Global Assessment Report
on Disaster Risk Reduction

2013 From Shared Risk to Shared Value:
the Business Case for Disaster Risk Reduction

ANNEX 1

GAR GLOBAL RISK ASSESSMENT: DATA, SOURCES AND USAGE

UNISDR Office of United Nations For Disaster Risk Reduction

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Contents

ANNEX 1

GAR GLOBAL RISK ASSESSMENT: DATA, SOURCES AND USAGE

Introduction

The GAR global risk assessment is based on original research carried out by different UNISDR partner institutions, including ACSAD, FEWS-NET, CIMA Foundation, CIMNE and associates, GEM Foundation, Geoscience Australia, NGI and UNEP-GRID. From this research, original data have been produced, new hazard models have been built and existing hazard and risk modelling tools have also been upgraded.

This Annex provides an overview of the models developed and used for the GAR global risk assessment, it recounts their starting point in GAR09 and GAR11 and traces their current status in GAR1. 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 A1.1, mainly following the terminologies adopted for the Global Assessment Report.

Box A1.1 Risk terminology

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

Hazard: Phenomena that can cause negative consequences such as loss of life, economic damages etc. GAR11 uses the term physical (rather than natural) hazard to refer to hazardous phenomena such as floods, storms, droughts and earthquakes.

Exposure: people, factories, offices or other business assets in hazard-prone areas.

Vulnerability: susceptibility of exposed elements or assets to suffer 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. In practice, the so-called empirical frequency (which is the number of times that an event is observed) differs from the theoretical probability, unless we have a very long record of observations.

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 exceedence probability: a 1 in 200 years event has 0.5% of chances to occur or be exceeded every year.

From GAR09 to GAR13 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, 2009). 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.

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 needs 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. This new global risk assessment has been under development since late 2011 and will be completed by 2015.

These losses are calculated by taking into account all the components of the risk: hazard, exposure and vulnerability. The hazard for earthquake, tropical cyclones and flooding is represented trough is produced 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. Once the hazard is 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 GAR13, full global probabilistic risk assessment was carried out for earthquakes and cyclonic wind. Probabilistic risk methodology and models were also developed for flood and agricultural drought, although the assessment was not carried out globally. Major improvements in tsunami probabilistic hazard assessment was also achieved. For landslides, given the complexity of the phenomenon, a methodology based on local data was implemented for the case of El Salvador.

The recipe of risk: exposure, vulnerability and hazard for earthquakes, flood and cyclonic wind

Flood, earthquake and cyclonic risk assessments were carried out using the Global Exposure Database developed for GAR13, and the same risk modelling tool (CAPRA-GIS, www.ecapra.org). The exposure, hazard, vulnerability and risk models for those hazards are therefore described together in this section.

The Global Exposure Database (GED)

A Global Exposure Database (GED) was developed for GAR13 by CIMNE and associates and UNEP-GRID. This database includes estimation on the economic value of the exposed assets, as well as their physical characteristics in urban agglomerations. This information is key to assess the potential damages from different hazards to each of the exposed elements.

The GED includes economic value and number of residents in dwellings, commercial and industrial buildings, as well as hospitals and schools (see De Bono, 2013). The physical areas were defined using an urban mask based on MODIS land cover (Schneider et al, 2009) and were divided into rural, minor urban and major urban areas. Number of people living in urban areas were extracted from the global population distribution data LandScanTM (ORNL, 2007).

For each country, the percentage of building for each building class at country level, were derived from various sources, including the World Housing Encyclopaedia, which are detailed in WAPMERR, 2013. The exposure is calculated by aggregating the urban areas in 5 Km x 5 Km cell grids (**Error! Reference source not found.**). Each cell contains information on the total area for each building class, reconstructed starting from the information on the population (such as income levels, occupation, scholarization etc.).

