

**Words into Action Guidelines:
National Disaster Risk Assessment
Hazard Specific Risk Assessment**

4. Flood Hazard and Risk Assessment

Key words:

floods, flood hazard map, historic flood risk assessment, preliminary flood risk assessment (PFRA), flood risk assessment (FRA)

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Description of the hazard, sources and setting

Water is a resource before being a threat. That is why it would be of little use to consider flood risk assessment (FRA) by itself without casting it in the framework of flood risk management and water management at large. Any measures undertaken to reduce flood risk have an effect on other segments of water use (e.g. potable water, industrial use and irrigation, recreation, energy production) and many of them modify flood risk in different geographical areas.

Flood risk can be analysed through the lenses of the main terms of the risk equation: hazard, vulnerability, exposure and capacity. In comparison to other types of risk, flood suffers from a very strong imbalance in the level of maturity in assessing the different elements: whereas hazard modelling is well advanced, exposure characterization and vulnerability analysis are underdeveloped.

This section presents some highlights on the most developed practices for flood risk assessment without entering into the details of specific methodologies. It will try to clarify the states of research and practice in FRA in relation to different uses of flood hazard and risk information. It will also discuss the issue of scale, the challenge in capturing flood correlation on large-scale events, the need to consider climate change, and the strong links with other perils determining complex multi-hazard scenarios.

Flooding occurs most commonly from heavy rainfall when natural watercourses lack the capacity to convey excess water. It can also result from other phenomena, particularly in coastal areas, by a storm surge associated with a tropical cyclone, a tsunami or a high tide. Dam failure, triggered by an earthquake, for instance, will lead to flooding of the downstream area, even in dry weather conditions. Various climatic and non-climatic processes can result in different types of floods: riverine floods, flash floods, urban floods, glacial lake outburst floods and coastal floods.

Floods are the natural hazard with the highest frequency and the widest geographical distribution worldwide. Although most floods are small events, monster floods are not infrequent.

In 2010, approximately one fifth of the territory of Pakistan was flooded, affecting 20 million people and claiming close to 2,000 lives. The economic losses were estimated to be around US\$ 43 billion. One year later, another monster flood struck South-East Asia. The flood event extended across several countries and a few separate limited flood events affected parts of the same countries: Thailand, Cambodia, Myanmar and Viet Nam. Meanwhile, the Lao People's Democratic Republic also sustained flood damage, with the death toll reaching close to 3,000.

If we consider only Thailand in terms of economic losses, this flood ranks as

the world's fourth costliest disaster as of 2011,¹ surpassed only by the 2011 earthquake and tsunami in Japan, the 1995 Kobe earthquake and Hurricane Katrina in 2005.

The 2014 floods in South-East Europe killed 80 people and caused over US\$ 3.8 billion in economic losses; and the levee failures in Greater New Orleans in 2005 during Hurricane Katrina, the costliest disaster from a natural hazard in the United States in recent history, caused losses of around US\$ 150 billion.

Flood magnitude depends on precipitation intensity, volume, timing and phase, from the antecedent conditions of rivers and the drainage basins (frozen or not or saturated soil moisture or unsaturated) and status. Climatological parameters that are likely to be affected by climate change are precipitation, windstorms, storm surges and sea-level rise.

Climate change has a prominent role when assessing flood risk, as it is captured in many legal documents and directives. However, the uncertainty connected to climate-change impacts on flood hazard and vulnerability sometimes limits the possibility of evaluation adaptation measures according to classical methodologies such as cost-benefit analysis. It is therefore suggested to tackle the problem by adopting the following guidelines.

First, base the risk assessment studies on a sufficiently large climate-change scenario ensemble in order to capture as much as possible the uncertainty associated with such evaluations. Second, choose robust strategies of adaptation rather than aiming at optimal ones, focusing on the ones that meet the chosen improvement criteria across a broad range of plausible futures. Third, increase the robustness of the adaptation process by choosing "adaptive" strategies that can be modified as the future scenarios unfold.

Including climate change in a scientifically sound way in flood risk assessment and management remains a challenge. The basic concepts that represent the basis of decision-making are sometimes being invalidated. As an example, the widely used concept of "return period", at the basis of flood protection design targets, needs to be rethought in a non-stationary context as the one put forward by climate change. Therefore, new approaches have to be developed so that the risks can be quantified.

