B. Why Invest in Probabilistic Risk Assessment?

Key words:
probabilistic, stochastic deterministic, scenario, uncertainty

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Background to probabilistic models

Policy and investment decisions for managing disaster risk rely on a sound knowledge of the risks. During the past decade, substantial progress has been made across the world in improving tools for hazard and risk assessment and producing risk information at different levels and on different scales. Much of this information exists in the form of probabilistic models and risk data that originated in the insurance sector in response to disasters in the late 1980s and early 1990s, which were costly in terms of insurance and economic losses.

Since then, probabilistic models have become a staple tool for facilitating better risk management in (re)insurance and are increasingly forming the basis for comprehensive risk-management strategies in civil society, government and the private sector – ultimately enabling risk reduction, risk adaptation and risk transfer mechanisms to be assessed individually and together as part of a holistic approach

Probabilistic risk modelling provides estimates of risk in terms of numbers of people affected and value of losses, as well as a measure of uncertainty around those estimates. A probabilistic risk model inherently includes all possible "impact scenarios" for a specific hazard and assets located in a specific geographical area (figure 1), incorporating both low-frequency and high-impact events, and high-frequency and lower-impact events. It is more sophisticated than deterministic ("scenario") modelling, which employs disaster scenarios (namely, a severe historical event or a "worst-case" scenario) to communicate risk in terms of the damage or loss that could result if the disaster occurred.

Probabilistic approaches are used to communicate risk in terms of the likelihood of an event and an associated severe impact occurring. To do this, probabilistic models use a large number of events that, as far as possible, represent the full range of events that might occur over a time frame of thousands of years. Typically, this will be tens of thousands of possible events, each with different permutations of event characteristics (e.g. wind speed, pressure and track direction for cyclones). These events are used to build "exceedance curves", which highlight the level of risk for different return periods – where flood might have the highest risk over shorter time frames (high-frequency events), but earthquakes and volcanic eruptions might have the highest impact if longer time frames (low-frequency events) are considered.