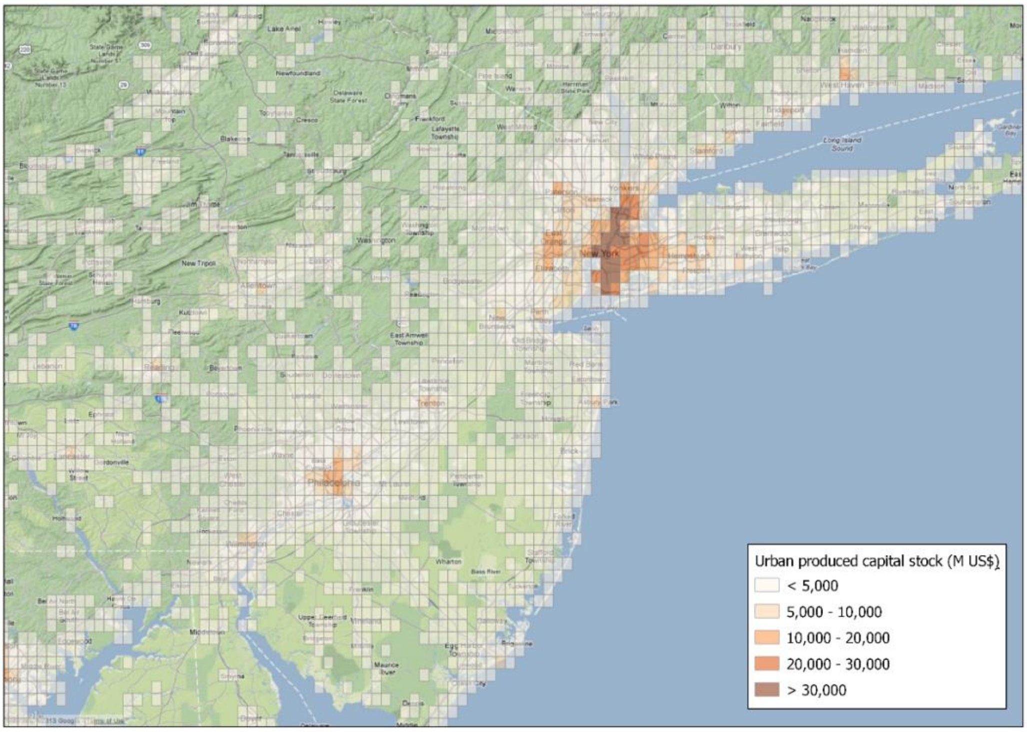

Figure 1: Example of the 5Km x 5Km grid constituting the exposure database

The economic value of each building class in one cell was then assessed based on the disaggregation of the (national) Produced Capital at cell level. This downscaling was done by using the sub-national values of GDP as a proxy (see CIMNE et al., 2013). The result is the global distribution of the economic value of the urban produced capital by building class (Figure **2**).

