc.

Hazard: GAR15 uses the term physical hazard to refer to hazardous phenomena such as floods, storms, droughts and earthquakes with adverse effects on people and properties. Processes such as urbanization, environmental degradation and climate change shape and configure hazards; therefore its becoming increasingly difficult to disentangle their natural and human attributes. Hazards differ in severity, size and frequency and are often classified by cause (i.e. geological, hydrological, meteorological, and climatological).

Exposure: Assets such as people, houses, factories, offices, agricultural land, etc located in hazard-prone areas and thereby subject to potential losses.

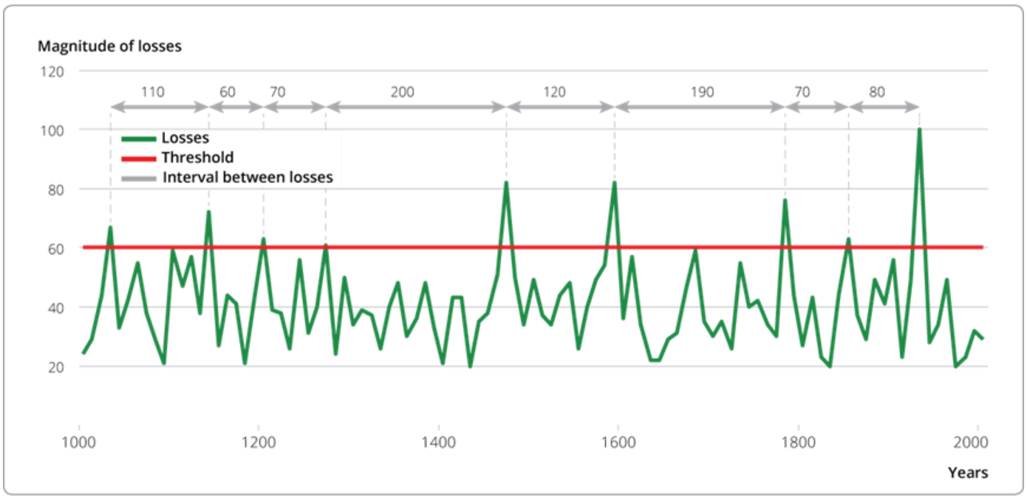
Vulnerability: The conditions of economic, political, physical, social and environmental infrastructure of a community, system or asset that determines the probability that a certain hazard intensity will cause a certain degree of damage. GAR global risk assessment only incorporates physical vulnerability in assessing the damage and loss.

Probability: likelihood of an event occurring compared to all the possible events that might occur. The exceedence probability is the likelihood of one event of a given magnitude occurring or being exceeded within a defined time span.

Frequency: expected number of times that a particular event occurs in a defined time span. In theory, the frequency should equal the inverse of the probability of occurrence for any certain time frame.

Return period: average frequency with which a particular event is expected to occur. It is usually expressed in years, such as 1 in X number of years. This does not mean that an event will occur once every X numbers of years, but is another way of expressing the exceedance probability: a 1 in 200 years event has 0.5% of chances to occur or be exceeded every year.

Figure 1: Return periods

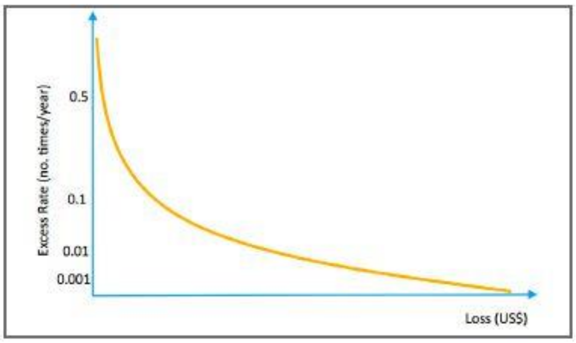


Source: UNISDR.

Probabilistic Risk Assessment: Uses a combination of probabilistic hazard scenarios, exposure and vulnerability, which is produced through modeling. Unlike historical estimates, probabilistic risk assessment takes into account all the disasters that could occur in the future, including very intensive losses over long return periods, and thus overcomes the limitations associated with estimates derived from historical disaster loss data.

Loss Exceedance Probability (EP) Curve: Is a graphical representation of probability that a certain level of loss will be exceeded over a future time period.

Figure 2: Loss Exceedance Curve



Source: UNISDR

Annual Average Loss (AAL): The long-term expected loss per year, averaged over many years. While there may actually be little or no losses, over a short period of time, the AAL accounts much larger losses that may occur more infrequently. In other words, it is the weighted average of expected loss from every event conditioned on the annual probability of each loss's occurrence.

Probable Maximum Loss (PML), or loss expected at a certain annual probability or return period: is the value of the largest loss that could result from a disaster in a defined return period such as 1 in 100 years. The term PML is always accompanied by the return period associated with the loss.

The PML for different return periods can therefore be expressed as the probability of a given loss amount being exceeded over different periods of time. Thus, even in the case of a thousand-year return period, there is still a 5 per cent probability of a PML being exceeded over a 50-year time frame.

Table 1: Probabilities for different return periods

Return Period PML	Probability of loss exceedance per year	Probability of loss exceedance in 20 years time frame	Probability of loss exceedance in 50 years time frame
25	4%	56%	87%
50	2%	33%	64%
100	1%	18%	39%
250	0.40%	8%	18%
500	0.20%	4%	10%
1000	0.10%	2%	5%

Source: Author

From GAR09 to GAR15 risk modelling: rationale for the probabilistic approach to risk assessment

"Risk" is a forward looking concept that implies an eventuality of something that can occur. Therefore, assessing risk means looking at what are the possible events that can occur, quantifying how likely they are to happen and appraising the potential consequences should they occur.

Subject to data availability and other constraints, this may be done by looking at past events and their consequences. This essentially deterministic approach was employed for some hazards in GAR09 and GAR11, where the risk was estimated by extracting the exposure and vulnerability parameters of past hazardous events for the last 30 years (UNISDR , 2009a). The models were then extrapolated using values for selected years and smoothed frequencies to estimate losses for any given year from 1970 to 2010. These results were then used to produce a proxy of current risk and past trends by region. The main strength of this model was its capacity to reveal and measure underlying risk factors and drivers.

This approach, however, requires having a complete record of events and their related consequences. In reality, records of past events have many limitations:

- Most catastrophic events have not yet occurred
- They cover a limited amount of time, thus might not include many infrequent but severe hazards simply might not have occurred within the time covered by the catalogue
- They do not cover all the possible physical realization of the events; in fact, events are never exactly the same, thus basing the risk assessment only on past event might hide unobserved, but yet possible, consequences
- They usually lack in providing temporal and spatial information about the event and detailed records of consequences, especially linked with the local severity of the hazard and performance of the buildings.

It is therefore important to use an approach that is built on past records, but also take into account events that can physically occur but are excluded in the catalogues. Such approach not only allows a better coverage of the possible events, but also provide an improved estimation of the probability of occurrence of each event and associated losses. In fact, decision makers not only need to know which events and losses can possibly occur, but also what is their likelihood and frequencies of occurrence.

For these reasons, a probabilistic risk assessment approach was undertaken for GAR13 and now GAR15. This new global risk assessment has been under development since late 2011, some results published in 2013, and now completed for release of March 2015. All the models and datasets of exposure, hazard, and risk are available openly online.

The recipe of risk: hazard, exposure, and vulnerability in probabilistic risk modelling

In probabilistic risk methodology, the common three components of hazard, exposure, and vulnerability are in play to provide the risk information. The hazard is modelled basing on a stochastically generated set of all the events that could possibly occur, each associated with a frequency of occurrence. In this way the model is able to statistically represent the probability of events that have not yet occurred at a given location. The exposure is model provide information on location, and characteristics of assets of interest. The vulnerability model is developed for each of construction types existing in the exposure dataset which incorporates the uncertainty in how a building of certain construction type may react to a hazard force. Once the hazard, exposure, and vulnerability are defined, it is then possible to calculate the losses related to each of the 'possible' events. Each of these losses is thus linked with their actual annual probability of occurrence (or frequency). Different events with the same probability of occurrence are modelled, to allow for a relevant spatial coverage but also to obtain a satisfactory spectrum of losses for each frequency. The key output of a fully probabilistic risk assessments are normally expressed as a loss exceedance curve, in other words the likelihood of having certain losses expressed in terms of their occurrence rate, usually expressed per year.

For GAR15, global probabilistic risk assessment was carried out for earthquake, tropical cyclones wind and storm surge, tsunami, riverine flooding, and volcanic ash fall. Probabilistic risk methodology and models were also developed for agricultural drought in five sub-Saharan countries, and for volcanic ash fall for 16 countries in Asia Pacific.

Introducing components of GAR Global Risk Assessment

As mentioned GAR15 global risk assessment is the result of multi-year collaboration among many UNISDR partners. Table 2 provides an overview of how these technical institutions joined forces for various components of this work.