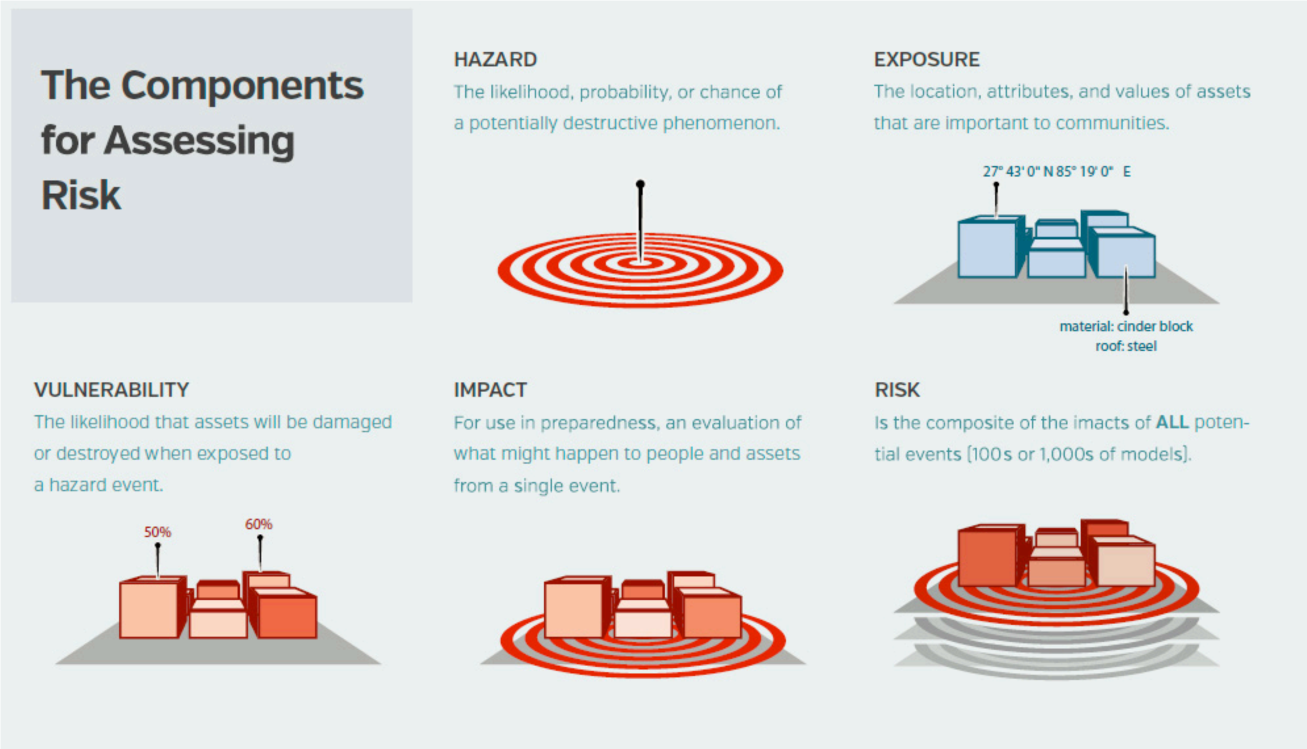

Figure 1 – Components of a risk assessment

Benefits of probabilistic modelling

Owing to the short and incomplete nature of our historical disaster catalogues (most records go back much less than 100 years and omit extreme events), we have an incomplete picture of possible events, although records from pre-history can be obtained from geological and paleoclimate archives. Figure 2 gives perspective on how limited a 100 years sample can be in giving the complete information about historical events. For most hazards, less is known about the characteristics of historical events prior to the advent of modern technological monitoring systems in the 1950s. A combination of understanding the physical drivers of the hazard in question and statistical analysis of historical observations is used to develop simulations of new events that could realistically occur but might not have done so in the recorded historical period. Each event is assigned a frequency of occurrence based on observed and science-theory-based relationships between event severity and frequency (with minor events generally occurring more frequently than severe events).

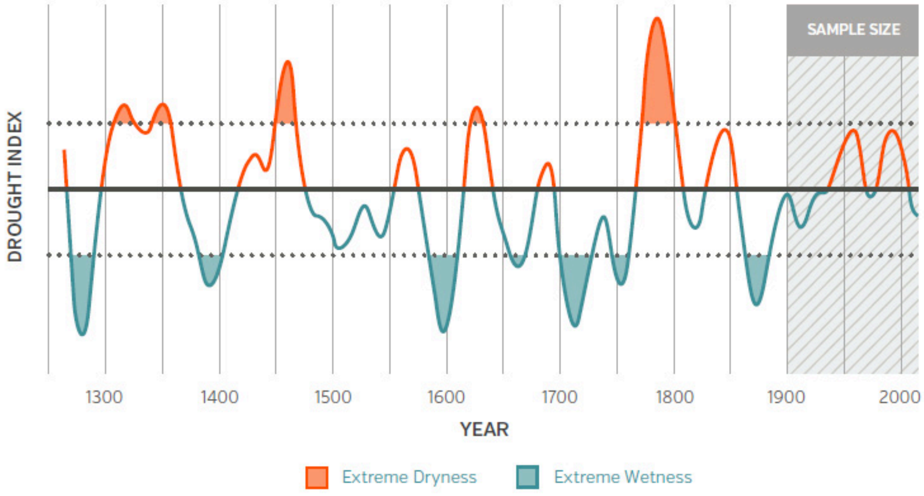

Figure 02–1
Hypothetical drought index showing periods of extreme dryness (above the dotted red line) and periods of extreme wetness (below the dotted blue line); the historical record does not capture extreme dry and wet periods experienced prior to its start in 1900.

Figure 2 – Drought index

Probabilistic models also account for uncertainty in the impact at a given location if an event occurs. This is a result of uncertainty in local intensity (e.g. how ground shaking varies from one site to another due to small-scale variations in rock or soil type) and in translating hazard intensity to damage proportion and loss, which is derived using information in the exposure and vulnerability data.

These uncertainties can arise from a combination of imperfect knowledge of the physical environment, the choice of model methodology, and other scientific and engineering factors.

The quantification of risk across a range of time horizons, enabling loss potential to be assessed in terms of its frequency, is a vital basis for decision-making in DRM/DRR, where both the frequency and severity of loss influence the choice of a mitigation strategy. Probabilistic models are important in providing evidence and informing risk reduction strategies and tools by assessing the extent of structural and infrastructure damage, population affected, and loss of income, etc. due to all possible hazards, at various time horizons.

This assessment forms the evidence base for the following DRM strategies:

- Assessing the vulnerability of a certain sector or geography to different natural hazards over different time periods. For example, it is possible to assess the overall risk profile of a country driven by frequent flood events, droughts, or rarer but potentially more costly and damaging earthquakes. Is the north of a country more at risk than the south? Is the education sector more vulnerable to flood than the transport sector? Probabilistic risk analysis can also enable a government to compare disaster risks alongside other risks (e.g. currency, cyber security risk).
- Identifying assets that are exposed to different hazards. For example,

which schools in a country are more vulnerable to earthquakes or flood?

- Identifying building types that are most vulnerable and drivers of risk. For example, which building type (steel, reinforced concrete, or unreinforced masonry, low rise or high rise) in residential housing stock is causing the highest loss of life and number of injuries in earthquakes? Where should a government invest its limited resources to get the greatest reduction in risk?
- Assessing the impact of climate change on risk levels in the future by modelling the impact of different climate change scenarios on hydrometeorological hazards or sea-level rise. For example, how will the frequency and severity of floods in a certain flood plain increase due to climate change and what are the consequences for flood protection design?
- Assessing socioeconomic factors of risk to estimate how risk is changing into the future – such as the extent to which urbanization is contributing to a growth in risk and how urban planning and building design can reduce this growth rate.
- Sovereign disaster risk financing:
    - Estimate the potential loss (and therefore impact on budget) due to multiple risks, and how this can be used in developing risk transfer strategies
      (e.g. insurance pools, bonds, reinsurance).
- Cost benefit analysis, e.g.:
    - Assessing the cost of building river flood defences (over the river defence design lifetime) versus the value of avoided losses, in terms of people and socioeconomic impacts.
    - Estimating the benefit of a structural "retrofit" programme (in both social and economic terms) on collapse rate of buildings in a city as the result of earthquakes of different frequency and severity.
    - Assigning hazard prone land to mixed light recreational use such as sporting, or for natural habitat creation rather than allowing urban development.