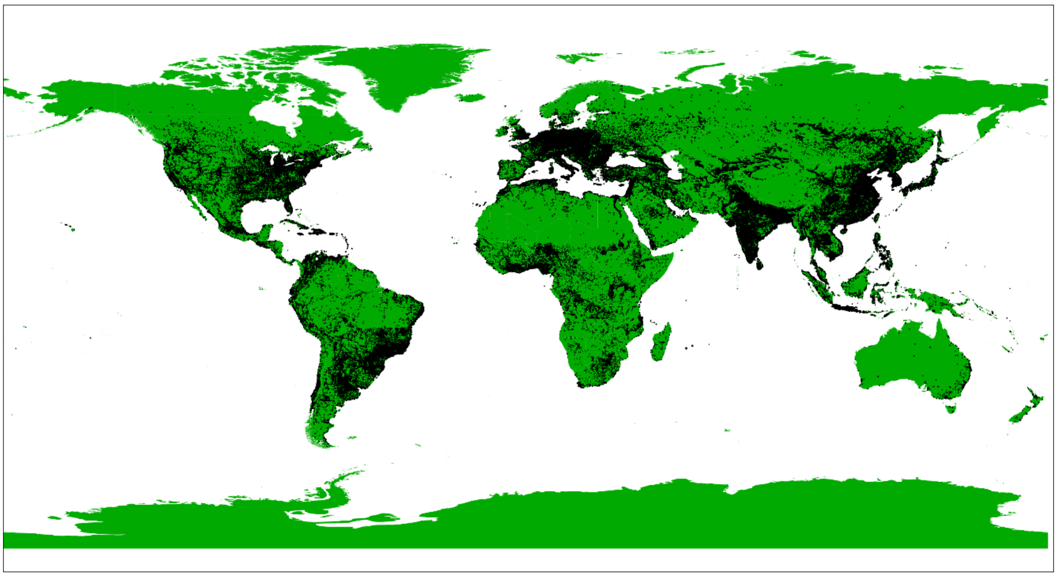

Figure 2: Distribution of the urban produced capital obtained for the Global Exposure Database

Further details on the GED can be found in De Bono, 2013; WAPMERR, 2013 and CIMNE et al., 2013.

Earthquake hazard

The earthquake hazard was calculated starting from identification of the principal seismic sources based on geological and neotectonical information, to characterize the tectonic regions and seismic provinces.

These data, together with the information on past earthquakes included in the USGS NEIC catalogue, allowed generating a set of stochastic earthquake scenarios (compatible with characteristics of location, depth, frequency and magnitude).

For the Global Assessment Report, the calculation of the earthquake scenarios was carried out using the program CRISIS 2012 (Ordaz et al., 2012), that is compatible with the CAPRA modelling suite (www.ecapra.org). Further details on the methodology are provided in CIMNE et al., 2013.

Each of the modeled seismic event provides, in each point of the 5x5 km grid, the intensity (level of hazard) for the same event. For earthquakes, this is represented by the ground shaking, expressed in terms of spectral accelerations. This hazard characteristic is then combined with the exposure characteristic to assess the possible future losses. The combination of the modelled losses for each building class in each cell of the exposure grid is used to calculate the seismic risk for the cell.

Cyclonic wind hazard

To model cyclonic wind hazard, information on the wind fields, terrain roughness and past cyclone tracks were used. For the model developed for GAR13, the topography was derived from NOAA, while the terrain roughness was derived by combining the global coverage from the GlobCover initiative with the urban coverage provided by the Socioeconomic Data and Applications Centre, SEDAC. Track information from the IBTrACS database of NOAA were also used. From each of the tracks in the NOAA cyclone catalogue, series of “children tracks” were stochastically derived.

These propagation of the wind field for these tracks was calculated using the Hurricane model of the CAPRA risk modelling suite (www.ecapra.org). This model is based on field equations that consider the cyclone forward speed, cyclostrophical speed, central pressure, track-to-site angle and eye location latitude (CIMNE et al., 2013).

This model represents only wind speed, which means that tropical cyclone losses estimated for GAR13 only consider damages caused by cyclonic wind. Storm surge is another hazard directly caused by cyclones, and it is likely to contribute substantially to the losses caused by this hazard. This, however, is not considered here and will be included in the 2015 GAR. The introduction of flooding due to cyclonic surges will also partially cover the need of covering coastal flood risk (derived from storm surge), which is not included in the current flood model.

River flood hazard

A new, fully probabilistic Global Flood Model is being developed as part of the GAR Global Risk Model.

This model calculates flood discharges associated to different return periods, in each of the world's major river basins. The flood discharges statistics are calculated starting from the information available from 7,552 gauging stations worldwide. Where time series of flow discharges are too short or incomplete, these series were improved with data from stations located in the same "homogeneous region". Such homogeneous regions were calculated taking into account information such as climatic zones, hydrological characteristics of the catchments and statistical parameters the stream-flow data. Once the probabilistic discharges are calculated, the model input them into the river sections, whose geometry are derived from topographic data. Then a simplified approach (based on Manning's equation) is used to model the water levels downstream.

This new approach of modelling flood risk overcomes some of the limitations of the previous model developed for GAR11. For instance, it is able to model large river flood risk and take into account the lamination effect due to large water retention structures such as dams and reservoirs. The full technical description of the model can be found in Herold et al., 2013.

The results of the first proof of concept were provided for GAR13. The Global Flood Model will be further improved, and the full results will be made available in 2015.