Table 2: GAR15 global risk assessment contribution partners and reviewers

Exposure model at global scale	▪ United Nations Environment Programme–Global Resource Information Database (UNEP-GRID) ▪ University of Geneva ▪ World Agency for Planetary Monitoring and Earthquake Risk Reduction (WAPMERR) ▪ Joint Research Center (JRC) ▪ Kokusai Kogyo, Beijing Normal University
Earthquake hazard model at global scale	▪ International Center for Numerical Methods in Engineering (CIMNE) and INGENIAR Ltd.
Cyclone wind and storm surge hazard model at global scale	▪ International Center for Numerical Methods in Engineering (CIMNE) and INGENIAR Ltd.
Tsunami hazard model at global scale	▪ Norwegian Geolotechnical Institute (NGI)
Flood hazard model at global scale	▪ Centro Internazionale in Monitoraggio Ambientale (CIMA) Foundation
Volcano hazard and risk assessment Including a global volcanic ash fall hazard model and	▪ Global Volcano Model (GVM)
Asia Pacific volcanic ash fall hazard model	▪ Geoscience Australia
Vulnerability model for each region	▪ International Center for Numerical Methods in Engineering (CIMNE) and INGENIAR Ltd. ▪ Geoscience Australia (for Asia Pacific)
Probabilistic risk model of all earthquake, cyclone wind and storm surge, flood, tsunami, and volcanic ash fall (Asia Pacific)	▪ International Center for Numerical Methods in Engineering (CIMNE) and INGENIAR Ltd.
Agricultural drought hazard and land degradation assessment of Africa and Middle East	▪ Arab Centre for the Studies of Arid Zones and Drylands (ACSAD)
Probabilistic agricultural drought loss including climate change impact in three African countries	▪ Famine Early Warning Systems Network (FEWS NET)
Others: ▪ World Meteorological Organization (WMO) coordinated and conducted peer review of the hydrometeorological hazard models ▪ UNESCO coordinated and conducted peer review of the geo hazard models and vulnerability model ▪ Global Earthquake Model (a) earthquake catalogue and ground motion equations were adopted for earthquake hazard model, (b)	

- GNS New Zealand coordinated a peer-reviewed UNISDR exposure and earthquake hazard model. All the reviewers are members of GEM governing board

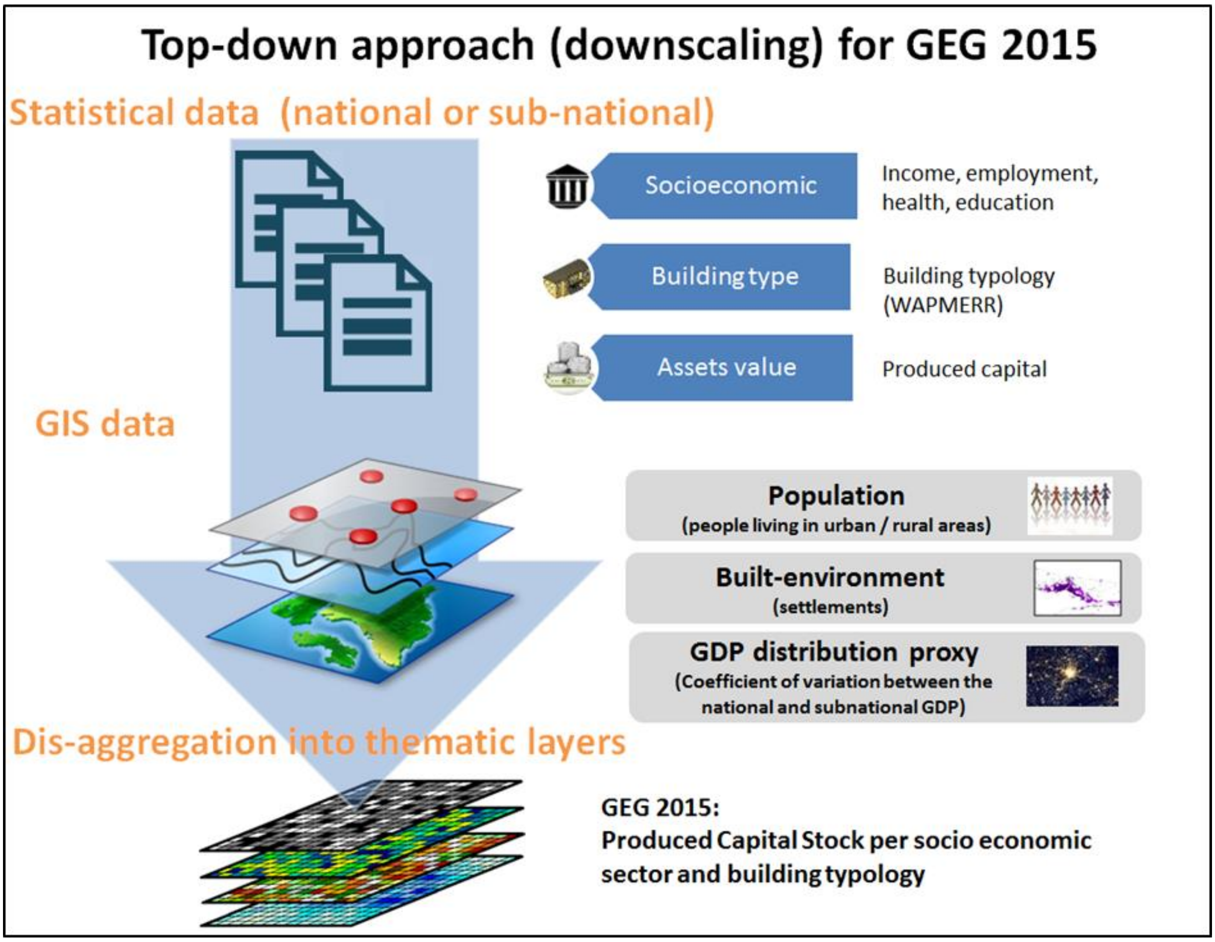
The Global Exposure Database for GAR

A Global exposure database was developed for GAR15 by UNEP-GRID with close collaboration and inputs from WAPMERR (World Agency of Planetary Monitoring and Earthquake Risk Reduction), EU Joint Research Center (JRC), and Kokusai Kogyo. This database includes estimation on the economic value of the exposed assets, as well as their physical characteristics in urban and rural agglomerations. This information is key to assess the potential damages from different hazards to each of the exposed elements.

The global exposure database is developed at 1km spatial resolution at coastal areas and at 5km spatial resolution everywhere else on the globe. It includes economic value, number of residents, and construction type of residential, commercial and industrial buildings, as well as hospitals and schools (De Bono et al., 2015).

GAR15 global exposure database is based on a top-down approach where statistical information including socio-economic, building type, and capital stock at a national level are transposed onto the grids of 5x5 or 1x1 using geographic distribution of population data and gross domestic product (GDP) as proxies (figure 3). Each grid cell contains

Figure 5: Dataset and approach in developing global exposure dataset



Source: DeBono et al., 2015

Main components of the global exposure dataset:

Reference Grid

The so 5x5km reference grid for GAR global exposure dataset includes the whole earth land surface, comprising uninhabited land areas. In this way the reference Grid will be able to handle eventually future data on crops pastures and forest areas. The total number of cells of the grid is 9,008,829. Inhabited cells correspond to 4,574,010. The 5x5km grid size was the choice balancing three criteria of (a) satisfactory size to capture effects for large scale hazards such as earthquake and cyclones at global scale, (b) consistency with the openly available socio-economic datasets with national or global sources, (c) optimizing the computation time

Another grid at 30" resolution (around 1x1 km at equator) was set in order to hold exposure data related to coastal areas. The grid was only built for a sector including the first 10 km of coast worldwide.

Boundaries of built-up environment (using BUREF)

The next task is to define the boundaries of human settlements or building stock on the global and identified as urban, sub-urban, or rural. The boundaries of building stock is defined using satellite-imagery of land cover. The Global Built-up Reference Layer (BUREF2010) generated by JRC is a spatial raster dataset containing an estimation of the distribution and density of built-up areas (Pesaresi et al., 2015). It uses publicly available satellite-derived land cover information and per grid population density data to define the percentage of land occupied by buildings per each grid.

Defining the "content" of each grid in exposure dataset using combination of various datasets:

Population distribution

The primary source of global exposure information is the distribution of people on the earth surface. A gridded population dataset is based on a regular grid, where each cell indicates the number of people living on it.

In GEG-2015 development, the new LandScan data published on June 2012 by Oak Ridge National Laboratory was used and refer to the population as of July 2011 at 30" resolution (approx. 1 km equator).