In the stationary case, there is a one-to-one relationship between the m-year return level and m-year return period, which is defined implicitly as the reciprocal of the probability of an exceedance in any one year. Return periods were assumedly created for the purpose of interpretation: a 100-year event may be more interpretable by the general public than a 0.01 probability of occurrence in any particular year.

1 From World Bank estimates.

Hazard assessment

The sudden changes of the inundation maps and flood hazard maps is a distinctive feature that influences flood hazard assessment. This implies that different methodologies are needed to define flood hazard when different scales are considered.

Implementing very detailed inundation models is often very expensive: data hungry and calibration intensive. That is why flood hazard and risk assessment exercises are often broken down into two stages: a preliminary flood risk assessment (PFRA)² and a final, more detailed, flood risk assessment (FRA).

PFRA is extensive geographically and in terms of the flooding mechanisms considered (i.e. different types of floods), while it uses approximated approaches to hazard and many times neglects vulnerability. PFRA has the objective of defining priority areas for further characterization with advanced models using detailed information about topography (digital elevation models (DEMs)), break lines and flood defences.

In this way resources are invested where risk is higher, maximizing the return on investment in detailed assessment in areas where high social and economic value are threatened. Attention should also be paid to areas of potential new development that might not appear as priorities in the preliminary assessment from the point of view of exposure and existing risk.

PFRA is related to areas where potential significant flood risks exist or are probable in the future. Such areas are identified as "areas of potentially significant flood risk"(APFSR). If in a particular river basin, sub-basin or stretch of coastline no potential significant flood risk exists or is foreseeable, no further action would have to be taken. If APFSR are identified, a full detailed flood hazard and risk assessment should be undertaken.

As in the case of all natural and technological hazards, and both in the case of PFRA and the full FRA, the hazard assessment needs to physically and statistically model the initiation event (i.e. the trigger, which is usually rainfall)³ and after that to model the run-out/evolution of that event. In the case of fluvial flooding hazard, the run-out is modelled using a hydrological model to properly assess the routing of precipitation from rainfall to runoff and a hydraulic model to evaluate in detail the spatial extensions of floodable areas.

After the hazard assessment is completed, a risk assessment should be conducted. FRA should quantitatively assess the potential adverse

² A Communication on flood risk management: flood prevention, protection and mitigation. Available from http://ec.europa.eu/environment/water/flood_risk/com.htm

³ Many other triggers for flooding exist, e.g. sudden outbursts from glaciers (ephemeral lakes), collapses of hydraulic structures such as dams or levees, surges caused by wind, tides.

consequences associated with flood scenarios and should consider impacts on the potentially affected inhabitants, on the relevant economic activity of the potentially affected area and on all relevant risk receptors.

The definition of risk receptors is also a political decision and a discussion phase with relevant governmental bodies and stakeholders should be made. In both PFRA and FRA, a combination of the following approaches should be used when possible:

- Historic flood risk assessment: information on floods that have occurred in the past, both from natural sources of flood risk and floods from infrastructure failure.
- Predictive analysis assessing the areas that could be prone to flooding, as determined by predictive techniques such as modelling, analysis or other calculations, and the potential damage that could be caused by such flooding.
- Expert opinions especially of departments and agencies to identify areas prone to flooding and the potential consequences that could arise both as a validation step and as complementary information for the predictive analysis.

In the case of flood risk, this type of approach connects to the planning phase that informs land-use planning in order to not create new flood risk by locating new assets in flood-prone zones and, if possible, to reduce the current level of risk by strategies for modifying the land use or developing appropriate flood protection.

Therefore, the main tools to use are the hazard maps; and risk maps are intended as a simple overlay of hazard maps and exposure in order to identify the exposed elements on which to intervene; while a full probabilistic approach, based on the development of a full scenarios set, is often neglected.

The outputs of probabilistic quantitative risk approaches are the probability of occurrence of certain loss levels usually presented as risk curves (a) plotting expected losses against the probability of occurrence for each hazard type individually and (b) expressing the uncertainty by representing a probability distribution at each point of the curve, in many cases drawn as a confidence interval at a certain significance level or generating at least two loss curves expressing the minimum and maximum losses for each return period of triggering events and associated annual probability.

The risk curves can be made for different reference asset units, e.g. administrative units such as individual slopes, road sections, census tracts, settlements, municipalities, regions, provinces or a country.