Ponding flood hazard

A different approach was used to understand possible damages due to flooding in some Caribbean countries. The direct runoff of the rainfall water causes extensive flooding events in these countries where an underdeveloped river network exist and flooding is caused by several ephemeral streams that concentrate the high rainfall intensities into morphologically convergent areas. To understand how this phenomenon would translate in average annual damages, a model able to represent this type of hazard was developed.

The model used for GAR13 was developed purposely for the GAR, and it starts from the elaboration of three basic inputs: digital elevation maps, land use maps and precipitation data. From the latter the model calculates a series of stochastic events that can be used to assess the probabilistic damage assessment (Rudari et al., 2013). The model is based on a method that reproduce the spatial diffusion of the rainfall water through the topography. The rainfall is derived from analysis of climatologic parameters and rainfall maps, to generate probabilistic rainfall scenarios. For each scenario, the rainfall is then converted to water runoff using a modified version of the Curve Number – SCS method. Each of the cells representing the analyzed domain is assigned a "retention capacity", function of the land cover and soil type, and a "drainage efficiency", function of the terrain's slope at the cell. When retention capacity and drainage efficiency are smaller than the rainfall intensity the water transfers to the next cell. The velocity in which the water is transferred is function of the local hydraulic gradient. Using this method it is possible to calculate the flood depth associated to each scenario. For each return period, 100 scenarios were built to allow obtaining both the average water depth and the standard deviation, which are needed for the probabilistic risk calculation using the CAPRA-GIS.

Vulnerability functions

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 a specific hazard. This is done by defining relationships between a measurement parameter of the hazard (e.g. water depth in case of flooding or the spectral acceleration in the case of earthquakes) to the likely damage 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 as well as the variance, representing the probability distribution of the losses that are likely to occur following the given hazard intensity (Figure 3).

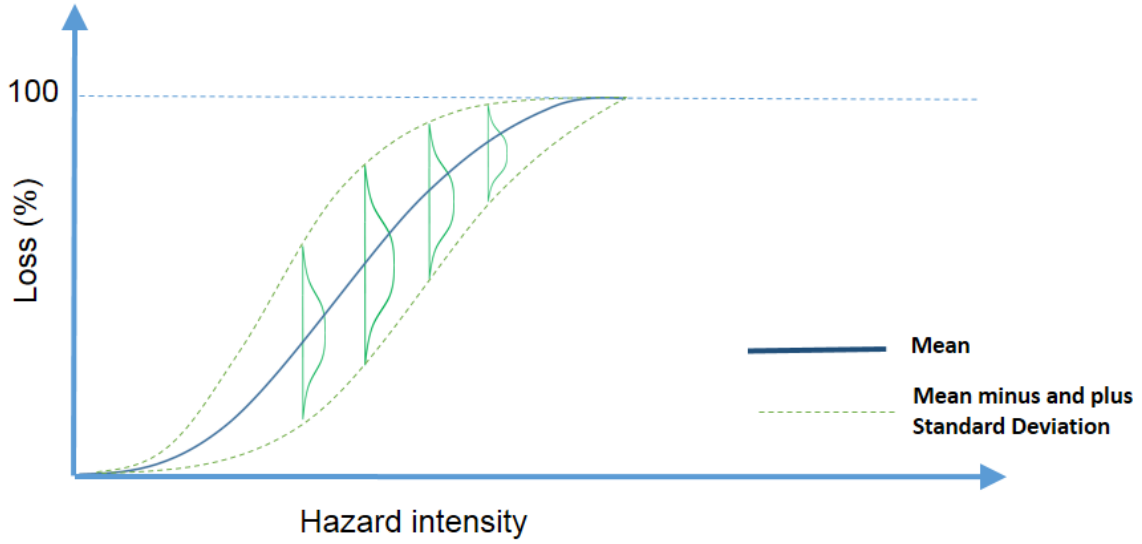

Figure 3: example of vulnerability curve

Therefore for each hazardous event, and for each building typology in each cell, a probability distribution of the losses is calculated.