Night time light intensities or Visible Infrared Imaging Radiometer Suite (VIIRS)

The intensities of nighttime lights represents a good proxy of human activities and they were already used at global scale to map economic activity by (Gosh, T. et al., 2010)

Produced capital stock

The economic value of buildings (capital stock) per country is estimated using a dataset for 152 countries from The World Bank (World Bank, 2011) hat provides broad estimates of the current (2005) capital stock of machinery and structures, based on the Perpetual Inventory Method (PIM) and historical Gross Capital Formation (GCF) data. Furthermore, the World Bank scale-up this estimate by 24% to account for the value of Urban Land.

Gross regional product

A raster of Gross Regional Product (GRP) distribution is generated by collecting and assembling all available information for 71 major countries using the following sources:

- Eurostat: 25 countries
- Beijing Normal University: 1 country (China)
- OECD: 1 county
- World Bank DECRG: 44 countries

The GRP will be further integrated with the outputs from night time light intensities in order to generate a new indicator showing the GDP variation between national and subnational scales. These regional variations of economic activity within a country are used as the basis for geographical distribution of capital stock.

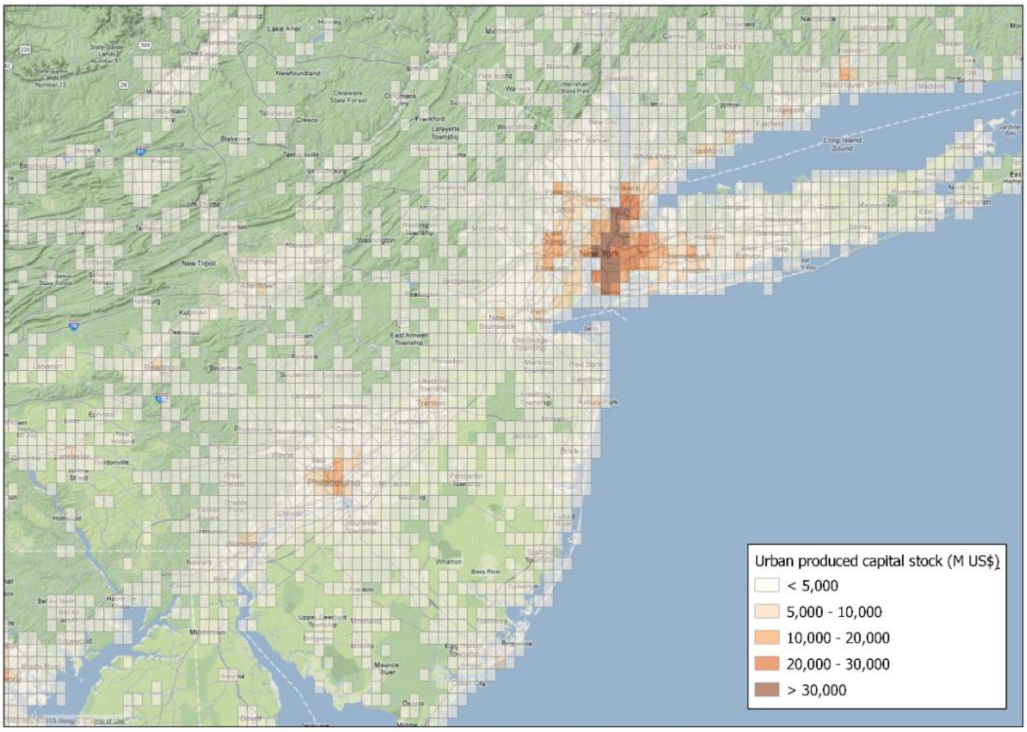
Socio-economic indicators
Socio economic indicators are used as proxies to estimate the use of the building stock for various sectors of commercial, industrial, public, education and health and various economic level for residential sector.

Defining construction classes and distribution

Once the density, values, and sectorial distribution of building stock in each cell are defined, the next step is to define the construction classes and the distribution of various construction classes in each grid.

The World Agency of Planetary Monitoring & Earthquake Risk Reduction (WAPMERR)
gathered data on the sub-national distribution of building types for 18 countries using household data from national census as proxies. Countries selected include the largest heterogeneous ones (China, India and Indonesia) and represent 3.6 billion people, about 50% of the total population of the world. Data on characteristics of houses or households are given for residential/nonresidential groups and mainly divided in large urban small urban and rural areas classification. WAPMER developed the dataset for all countries using construction types defined by PAGER, a program of USGS.

Figure 6: Example of the 5Km x 5Km grid constituting the exposure database



Accessing national census has proved to be quite challenging. For estimating the non-residential distributions, especially for the countries for which no relevant published census data were available, several other sources such as World Housing Encyclopedia[1] as well as expert judgment are used to make assumptions necessary to estimate the properties of the building stock (Tolis et al., 2013).

Combining all the components mentioned above, the economic value of each building class in one cell is assessed based on the disaggregation of the (national) Produced Capital at grid level. This downscaling was done by using the sub-national values of economic activity as a proxy. The result is the global distribution of the economic value of the urban and rural produced capital by construction class.

Further details on the GAR Global Exposure Dataset can be found in technical background papers (De Bono, et.al, 2015), (Tolis et al., 2013) and (Pesaresi, et.al, 2015).

[1] http://www.world-housing.net/

Earthquake hazard

For the GAR15, a fully probabilistic seismic hazard assessment at global level was developed by International Centre for Numerical Methods in Engineering (CIMNE) and INGENIAR Ltda. The purpose was to conduct a probabilistic hazard assessment at global level intended to be used in the probabilistic risk assessment estimating the order of magnitude of potential losses. From GAR13 version, there has been some changes, updates and improvements in input data, but the same methodology has been used which detail information can be found in GAR13 technical background paper (CIMNE et al., 2012). The changes are explained in the technical background report: “Update on the probabilistic seismic hazard assessment at global level,” (CIMNE et al., 2015a).

The main steps of the probabilistic seismic hazard assessment methodology are as following:

1) Identification of the principal seismic sources based on geological and neotectonical information, to characterize the tectonic regions and seismic provinces.

2) Calculation of the seismicity parameters of each seismic source based on the seismic catalogue and using a smoothed seismicity methodology

3) Generation of a set of stochastic set of scenarios based on the information on past earthquakes included in the historical catalogues of NEIC-USGS (2014) and ISC-GEM (Storchak et al., 2013), allowed generating a set of stochastic earthquake scenarios. The generation of the earthquake scenarios was carried out using a new version of seismic hazard module of CAPRA Platform, CRISIS 2014 V1.2 (Ordaz et al., 2014b).

4) Assigning ground motion prediction equations (GMPE) to model the probability distributions of ground motion intensity associated with a given earthquake magnitude.

5) Generation of hazard maps for representative events. Each of the modeled seismic event provides, in each point of the 5x5 km grid, the intensity (level of hazard) for the same event as well as the probability of that event occurring. For earthquakes, the intensity is represented by the ground shaking, expressed in terms of spectral accelerations.

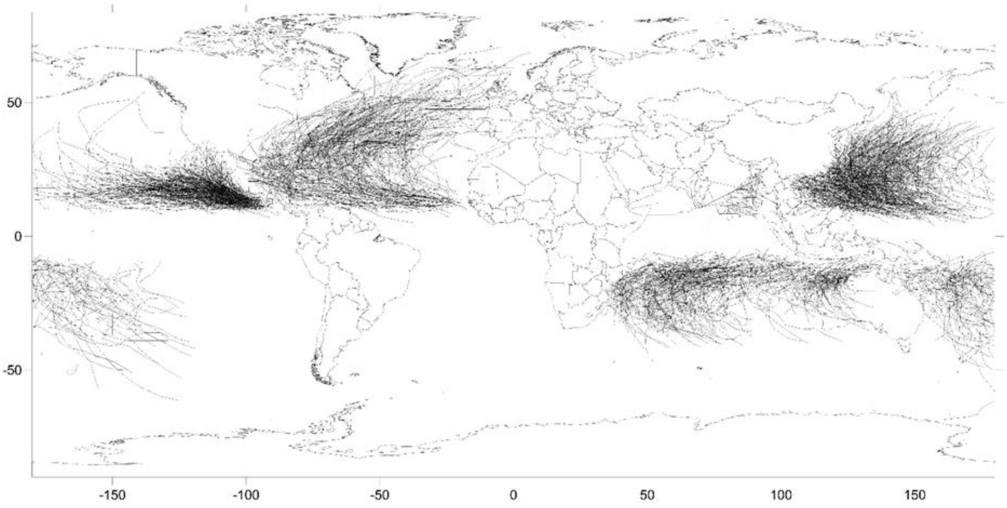
Tropical Cyclonic Wind and Storm Surge hazard

The tropical cyclonic strong wind and storm surge model use information from 2594 historical tropical cyclones, topography, terrain roughness, and bathymetry. The storm surge hazard is the new addition to the GAR cyclone model from 2013, which models the sea water run-up height at the shore line as a consequence of the tangential stress exerted by strong winds and the lower atmospheric pressure. In coastal regions, storm surge is often the deadliest phenomenon associated with tropical or extratropical systems. Storm surge from intense storms can exceed seven meters in some locations. The maximum potential storm surge for a particular location depends on a number of factors such as storm intensity and its characteristics (speed, size, angle of approaching the coast) and the shape and characteristics of the coast including the slope of the shore.