Whereas for some hazards (e.g. seismic hazard) quantitative approaches to

risk assessment are frequently fully probabilistic in nature, this is not always so for floods. Many times, the approach to flooding assesses the geographical distribution of the severity of loss due to the occurrence of a postulated event (i.e. scenario) or based on a hazard map with assigned frequency, which does not take into consideration spatial correlation within a catchment or among different catchments.

Source events are non-homogeneous in space and non-stationary in time, and the probability of a source event is a complex function of both location and time. For rainstorms, in any given year, the probability of a source event depends on spatial differences in topography and atmospheric circulation patterns that change relatively slowly with time (here, atmospheric circulation patterns refer to average annual climatic conditions, not day-to-day variability).

Among all source events, rainfall probabilities are among the most difficult to model because of the unlimited scope of potential source events that must be considered when evaluating flood hazards. Every rainstorm has a different temporal and spatial signature that defies classification, although some classification attempts can be found in the literature.⁴

Even an objective definition of an event, especially when large spatial domains are considered, magnitude is still a debated research topic that hampers the definition of proper magnitude-frequency relationships, constraining scientists to less efficient scenarios simulation methodologies. Eventually, the very expensive modelling of the flooding process sometimes causes the impossibility of using methodologies (e.g. logic trees) for uncertainty estimation and propagation that are widely used in other “hazard” communities. All of these reasons make probabilistic risk assessment a challenge in the case of floods.

Nevertheless, the management of flood risks is based on a judicious combination of measures that address risk reduction, retention and transfer through a strategic mix of structural and non-structural measures for preparedness, response and recovery.

Decisions have to be made on how to share the cost of taking risk among governments (central, regional and local governments), interested parties (such as private companies), communities and individuals. This is even more true if we consider that vicinity to water is an advantage for all main human activities (e.g. urban development, transport, energy production, entertainment) and coastal and flood-plain areas are valuable assets in this sense. Therefore, a full quantitative assessment based on a fully probabilistic approach is essential to properly meet the flood risk management objectives.

⁴ Pinto, J. G. and others (2013). Identification and ranking of extraordinary rainfall events over Northwest Italy: the role of Atlantic moisture. *Journal of Geophysical Research – Atmospheres*, 118, doi:10.1002/jgrd.50179

DTM	National cartographic institute	SRTM Global DEM, ASTER G-DEM
Land cover/ Land use	National cartographic institute	Global Land Cover from different organizations (NASA, FAO), GlobCover from Envisat/Meris, MODIS GlobCover
River hydrography	National cartographic institute	Hydrosheds
Rainfall data	National hydro-meteorological services	gauge data sets (e.g. CRU TS , GPCC , APHRODITE , PREC/L), satellite-only data sets (e.g., CHOMPS) and merged satellite-gauge products (e.g. GPCP , CMAP , TRMM 3B42)
Streamflow data	National hydro-meteorological services	Global Runoff Data Centre (GRDC)
Geologic/ pedologic/soil parameters	National cartographic institute	Harmonized World Soil Database
Dams	National dam-regulation body	Global Reservoir and Dam Database

Exposure and vulnerability

Table 1 - Some of the key basic data sets to perform a flood hazard assessment

Vulnerability represents a crucial step in properly evaluating flood impact and all quantitative indicators that are the final product of probabilistic risk assessment. So far, in flood risk assessment, this is probably the weakest link. Convincing methodologies exist to evaluate social vulnerability to floods⁵ and can be considered up to the reliability level that is expressed for other hazards.

When a more quantitative vulnerability assessment for floods is needed, which involves as a first step the evaluation of the physical damage through a vulnerability or fragility curve or table, the level of accuracy and data availability is still a challenge.

For seismic risk, the loss quantification is driven by the necessity of evaluating residual risk in the aftermath of an event to quantify the numbers of displaced

⁵ Samuel Rufat and others (2015). Social vulnerability to floods: review of case studies and implications for measurement. *International Journal of Disaster Risk Reduction*, vol. 14, part 4, pp. 470-486. Available from <http://dx.doi.org/10.1016/j.ijdr.2015.09.013>

people that need to be managed. This results in a more organized and refined loss data collection.

For floods, structural safety is less of a concern and the loss data gathering is less structured, resulting in heterogeneous data sets that could hardly be used to derive empirical vulnerability curves. Additionally, a large part of the loss is due to the damaged content, which increases the data variability, hampering the application of regression methods to derive vulnerability curves directly from the data. Physical modelling of vulnerability to floods is based on isolated attempts due to the high cost of this approach, which is not compensated by other applications as in the case of other perils (e.g. for seismic for the evaluation of retrofitting strategies).