The vulnerability functions used for the GAR13 global risk assessment are based on those developed for the HAZUS-MH (CIMNE et al., 2013), taking into account different resistant construction qualities and level of countries' development (for which depends, for example, the completeness and application of building codes).

Risk assessment

For GAR13, the risk was calculated with the CAPRA-GIS platform which is risk modelling tool of the CAPRA suite (www.ecapra.org). 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).

The CAPRA model follows a state-of-art procedure for calculating risk. In each point of the exposure database, and for each building class in the point, the risk is calculated by assessing the damage caused by each of the modelled hazard events (Figure 4).

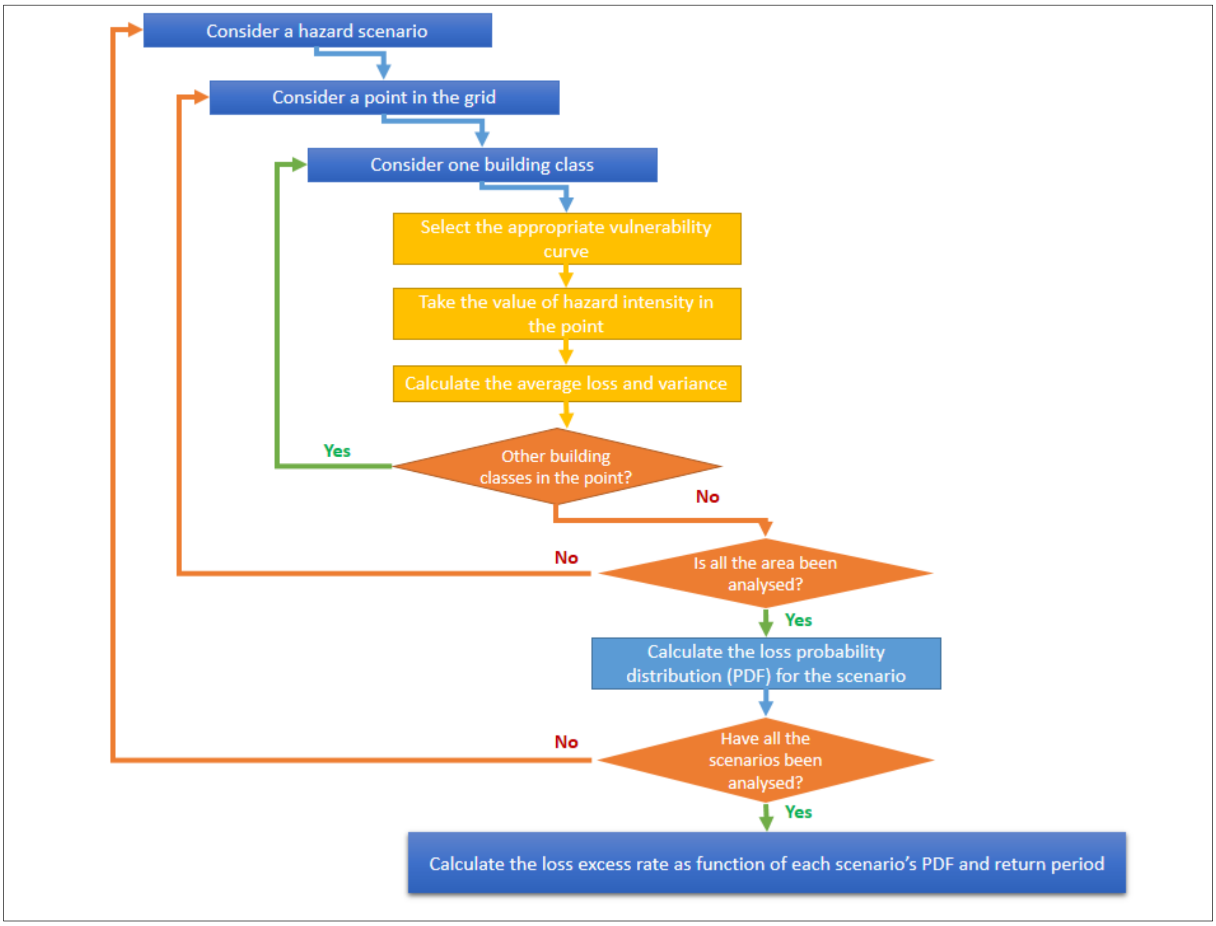

Figure 4: simplified flowchart of the procedure followed for risk calculation

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

Therefore, in each point of the space, for each modelled event, and for each building class, 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 5).