The historical tropical cyclones used in GAR15 cyclone wind and storm surge model are from five different oceanic basins: Northeast Pacific, Northwest Pacific, South Pacific, North Indian, South Indian and North Atlantic and the tracks were obtained from the IBTrACS database (Knapp et al. 2010). This database represents the repository of information associated with tropical cyclones that is the most up to date. IBTrACS provides the following information:

- Record date (hour, day, month and year).
- Central pressure of the cyclone (in milibars)
- Geographical positioning (latitude, longitude).
- Maximum sustained speed of the wind averaged at 1 min
- Basin and sub-basin to that the recorded cyclone belongs.

Figure 7: Worldwide tropical cyclones' strong winds hazard map for 25 years return period.



Topography was taken from the Shuttle Radar Topography Mission (SRTM) of NASA, which provides terrain elevation grids at a 90 meters resolution, delivered by quadrants over the world. To account for surface roughness, polygons of urban areas worldwide were obtained from the Socioeconomic Data and Applications Centre, SEDAC (CIESIN et al., 2011). This was considered a good proxy of the spatial variation of surface roughness.

A digital bathymetry model is employed with a spatial resolution of 30 arc-seconds, taken from the GEBCO_08 (General Bathymetric Chart of the Oceans) Grid Database of the British Oceanographic Data Centre (2009). Bathymetry is the information about the underwater floor of the ocean having direct influence on the formation of the storm surge. More information about the cyclone wind and strom surge hazard can be found in CIMNE et al., 2015a).

Hazard analysis was performed using the software CAPRA Team Tropical Cyclones Hazard Modeler (Bernal, 2014). The vulnerability models used in the risk calculation for GAR correlate loss to the wind speed for 3-seconds gusts. The risk assessment was also conducted by CIMNE and Ingeniar to produced AAL and PML values for cyclone risk.

North Atlantic basin strong winds hazard assessment with Climate Change scenario

For GAR15, the cyclone strong wind hazard and risk was also modelled with a climate change scenario in the North Atlantic basin. Probable future cyclone tracks in the North Atlantic Ocean basin were used to perform the calculations for the countries in the Caribbean region. These tracks were obtained from the results of the Nested Regional Climate Model (NRCM) developed by the National Center for Atmospheric Research of the United States (NCAR). The set of simulations of possible future trajectories were simulated for the decades of 1995-2005 (control decade), 2020-2030, and 2045-2055. The gap years were filled using statistical techniques. The empty periods were completed using statistical techniques based on projections of the North Atlantic multi decadal variability (AMO for short- Atlantic Multidecadal Oscillation), which is a natural climate variability manifested as an oscillating change through time in the temperature of the ocean surface. This gap in the tropical cyclones catalog was completed taking into account the following criteria:

- One of the main causes of generation of hurricanes is the increasing of the Sea Surface Temperature (SST).
- The SST has a multidecadal variation (AMO), due to the thermohaline circulation of the oceans.

As shown in GAR15 chapter 3, in the Caribbean region the total losses modelled with the climate change scenario is about $1.4Billion USD higher than the scenario modelled based on historical tracks.

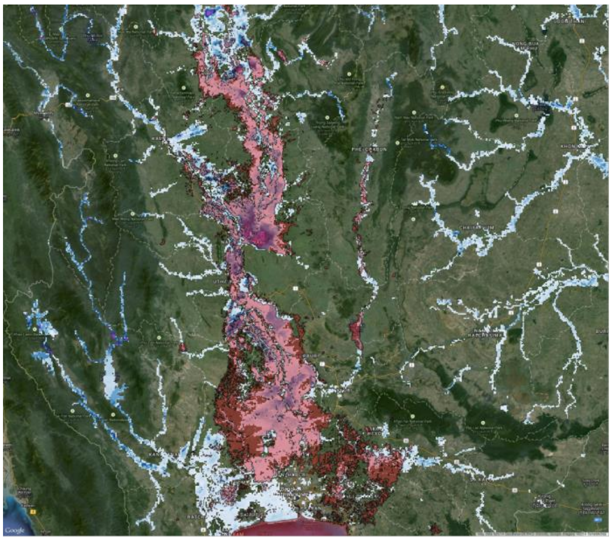
Riverine flood hazard

The GAR 15 global flood hazard assessment uses a probabilistic approach for modelling riverine flood major river basins around the globe. The main steps in this methodology consists of:

- Compiling a global database of stream-flow data, merging different sources gathering more than 8000 stations over the globe.
- Calculating river discharge quantiles at various river sections. In another word calculating the range of possible discharges from very low to the maximum possible at series of locations along the river. The time span in the global stream-flow dataset is long enough to allow extreme value analysis. Where time series of flow discharges were too short or incomplete, they were improved with proxy data from stations located in the same "homogeneous region." Homogeneous regions were calculated taking into account information such as climatic zones, hydrological characteristics of the catchments, and statistical parameters of the streamflow data.
- The calculated discharge quantiles were introduced to river sections, whose geometries were derived from topographic data (SRTM), and used with a simplified approach (based on Manning's equation) to model water levels downstream.

This procedure allowed for the determination of the reference Flood hazard maps for different return periods (6 are shown in the global study: T= 25, 50, 100, 200, 500, 1000 years). The hazard maps are developed at 1kmx1km resolution. Such maps have been validated against satellite flood footprints from different sources (DFO archive, UNOSAT flood portal) and well performed especially for the big events (Figure 8)

Figure 8: 200-year map for Thailand compared with the 2011 Thailand flood satellite flood maps from UNOSAT. Conditioned DEM in the Background.



For smaller events (lower return periods), the GAR Flood hazard maps tend to overestimate with respect to similar maps produced locally (hazard maps where available for some countries and were used as benchmark). The main issue being that, due to the resolution, the GAR flood maps do not take into account flood defences that are normally present to preserve the value exposed to floods. This can influence strongly the results of the risk calculations and especially of the economic parameters. In order to tackle this problem some post processing of the maps has been performed, based on the assumption that flood defences tend to be higher where the exposed value is high and then suddenly drop as this value reduces.

The flood hazard assessment was conducted by CIMA Foundation and UNEP-GRID. The flood maps with associated probability of occurrence, is then used by CIMNE as input to the computation of the flood risk for GAR15 as Average Annual Loss values in each country. Hazard maps for six main return periods are developed and available, and probable maximum loss calculations are underway which will be available within few months of GAR15 launch.

This work also includes a climate change scenario pilot cases in Amazon basin and South East Asia. More information about the flood hazard assessment can be found in the background paper (CIMA Foundation, 2015).

Tsunami hazard

Tsunami hazard model of GAR15 uses 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. In this method, individual tsunami inundation maps were developed for several thousand possible tsunami events with each event having an associated probability of occurrence.

Tsunami occur when a significant mass of water is moved in a very short period of time. Almost 80% of tsunamis are caused by earthquake occurring under water causing movement of sea floor leading to tsunamis. GAR15 tsunami hazard model only considers the tsunami caused by earthquake. The other causes of tsunami are landslide, volcanoes.

The global PTHA analysis was split into two geographical domains:

1. The Indian and the Pacific Oceans; and
2. The Atlantic Ocean and Mediterranean Sea.

As large tsunamis can propagate between ocean basins, the domain overlapped and therefore a number of source regions were included in both.

The modelling of GAR15 tsunami hazard assessment starts with defining of tsunami sources, in this case only the earthquake faults. Then based on the characteristics of the fault a synthetic earthquake catalogue is generated as well as a seafloor deformation calculation. Then using wave theory, the propagation of resulting tsunami from each event to the coastline is modelled. Then the maximum run-up height is calculated using amplification factors and at last the inundation area for the event is estimated applying the height to elevation data. Shuttle Radar Topography Mission (SRTM) of NASA, which provides terrain elevation data at a 90 meters resolution, was used.

In use of GAR15 Tsunami hazard assessment it's important to note that the method is based on simplifications and approximations, and is focusing on overall trends rather than details to be able to conduct the analysis at global scale. Also the study focuses on tsunamis caused by large earthquakes only (larger than Mw 7.85). The results of the study are hence a rough assessment of the tsunami hazard.

The hazard analysis, which was conducted by Norwegian Geolotechnical Institute (NGI) and Geoscience Australia (GA), is used to produce thousands of independent inundation maps with associated probability of occurrence, serving as input to the computation of the tsunami risk for the GAR15 probabilistic tsunami risk assessment conducted by CIMNE. More detailed information can be found in the technical background paper (NGI et al., 2014).