Expert judgement remains the most diffuse approach. However, as flood vulnerability is affected by factors such as settlements conditions, infrastructure, policy and capacities of the authorities, social inequities and economic patterns, expert judgement is sometimes unable to capture all these aspects. Therefore, a competent mix of expert judgement verified by field data seems the most robust methodology to derive quantitative vulnerability curves.

Vulnerability assessment is closely related to the ability to properly characterize the exposed elements to floods. The exposure characterization is another field where cooperation in a multi-hazard framework would be beneficial for different reasons. Although some exposure characteristics are functional to the flood vulnerability assessment only (e.g. the height of the entrances with respect to the street level) most are common and could be collected in a joint effort when performing a full disaster risk assessment study. To make this process efficient, proper standardization would be needed, starting from the taxonomy up to the IT formats to describe the assets.

Exposure data class	Parameter to be collected relevant to FRA
buildings	monetary value
buildings	type of construction
buildings	building height
buildings	ground floor use
buildings	main occupancy
critical infrastructures	critical facilities
critical infrastructures	line infrastructures
population	population distribution
population	age distribution
population	gender distribution
land use	predominant land-use type
land use	monetary value per m ² /ha/km ²
economy	workplaces
economy	gross domestic product
economy	income distribution

Table 2 - Some of the key attributes to be collected for exposure

Risk assessment and use in national DRR measures

Floods are the most frequent and damaging in terms of cumulative and annual expected loss (AEL) worldwide. People tend to gather close to rivers and lakes or concentrate in the coastal areas because water is a resource before being a threat: this determines a high that concentration of assets, and therefore a high level of risk, in flood-prone areas – a tendency will likely increase in future.

Flood risk assessment, therefore, needs to be closely linked to flood management or even integrated flood management, where the goal is to maximize the net benefit from the use of flood plains rather than try to fully control floods.

In this sense it is necessary to put forward the concept of integrated flood management. This concept is promoted by the Associated Programme on Flood Management (APFM) of both the World Meteorological Organization (WMO) and the Global Water Partnership; it manages flood risk through the application of risk management principles such as:

- Adopting a best mix of strategies
- Reducing vulnerability, exposure and risks

- Managing the water cycle as a whole by considering all floods, including both extremes
- Ensuring a participatory approach
- Integrating land and water management, as both have impacts on flood magnitudes and flood risks
- Adopting integrated hazard management approaches (including risks due to all related hazards such as landslides, mudflows, avalanches, storm surges) and creating synergies.

A guidance document has been developed by APFM to support the design of well-balanced strategies for Integrated Flood Management.⁶

The last point ties into one of the other peculiarities of flood risk, which is the strong correlation with other perils that are either triggered by the same event or that materialise as a cascading effect either downstream or upstream of the flood event. A complete flood risk assessment should take into consideration those aspects at least in a worst-case scenario approach.

Floods are in essence a multi-hazard phenomenon, as their trigger (e.g. storm) frequently brings along compound effects (e.g. combined riverine flood and storm surge in coastal areas), coupled effects (e.g. diffuse landslides during high-intensity precipitation events), amplification effects, disposition alteration and cascading effects. It would be an incomplete risk assessment if those conditions were not taken into account at least in a qualitative way.

However, despite the growing demand for multi-hazard risk assessment capabilities worldwide, and the many global initiatives and networks that develop and deliver natural hazard and risk information, the focus of global initiatives has been mainly on hazards and in individual hazard domains. Moreover, while existing global initiatives recognize the importance of partnerships with local experts, connecting hazard and risk information from local to global scales remains a major challenge.

Even if science may not be ready to perform a scientifically sound and exhaustive multi-hazard risk assessment in fully probabilistic terms, it would be incautious to take decisions without considering at least a set of “reasonable” worst-case scenarios able to capture the multi-hazard essence of the environment analysed.

It is therefore suggested to start from a multi-hazard risk identification process to identify how the complexity of the territorial system interacts with multiple causes. This analysis starts with, but is not limited to, a deep historical analysis by means of conventional and unconventional sources of information. From there, the expert performing the analysis should select the

⁶ Most, H. van der and M. Marchand (2017). Selecting Measures and Designing Strategies for Integrated Flood Management, a Guidance Document. World Meteorological Organization. Available from www.floodmanagement.info/guidance-document

most appropriate scenarios and characterize them in terms of impacts of their likelihood and uncertainty. This would represent a fundamental part of the risk assessment determining coping capacity and resilience of the system analysed.