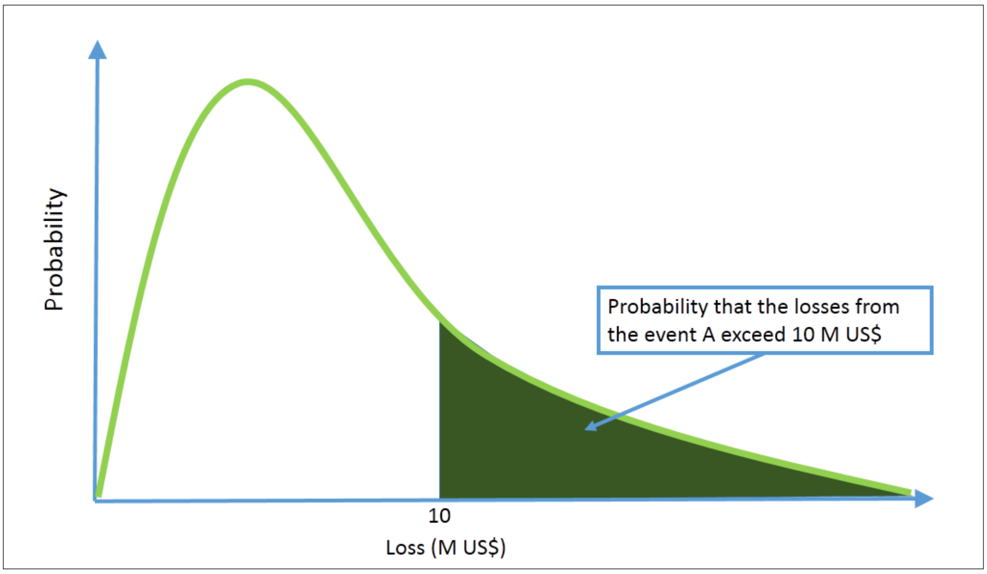

Figure 5: Probability distribution of losses for one event

The combination of all these distributions, for all the building classes and the points of the exposure database, produce the loss exceedance curve for the country, which likewise represents the probability distribution of losses in the country (Figure 6). 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 ("Excess Rate") in each given year.

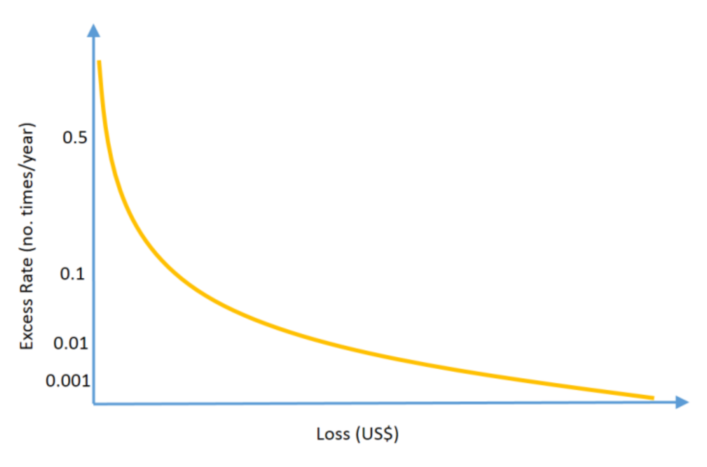

Figure 6: Example of loss exceedance curve

The integral of the loss exceedance curve (the area underneath the curve) is the Annual Average Loss (AAL). For GAR13, the full loss exceedance curve was not calculated, and instead the AAL was calculated by a mathematical approximation of the integral:

$$AAL = \sum_{i=1}^{N} E(P|S_i)F_i$$

where: *E* is the expected value of the loss *p*, conditional to the occurrence of the event S*i*; *i* goes from 1 to *N*, where *N* is the total number of events; and F_i is the annual occurrence frequency of the event *i*. Further details on the risk calculation are provided in CIMNE et al., 2013.