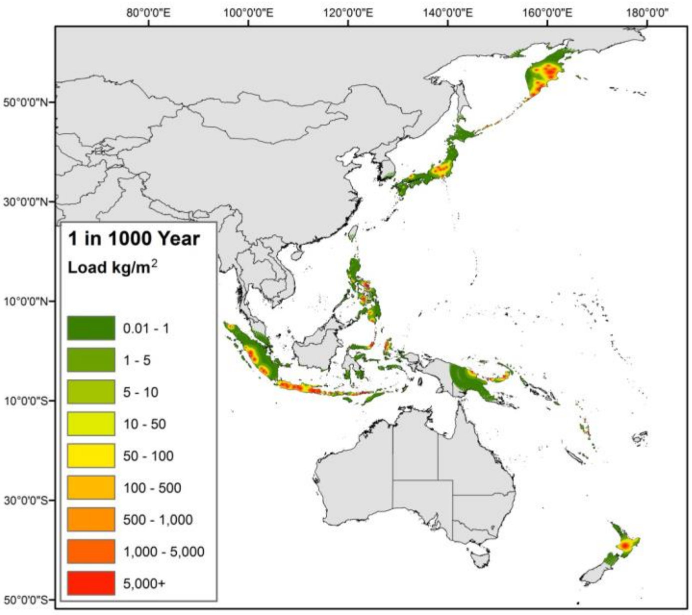
Volcanic Ash Fall Hazard of Asia Pacific

The information and analysis on volcanic hazard and risk provided to GAR15 consists of four different components. The component, which is described here, is the volcanic ash probabilistic hazard assessment in Asia Pacific which uses tool and methodologies developed and implemented by Geoscience Australia (GA). Three other components, which will be discussed later in this document, are conducted by Global Volcano Model (GVM) and The International Association of Volcanology and Chemistry of the Earth's Interior(IAVCHI).

Numerous hazards are associated to volcano eruptions and each have different kinds of impact on physical, social, health and economies. Physical impact of ash fall is one of the many of consequences from a volcanic eruption.

GA team has developed a framework for multi-scale Probabilistic Volcanic Ash Hazard Analysis (PVAHA) by adapting Probabilistic Seismic Hazard Analysis (PSHA). Also the Volcanic Ash Probabilistic Assessment tool for Hazard and Risk (VAPAHR) as a mechanism to facilitate PVAHA at multiple spatial scales. At last PVAHA and VAPAHR was used to provide a broad overview of regional scale volcanic ash hazard in Asia-Pacific. This methodology do not consider the wind effect (Figure 9).

Figure 9: Estimated maximum volcanic ash load for the Asia-Pacific region at the 1000 year return period from PVAHA.



The colour bar indicates the maximum ash load in kg/m2.

VAPAHR outputs have been designed to be compatible with and incorporated into risk models such as the CAPRA/CIMNE risk-modelling platform (CIMNE et al., 2013). The hazard outputs from GA study were designed to be integrated with vulnerability and exposure information for buildings across the Asia-Pacific region at the 5 x 5km resolution using the CAPRA risk engine to provide a partial assessment of volcanic ash risk. The VAPAHR tool simplified the process of tailoring outputs for this application (e.g. scale and setting of return periods). However the tool can be configured to run at 1 x 1km resolution if needed for integration with global population datasets.

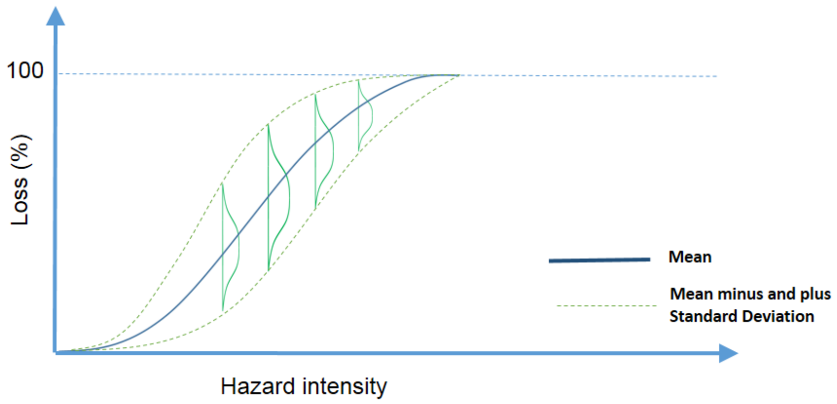
More information on PVAHA, VAPAHR, and the volcano ash fall hazard model of Asia Pacific can be found in background paper titled: “Emulating volcanic ash fall for multi-scale analysis” by (GA, 2014a).

Vulnerability functions

A vulnerability function defines the level of damage as a function of an intensity measure of hazard. Once the physical characteristics for each building class are defined, it is possible to establish and assign the likely damage, and subsequently losses to that specific building class subjected to various levels of specific hazard intensity. This is done by defining relationships between a measured parameter of the hazard intensity (e.g. water depth in case of flooding or the spectral acceleration in the case of earthquakes) to the likely damage level of the particular building class. The damage is expressed in relative terms to their replacement value. These relationships are the so-called "vulnerability functions" (otherwise called "damage functions").

For each hazard and each building typology, one vulnerability function is defined. Each point of the curve links a characteristic of the hazard to a mean loss value and in order to consider the fact there is an uncertainty in how a building perform, the curve also includes the variance, representing the probability distribution of the losses that are likely to occur following the given hazard intensity (Figure).

Figure 10: example of vulnerability curve



With vulnerability functions, for each hazardous event, and for each building typology in each cell, a probability distribution of the losses can be calculated.

The vulnerability functions used for the GAR15 global risk assessment are region specific. For Aisa Pacific building classes, the vulnerability functions for earthquake, tsunami, volcano and flood, were developed by Geoscience Australia with input from regional experts convened at an expert group workshop (GA, 2014b)). In Latin America, the vulnerability curves were developed by Ingeniar and CIMNE using local studies, and the HAZUS-MH[2] vulnerability functions were used for other region. In all regions, construction quality and level of countries' development (for which depends, for example, the completeness and application of building codes) were taken into account.

[2] The Federal Emergency Management Agency's (FEMA's) Methodology for Estimating Potential Losses from Disasters (https://www.fema.gov/hazus)