A case of a country good practice

FEMA flood hazard maps and the National Flood Insurance Program

In the United States, the Federal Emergency Management Agency (FEMA) is the government agency responsible for developing and disseminating flood hazard maps (flood insurance rate maps (FIRM)). Flood maps for a particular area are developed or updated through collaboration between local, state and federal government officials. A watershed is identified given the need, the available data and the regional knowledge.

The map is then developed by using the best available data and the scientific modelling approach that these data can support. The accuracy of the map depends on what kind of data and methods were used to develop it.

FEMA maps depict flood zones, ranging from high to low hazard. The source of flooding can be pluvial (induced by precipitation), fluvial (riverine) or storm surge. The maps are traditionally distributed in (~3.5 mi²) panels; but they can also be viewed seamlessly through an interactive geographic information system (GIS) portal.

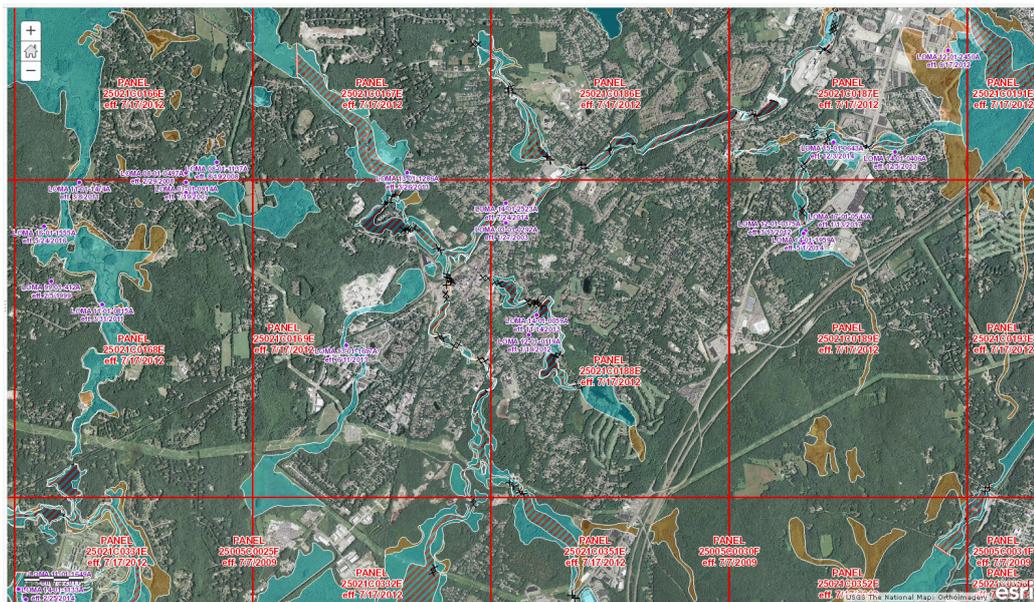


Figure 1 - GIS viewer showing the FEMA's national flood hazard layer (Official)

The map panels, associated flood insurance study (FIS) reports, data sheets and letters of modification can be downloaded from <https://msc.fema.gov/portal/availabilitySearch>. The maps are under an ongoing cycle of revision and updating due to the increasing availability of related information, whether scientific data or new events that change the assumed probability structures.

The maps can be used for residential and commercial or industrial insurance programmes. For residential insurance, the National Flood Insurance Program (NFIP) was created to enable property owners in participating communities to purchase insurance protection, administered by the Government, against flood losses. The programme requires flood insurance for all loans or lines of credit that are secured by existing buildings, manufactured homes or buildings under construction that are located in a community that participates in the programme.

FEMA, which administers the programme, publishes information and statistics to the public through the official NFIP website: www.floodsmart.gov/floodsmart/.

Malawi flood hazard risk profile

Africa shows a continuously increasing level of risk materializing through natural hazard extremes. These natural risks are a hurdle to the development of many African countries that see their gross domestic product and investments impaired by the impact of such natural hazards. This is particularly true for Malawi, which is periodically hit by severe floods like the one that occurred in 2015 when the Shire River south of Lake Malawi and tributaries flooded large parts of the country in several flood waves. More than 170 people lost their lives, thousands were displaced and crops were lost.