The AAL provides an estimator of losses that are likely to occur every year due to a specific hazard. As GAR global risk assessment is performed at global scale, the AAL assessed should be read as order of magnitude for the potential recurrent extent of losses in a country.

Another outcome from this analysis is the Probable Maximum Loss (PML), which are the loss expected associated to long return periods, for example 100, 200 or 500 years (depending on the hazard and the needs of the stakeholder). For GAR13, the return period of 250 years was used to assess the PML. This does not correspond to a loss that will happen exactly every 250 years, but to an event that has 0.4% of chances to occur in one year. The PML calculated for GAR13 should be read as a loss that might occur, which the society should anyway be required to brace. The full PML plot has been calculated for a set of countries and it is expected to be obtained for each country in the GAR15 using the same methodology.

Both AAL and PML estimated for GAR13 should therefore be used to understand what are the possible cost-benefits of interventions, and what are the potential extent of losses that can occur in a country due to earthquake and cyclonic wind hazard. For many countries, these values show that the cost in of carrying on detailed risk assessment analysis is irrelevant compared with the yearly probable losses. This detailed analysis would provide an important guidance on interventions to prevent future losses.

Although following a rigorous methodology, the values obtained from the model have an intrinsic degree of error. These are due to the simplification of the ‘real world’ through the modelling process but also to the limitations of the input data at each stage of the modelling (hazard, exposure, vulnerability). Examples of main potential sources of errors for the GAR13 model include: the assessment of the exposed value, which started from produced capital and building classes defined at national or sub-national level; the simplifications necessary to model the hazards at global scale; the use of non-country-specific vulnerability curves. The level of uncertainties from this simplification, even if it could be reduced with improving some of the input data, is considered acceptable for global scale model. As such these AALs should be considered as starting points to understand the degree of losses to which a country is subject every year, and to plan and budget actions for reducing these losses, including developing risk assessments at local scale.

Tsunami hazard and exposure

The global tsunami modelling carried out for GAR13 constitutes an improvement to the first global scale tsunami hazard and exposure assessment carried out for GAR09. In comparison with the previous study, the new model provides a more complete coverage of tsunamigenic earthquake sources globally. This allowed improving the model in many locations, such as East Asia and Europe. Another update in the new model consists in the use of two different methods for establishing the hazard. In some areas the methodology applied for GAR09, based on scenario analysis, was improved in the input data and applied for a greater number of sources. For the Indian Ocean and the South West Pacific, a probabilistic method was applied instead. This method, called Probabilistic Tsunami Hazard Assessment (PTHA), instead of assigning one rupture mode for each tsunami source, calculates a set of synthetic earthquakes to obtain a distribution of possible run-up heights rather than one value per location.

The hazard was calculated corresponding to return period of 500 year, imposing the convergence rate of the subduction zone and a locking of the fault during more than 500 years. Due to the infrequency of the tsunamis only earthquakes with 500 years return period were considered. These are those that are expected to provide the largest contribution to tsunami risk, thus are the first considered in this analysis. Further development of the model will include a range of tsunami return periods to better estimate the risk.

Reconstructing stochastic events for very long return periods is a non-trivial task. As the history of records for such events is limited, it is difficult to model them, particularly due to the large area represented in the model. Therefore, the return period attributed for the model needs to be considered as an estimate, and some events might have a slightly lower or higher return period than 500 years. Full details on the methodology and the results can be found in NGI, 2013a.

For GAR15 fully probabilistic model will be developed, which will provide a full risk assessment as those carried out for earthquakes and cyclonic wind.