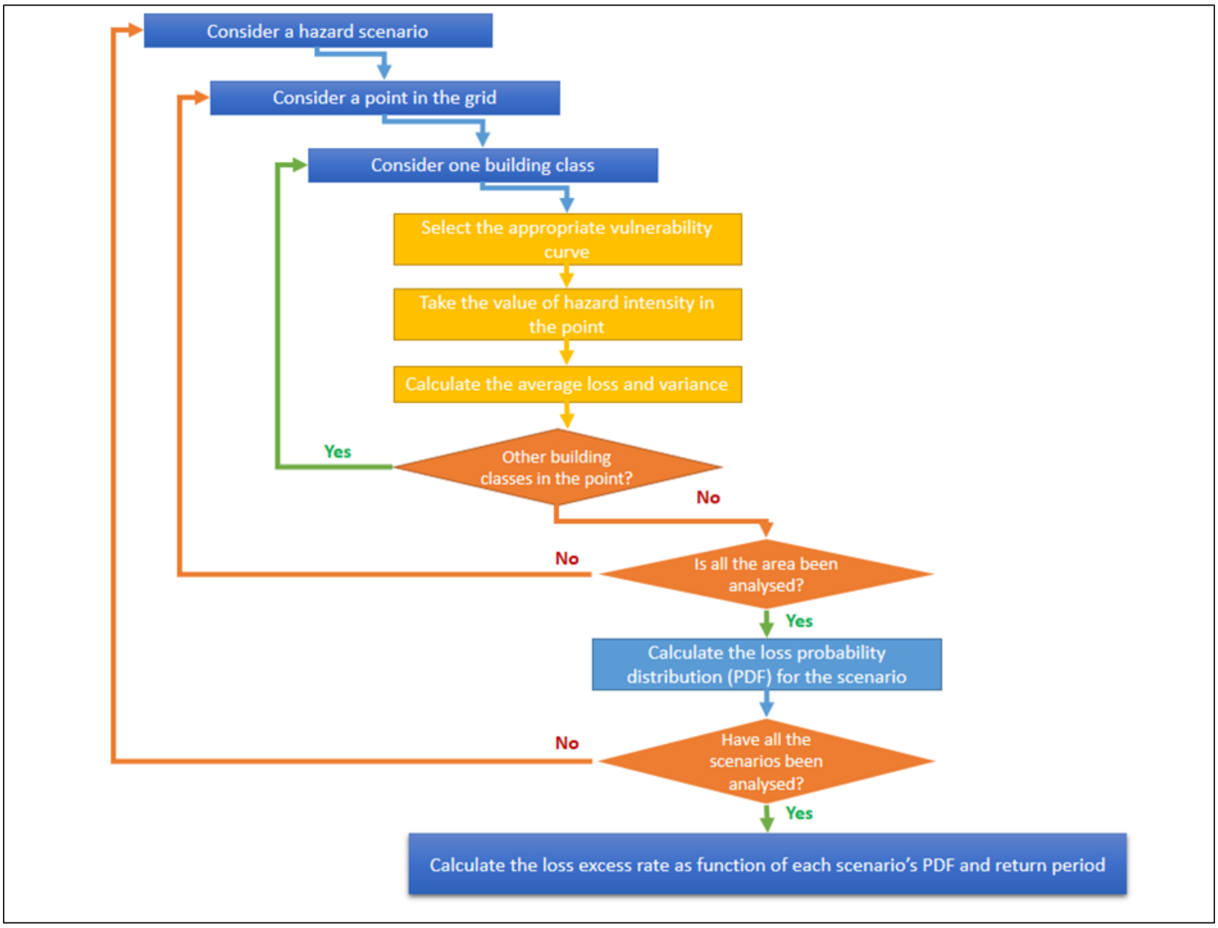
Probabilistic Risk assessment

Once the characteristics of hazard including the probabilities of occurrence with geospatial reference (for each grid on earth surface), and the characteristics of assets including their vulnerability to hazard intensities are defined with the same geospatial reference, then the probabilistic risk can be calculated.

For GAR15, the risk was calculated with the CAPRA-GIS platform which is risk modelling tool of the CAPRA suite (www.ecapra.org)[3].

The CAPRA model follows a state-of-art procedure for calculating risk. In each grid of the exposure database, and for each building class in the grid, the risk is calculated by assessing the damage caused by each of the modelled hazard events (Figure 10).

Figure 10: Simplified flowchart of the procedure followed for risk calculation



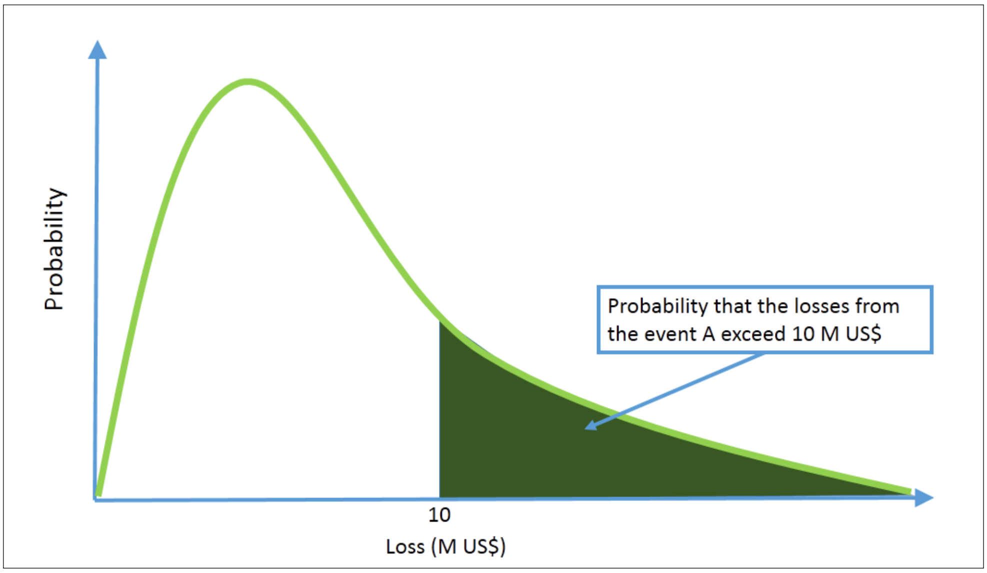
Source: UNISDR, 2013

[3] This modelling tool was developed as a partnership between Center for Coordination of National Disaster Prevention in Central America (CEPREDENAC), the UN International Strategy for Disaster Reduction (ISDR), the Inter-American Development (IADB) and the World Bank (www.ecapra.org).

Because CAPRA model consider different events, to each grid a probability distribution of the hazard intensity for a certain return period can be assigned. As each point of the vulnerability curve is itself a probability distribution, a different probabilistic distribution of damages is calculated in each grid for each event and for each building class.

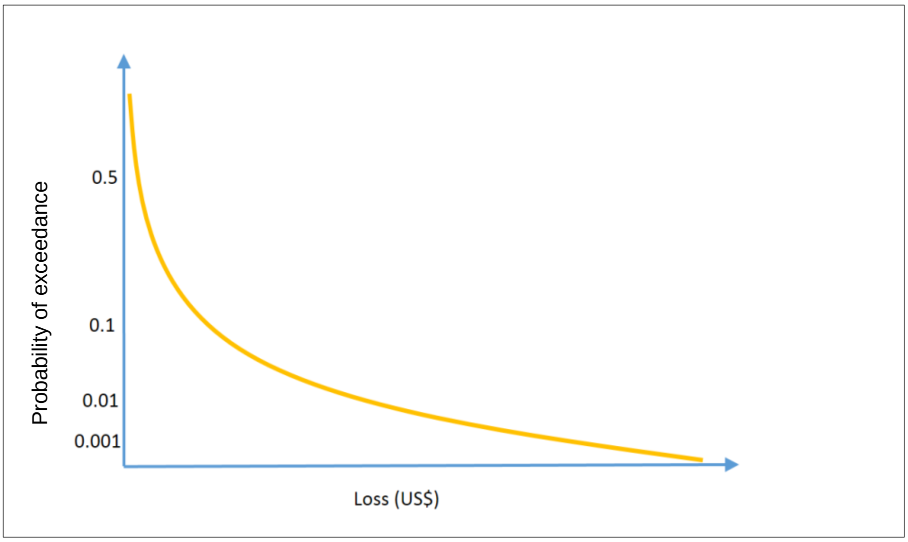
Therefore, in each grid in the area affected by each modelled event, and for each building class, considering the total number of that building class in the grid, we obtain a probability distribution of losses. For each value of losses X, the area underneath the probability curve represents the probability to exceed this value P(x > X) (Figure 11).

Figure 11: Probability distribution of losses for one event



The combination of all these distributions, for all the building classes and the grids of the exposure database, produce the loss exceedance curve for a chosen area such as a country, which likewise represents the probability distribution of losses in the country (Figure 12). It is important to mention that this curve can only be obtained if selecting the model's option that allows performing the risk analysis based on a scenario approach. Each point in this curve correspond to a particular loss X and is calculated as sum of the probabilities P(x > X) for all the events, each multiplied by the frequency of occurrence (inverse of the return period) associated to the event. As such, each point of the curve is not associated to a specific event, but it is the absolute probability of having a loss equal or higher than X ("Exceedance Probability") in each given year.

Figure 12: Example of loss exceedance curve



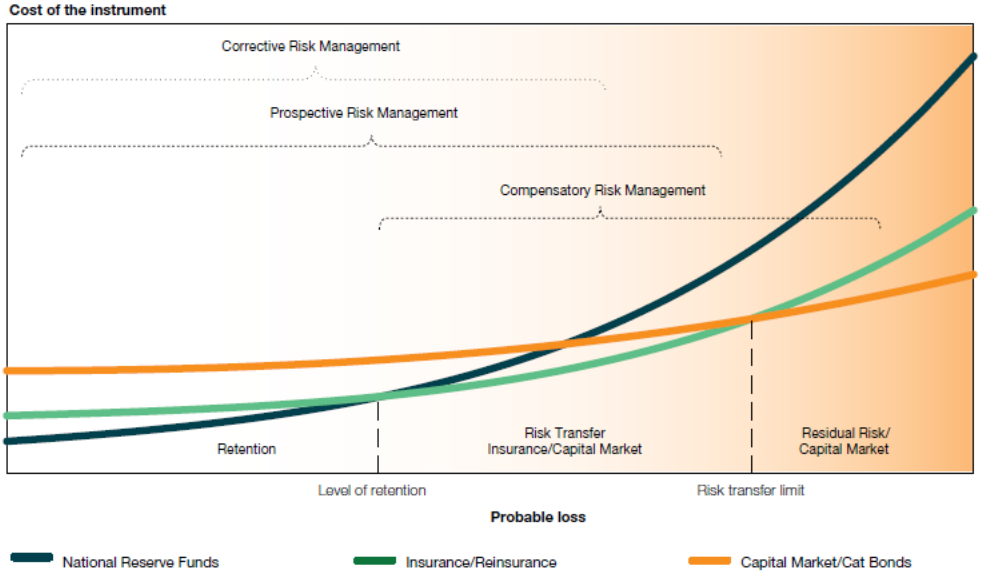
The integral of the loss exceedance curve (the area underneath the curve) is the Annual Average Loss (AAL). For GAR15, the full loss exceedance curve was calculated for each country.