In order to increase science-supported awareness of risk at the national and subnational level, the Global Facility for Disaster Risk Reduction, with European Union African, Caribbean and Pacific Group of States (ACP) funds, has financed the production of hazard flood maps to form the basis for a preliminary risk assessment work producing risk figures. The final purpose of that being engaging with the governments in a risk-financing programme for Malawi. Risk financing could play a key role in protecting the financial investments and could lead the way to a future where such risk is understood, reduced and controlled.

The study was conducted at country level using the TANDEM-X 12.5m resolution global DEM, producing maps with very fine resolution. Such maps are then used to compute in a full probabilistic manner economic parameters such as annual average loss caused by floods broken down into different categories of assets, residential, commercial, industrial buildings, agriculture, critical assets and infrastructures; as well as impact on the population and gross domestic product.

All this analysis is carried out in both present and climate-change conditions. Although the country-level scope frames this study as a preliminary flood risk assessment, the nature of the parameters computed enables an informed dialogue with the national authorities to plan necessary mitigation measures, including further studies in the hotspots highlighted by the study.

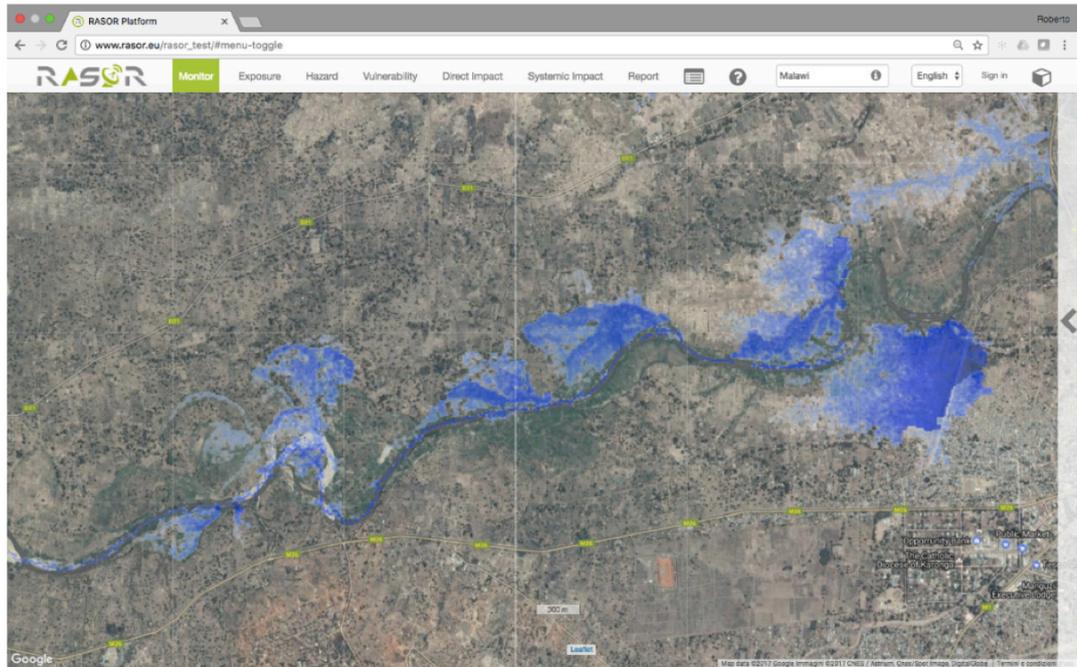


Figure 2 - 100-year flood map depicting maximum water depth for the river flowing into Karonga city in Malawi

Resources for further information

- International community of practice focused on this hazard
 - preventionweb.org
 - gfdr.org
 - UR
- Other substantial peer-reviewed guidelines from reputable institutions
 - APFM tools
- Open source hazard and risk modelling tools
 - Think hazard
 - GAR
 - RASOR
 - World Bank Caribbean Risk Information Programme
 - Aqueduct Global Flood Analyzer
 - GloFAS
 - GFMS
 - Dartmouth Flood Observatory
 - OpenStreetMap
 - InaSAFE
 - Global Assessment Report Risk Data Platform
- Successful and well documented national hazard and risk assessment with results used in DRR
 - United Kingdom
 - Netherlands

Authors

Roberto Rudari (CIMA Foundation)

Contributors and Peer Reviewers:

Contributors and Peer Reviewers: Yasir Kaheil (FMGlobal), Paolo Scussolini (Vrije Universiteit Amsterdam), Cees Van de Guchte (Deltares)