Landslide hazard and risk

As GAR09 highlighted, 80% of global landslide risk is concentrated in 10 countries in the world. Landslides are mainly triggered by earthquakes and precipitations. The susceptibility of an area to landslides depends on different factors, such as the slope of the terrain, the type of soil and the moisture content. The physic of a landslide event is complex, as strongly depends on the triggering factors as well as the geophysical characteristics of the soil. Similarly, consequences strongly depends on the type of landslides, but also on the location of the exposed elements on respect of the event. As such it is difficult to reproduce the physics of this hazard as well as assessing the consequences with a global model.

Due to the risk being concentrated in a limited number of countries and the complexity of building a global model, the risk from landslides has been appraised by the GAR through local drill downs.

The applied methodology correlates triggers, susceptibility factors and potential consequences using different statistical techniques, validated to recorded events (NGI, 2013b). This does not constitute a fully probabilistic approach, as although the definition of the hazard takes into account the probability of occurrence of an event, the method does not explore the full spectrum of potential consequences, as the correlation is based on events that are occurred within the limited time span of the losses database.

However, this method allows assessing the landslide hazard and potential consequences at national level, and can be extremely useful if detailed information (e.g. local geotechnical surveys) are not available.

For GAR11, the landslide risk in Indonesia was studied. For GAR13, a drill-down study has been carried out for El Salvador, whose results have been shown in the main report. The results from this study could not be interpreted in terms of potential consequences as it was not possible to establish a robust correlation with the hazard and the loss data. However, the model produced a good description of the hazard based on an extensive dataset including topography, land cover, and rainfall and earthquake at national level. The hazard results can be overlapped to the population distribution, to highlight the areas where the risk of landslides is likely to be higher. The results from the GAR13 study can be used to highlight which areas are critical in terms of hazard and exposure, for which detailed analysis should be undertaken. Further details on the methodology and the results can be found in NGI, 2013b.

Agricultural drought hazard and risk

As explained in the GAR13 report, the agricultural hazard is a complex phenomenon that cannot be easily reproduced using model describing the physical laws governing the event, as for other hazards. For GAR13, the agricultural drought was analyzed following a deterministic approach and a probabilistic approach.

The deterministic approach developed for GAR13 is based on a standard technique consisting of analysing the Normalised Difference Vegetation Index (NDVI), which is derived from satellite images. Studying the variations of this index for the past 10 years, together with the land use and the information on agricultural seasons, it is possible to have a regional indication of areas where drought may have occurred in the past 10 years. This methodology, albeit simplified and not providing a probabilistic assessment of the drought hazard, requires minimum data and it is useful for a general overview (Erian et. al, 2012).

The second approach adopted for GAR13 reproduces stochastically the relationships between the various factors (including precipitation, temperatures and soil conditions) and drought hazard or crop losses. The technique is based on modeling the water content needed by the soil to develop vegetation, by representing the relationship between this water requirement and other variables such as the potential evapo-transpiration, satellite-based rainfall, soil water holding capacity etc. The deficit in water content in specific times of the year (i.e. when the germination occurs) and for prolonged period of time translates into crop losses, which are also determined stochastically by relating known water deficits with data on crop losses. Once these relationships established, it is possible 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 as those seen in section 2. 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, and Probable Maximum Losses for different return periods (Jayanthi and Husak, 2012).

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 GAR global risk assessment provide an indication of the level of the levels of hazard, exposure and risk at national level. Once the level of risk and the potential losses are known, they cannot easily be ignored by the public and private sectors.

Some examples of uses of the results from the GAR global risk modelling are presented here:

- The results from the GAR global risk assessment can be used by government's officials and ministries as case to support the funding of local risk assessments, as well as encouraging countries to act upon disaster risk
- Governments engaged in trans-boundary and regional partnerships implying mutual support and collaboration in case of disasters (e.g. ASEAN) can 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., can 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 results can be used by investor to understanding the overall level of risk, thus to have an indicative measure of the potential losses that a country can face by which hazards. 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)

- Similarly, organizations representing small-medium enterprises (the commercial entities that are usually most affected by disasters) can use the GAR global risk assessment to have a broad estimation of how major hazards could translate in direct losses, and act upon it by encouraging businesses to assess their particular risk and leverage governments to adopt DRR strategies.

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

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