The AAL is the long-term expected loss per year, averaged over many years. While there may actually be little or no losses, over a short period of time, the AAL accounts much larger losses that may occur more infrequently. AAL is also an indication of the amount of savings a nation need to set aside each year to cover the cost of long term losses from that hazard. As GAR global risk assessment is performed at global scale, the AAL calculated should be read as order of magnitude for the potential recurrent extent of losses in a country. In GAR15, multihazard AAL is calculated for every country for earthquake, cyclone wind and storm surge, tsunami, and floods.

Another outcome from this analysis is the Probable Maximum Loss (PML), which are the loss expected associated to certain return periods, for example 50, 100, 200 or 500 years. Depending on the hazard and the needs of the stakeholder different return periods would be of interest. For GAR15, full PML curve is available for earthquake, cyclone wind and storm surge, and tsunami, meaning loss levels can be determined for any return period although 6 return periods have been used for analysis and communication of results in GAR report and on the platform. For volcano ash fall risk of Asia Pacific only AAL are calculated and for global flood risk, PML for 6 return periods was calculated which will be available in the first quarter of 2015.

Its worth note here, that the full PML curve allows definition of loss layers, given that the risk prevention and reduction measures will vary depending on the risk aversion and/or acceptance, among other trade-offs. Because GAR's global risk assessment results have low resolution, they should not be used for any detailed design or decision at national or subnational level.

Figure 13: A Loss Exceedance Curve is an output of probabilistic risk models.



This curve provides probabilities of exceeding various levels of loss. Understanding the frequency of different losses is necessary for deciding on types of measures to prevent or reduce different loss levels.
Source: UNISDR, 2011

The same methodology can be used for conducting risk assessment at local level (i.e., subnational or city level) to inform disaster risk management (DRM) interventions such as land-use and risk-sensitive urban planning, cost-benefit analysis of retrofitting and risk reduction measures, financial protection and risk transfer, and emergency response planning. But depending on the intended application, the quality and resolution of the needed data will vary, meaning that the overall process and amount of effort required will vary as well. Few case studies on local risk assessment and its applications can be found in CIMNE, 2014b.

The probabilistic risk assessment methodology integrates uncertainty into the results. However, it should be recognized that although the most appropriate datasets available at the time of conducting these assessment were used, the results keep a level of uncertainty that arises from assumptions and quality of the data sets used, or the simplifications necessary to model the hazards at global scale, or in modelling vulnerability of building classes in all countries. However, for the purposes of global-scale analysis and country-to-country comparisons, the level of uncertainty is considered acceptable. These results should thus be considered an initial step toward understanding the extent of disaster losses that a country might face and toward determining further actions, such as detailed country and subnational risk assessments.

More information about the probabilistic risk modelling for GAR15 global risk assessment can be found in CIMNE et al., 2014a.

Volcano hazard and risk assessment

A comprehensive set of information on global volcanic hazard, historical events, population exposure, vulnerability, and impact has been provided to GAR15 by Global Volcano Model (GVM) and The International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI). This work is the first of its kind in global coverage and level of contribution from a wide network of experts and institutions around the world. The work consists of three components: (a) Comprehensive technical information on volcanic hazard, historical events, exposure and vulnerability, (b) Profile of regions and all countries with active volcanoes, (c) Global volcanic ash fall hazard modelling

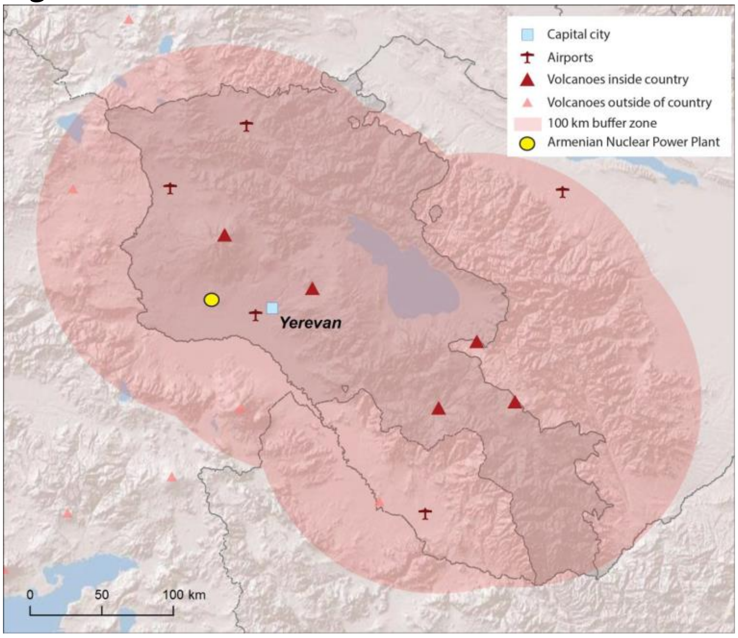
Currently more than 800 million people in 86 countries live within 100 km of a volcano that can potentially erupt. Indonesia, the Philippines and Japan are the countries with the greatest number of people exposed. However some small countries have a higher proportion of exposed population: over 90 percent in Guatemala and Iceland for example. Volcanoes are associated with multiple hazards including: pyroclastic flows and surges; volcanic ash and tephra (large quantities of intensely fragmented rock); ballistics (rocks ejected by volcanic explosions); lahars and floods (fast-moving and destructive mixtures of volcanic debris and water); debris avalanches, landslides and tsunamis; volcanic gases and aerosols; lava flows; earthquakes and lightning. Each hazard affects people, agriculture, the built environment and transport, such as aviation, in very different ways. For example, people living close to a volcano may be at direct risk from pyroclastic flows, avalanches or lahars. At the other extreme, volcanic ash has been associated with climate variability thousands of kilometres from its source.
The first component of GVM/IAVCEI contributions to GAR15 includes in-depth information on:

- Global inventory volcano and their activity rate
- Historical events, mortality data, and impacts
- Scientific description of volcanic hazards, types of volcanoes, and categories of eruption
- Characteristics of vulnerability to volcano hazards, including physical, social, agricultural, etc.
- Description of various methodologies for measuring eruption size, classifying hazard level of a volcano, and description of potential impact.
- Current status of hazard and risk modelling methods
- Current status of monitoring and early warning systems, as well as planning and emergency response practice around the world.

The information can be found in the technical background paper titled: "Global Volcanic Hazard and Risk," (GVM, 2014b). This paper includes 23 case studies from around the world on various topics related to volcanic hazard, risk, and risk management.

The second component of information on volcano hazard and risk consist of regional and country profiles for volcanic hazard and risk, as well as the current status of national capacity in monitoring and early warning and coping capacity. The comprehensiveness of information varies among regions and countries as some elements of the country profiles are developed using data and information contributed directly by the countries.

Figure 14



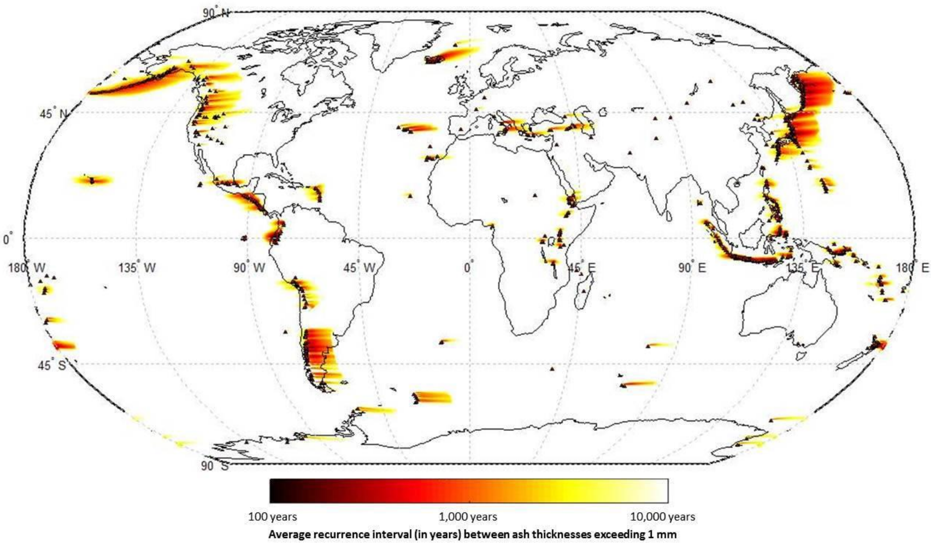
The location of Armenia's volcanoes and the extent of the 100 km zone surrounding them. Airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The regional and country profiles can be found in the background paper titled: "Global Distribution of Volcanism: regional and country profiles", (GVM, 2014c).

The third component is a global probabilistic hazard model for volcano *ash fall* using a methodology developed at University of Bristol. The focus of this assessment is on the ash fall, although the areas affected by volcanic ash are potentially much larger than those affected by ash falling to the ground, as fine particles can remain aloft for extended periods of time. For example, large portions of European airspace were closed for up to five weeks during the eruption of Eyjafjallajökull, Iceland, in 2010 because of airborne ash. In this case associated ash falls outside of Iceland were negligible.

The distance and area over which volcanic ash is dispersed is strongly controlled by wind conditions with distance and altitude from the vent, but also by the size, shape and density of the ash particles, and the style and magnitude of the eruption. These factors mean that ash falls are typically deposited in the direction of prevailing winds during the eruption and thin with distance. Forecasting ash dispersion and the deposition 'footprint' is typically achieved through numerical simulation.

Figure 15



Global map of probabilistic ash fall hazard, displayed here as the average recurrence interval between ash fall thicknesses exceeding 1 mm: a threshold that may cause concern for the aviation industry and critical infrastructure.

The technical background paper titled: "Volcanic Ash Fall Hazard and Risk," (GVM, 2014d) discusses the volcanic ash fall hazard modelling that has been implemented at the global and local (Neapolitan area, Italy) scales. These models are probabilistic, and they account for uncertainty in the input parameters to produce a large number of possible outcomes. Outputs are in the form of hazard maps and curves that show the probabilities associated with exceeding key hazard thresholds at given locations. As with any natural hazard, these results are subject to uncertainty and the local case study describes how ongoing research is working to better quantify this uncertainty through Bayesian methods and models. The report also includes information on potential ash fall impacts.

A summary of three components of GVM contribution written for a non-technical reader can be found in "Global Volcanic Hazard and Risk, a Summary Document," (GVM,2014a).

Agricultural drought hazard and risk

Probabilistic agricultural drought loss model

Agricultural drought hazard is a complex phenomenon and the diversity of modelling methodologies is wider than how other hazards are modelled by various expert groups. For GAR15, a probabilistic agricultural risk analysis used to quantify the agricultural drought on crop losses is based on modeling the water content in the soil needed by the crop to grow, by representing the relationship between this water requirement and other variables such as the potential evapo-transpiration, rainfall, soil water holding capacity etc. The hazard index, in this case the deficit in water content in specific times of the year and for prolonged period of time translates into crop losses.

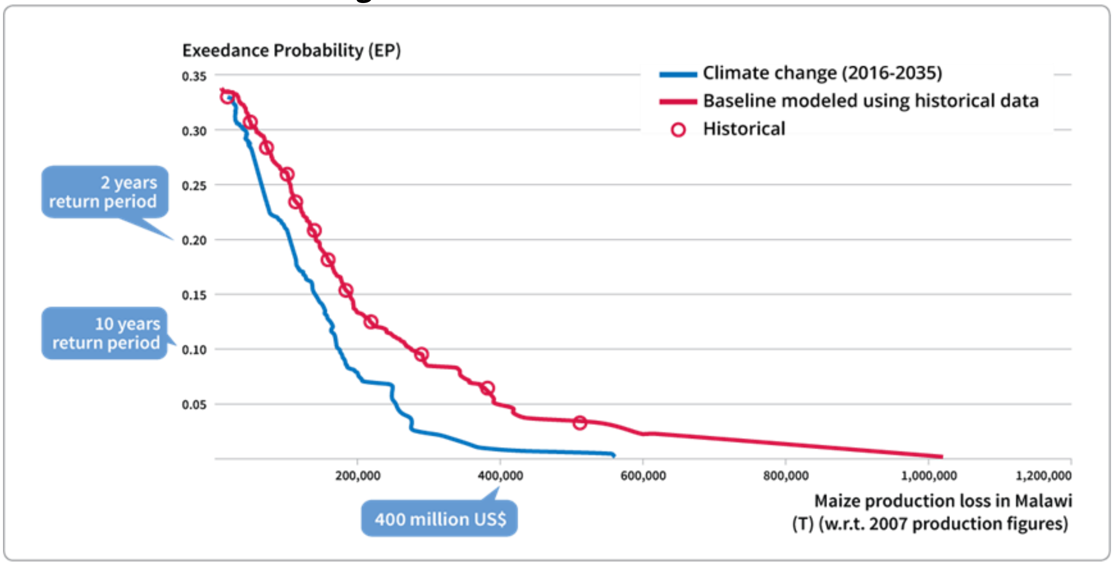
To develop the drought vulnerability curves, the relationship between production loss (yield deficit) of the rainfed crop to varying conditions of the soil moisture stresses in the crop's root zone were used from historical drought datasets.

Areas vs. yield statistics for certain period of times in the past in combination with the rain fall data of the same time period has been used to develop the exposure dataset.

Once these relationships established, FEWSNET algorithms have been used to generate long term (500 years) synthetic rainfall time series based on 1981-2010 rainfall records and to reproduce stochastic time series of water content, which in turns allow reproducing a synthetic series of crop losses. This allow calculating the probability of occurrence of losses of different magnitudes, thus building the loss exceedance curve which shows loss levels for any return period. (Figure X). The results from this model thus include values of Annual Average Loss, in terms of amount of crop losses that on average are lost every year over a long period of time, and Probable Maximum Losses for different return periods (Jayanthi 2014). This work is done for assessing drought losses for maize in Rift Valley, Kenya, maize in Malawi, and millet in Niger.

This work also includes the impact of climate change on agricultural crop losses in three of these countries. The Climate Hazards Group at University of California, Santa Barbara has noted a strong relationship in March-May (MAM) rainfall in the Greater Horn of Africa and West Sahel to Sea Surface Temperatures (SSTs) in the Indian and Pacific Oceans respectively. The approach used in the present study recognized the strengths of climate models in capturing variability and trends in Sea Surface Temperatures (SSTs), while minimizing the impact of less reliable precipitation forecasts. A hazard time series for near-future (2016_2035) climate scenario has been developed by FEWSNET and used for probabilistic loss model with climate change impact for agricultural crop loss of Maize in rift Valley, and Malawi, and Millet in Niger.

Figure 16: Loss exceedance curve for Maize production loss in Malawi. Baseline and near-future climate change scenario.



Source: GAR15 based on Jayanthi, 2014

Land degradation and agricultural drought index

The second set of work that was conducted for GAR15 is a deterministic approach using the Normalized Difference Vegetation Index, which is derived from 10 years of satellite imagery. This data set, which combines data on land use and agricultural information, provided a regional assessment of drought frequency. Combined with GAR 13, the regions that are covered include: Africa, Mediterranean, Middle East, South America as well forest lands of Amazon and Congo Basin. This methodology is useful in that it draws on easily available data and it gives a general overview.

Use of the GAR global risk modelling results

Most of the results from the GAR global risk assessment are produced at global scale and, as such, they should not be extrapolated at local scale. These results should not replace local risk assessment.

The main goal of the UNISDR GAR global risk assessment is to increase countries' awareness and understanding of the economic imperatives of disasters by presenting the results in the context of countries' economic and population indicators. In addition to countries, the GAR global risk assessment has a wide range of users who require different platforms and tools depending on their objectives and technical capacity. The broad range of user entities use the data sets and results of GAR global risk assessment directly, or in combination with other data sets, or as input to other tools to provide the information tailored to a specific sector (health, housing, energy, education and awareness, crisis management, food security, or insurance industry, among others). Few of such entities have accessed the dataset many months in advance of the launch in order to utilize it in their respective tools in a timely manner.

The numerous applications of the current global risk assessment inlcude:

- Raising the awareness of the public, politicians, and practitioners about risk levels and trends, as well as about the spatial characteristics of disaster risk at global level.
- Governments engaged in trans-boundary and regional partnerships implying mutual support and collaboration in case of disasters use the GAR results to have an overview of the risk levels of the partner countries
- International organizations, such as the International Financing Institutions (IFIs), the UN, international NGOs etc., gain an indication of how disasters are likely to affect different countries and use this information for strategic definition, programmatic prioritization and planning, budgeting etc.
- The investor use the results to understanding the overall level of risk, thus to have an indicative measure of the potential losses that a country can face by each hazard. As such, they should be a driver for investors to perform detailed risk analysis, budget for disaster risk reduction as part of their investment planning, and working with governments to reduce the risk for the country in which they invest (or plan to invest)

The brief version of the national risk profiles are developed based on both the GAR15 global risk assessment results and (where available) countries' historical loss databases.

More comprehensive and refined national risk profiles would require close interaction with national governments and technical experts to access higher-resolution data for various components, sectors, and subnational areas. While some countries already have invested in developing their national risk profiles, the GAR15 global risk assessment provides a first cut for a national risk profile in many countries, especially among low-income countries that lack information on the risk they face.

UNISDR has been using different platforms and tools, such as CAPRA-Viewer, and Tangible Earth for GAR, to effectively and comprehensively communicate results, and share data sets and models with beneficiaries and users.

The results and data produced within the GAR global assessment reports are available for viewing and downloading from http://www.preventionweb.net/english/hyogo/gar/2015/

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