Availability of probabilistic models

Probabilistic models are widely available for earthquake, tropical cyclones and windstorms, tornado, hail, and flood – especially in developed countries. There are a growing number of such models in other regions too, as more models on national to global scales are being generated by governments and intergovernmental organizations.

Probabilistic drought, tsunami, landslide and volcano models are not as widely available, but progress is being made rapidly. In recent years there has been growth in open-source probabilistic risk modelling, as there is now recognition that openly available and interoperable source data, hazard and exposure data sets, vulnerability relationships, model components and risk models can provide efficiency gains in utilizing modelling for DRR.

Probabilistic modelling for national disaster risk assessment

Probabilistic modelling should be incorporated into national risk assessment where a quantitative assessment of risk is required to inform the DRR dialogue and risk reduction measures, such as land-use planning, risk mitigation initiatives and risk financing. It is vital to define the scope and scale of the risk assessment at the beginning of the process in conjunction with end-users, to ensure that risk outputs align with user requirements.

Scoping should determine the exposure types and hazards to be analysed, and the detail of analysis required to meet users' needs. It should also determine the requirement for assessing future risk, which can guide long-term investment and planning in areas subject to climate- and socioeconomic-induced changes in risk. These factors heavily influence the staff, technical resources and costs of the assessment process.

Developing a probabilistic model is a multi-stakeholder process. Data development can benefit from access to local data and knowledge of exposure characteristics and vulnerability relationships specific to the study area. Development of the input data for each model component is a key part of building risk models and requires topic-specific expertise, including population distribution modelling, geophysics and hydrometeorology, and structural engineering.

Data acquisition being an intensive exercise, crowdsourcing can be a useful strategy, and in some cases remote development of exposure data sets can be done using remote sensing techniques combined with openly available data for validation. An important part of the risk assessment process is the adequate communication of outputs, ensuring that the risk information can be used sustainably and for the purposes for which it was designed.

In summary, probabilistic risk modelling enables a wide range of evidence-based decision-making, allows the decision maker to evaluate risks in both the short and the long term, including uncertainty. It also enables the estimation of the likelihood of extreme events that have not happened in recent history, or that are becoming more likely because of climate change. However, as this approach can be resource intensive, it typically requires strong collaboration and cooperation between private, academic and public institutions to ensure trustworthy and robust results, reflecting local data and knowledge, and that can be regularly updated as new data become available or as conditions change.

It is therefore important for countries to invest in the following over the long term:

- Improving the collection of, access to and quality of fundamental hazard and risk data and observations.
- Deepening and expanding the capacity of experts to design, implement, understand and use probabilistic risk models (often through postgraduate training).
- Clarifying institutional arrangements for the design, development, communication and long-term maintenance of risk data and information.

CASE STUDY

Box 1 - Probabilistic risk assessment: case studies Afghanistan, Peru, Turkey, Pacific Islands, Netherlands

Afghanistan

National risk profile

After years of conflict and under-investment in development, the Government is taking an evidence-based approach to disaster and climate-proof development and reconstruction. With support from GFDRR and the Government of Japan, and in partnership with the World Bank, in May 2017 the Afghanistan National Disaster Management Authority launched a fully open and probabilistic risk assessment that considers the risk from earthquake, flood, avalanche, drought and landslide under current climate and socioeconomic conditions.

This assessment highlighted the greatest risk – with flood expected to cause annual average damage of US$ 54 million, and with rarer events causing over US$ 500 million in damage. Similarly, it highlighted the 3 million people exposed to landslide, the 2 million people exposed to avalanche, and the 6.5 million people affected by drought in the last 20 years.

Beyond highlighting the risk – by undertaking probabilistic risk analysis – the study made concrete recommendations based on cost-benefit analysis. For example, improvements in flood protection in Kabul could reduce flood damage by US$ 600,000 per year, and retrofitting schools for earthquake could reduce fatalities by 90 per cent and economic losses by 60 per cent. Similarly, retention structures, concrete galleries and early warning systems could substantially reduce the impacts on the 10,000 km of roads in Afghanistan exposed to avalanche, including the critical Salang Pass.

Peru

Understanding seismic risk to schools in Lima

The Ministry of Education, in partnership with the World Bank and GFDRR, is working mitigate against damage, protect students against the impact of earthquakes, and safeguard educational development. A probabilistic seismic risk assessment was conducted by the World Bank, focusing on 1,969 schools in the Lima Metropolitan Area.

According to the assessment, only 8 per cent of schools complied with seismic resistance design codes, and 64 per cent of schools were highly vulnerable to earthquakes, leaving 600,000 children at risk. Based on these results, the Government has introduced a national school infrastructure plan focused on improving the amenity of school infrastructure and on reducing potential seismic vulnerability for the 252 most vulnerable school facilities, with an estimated US$ 17 million investment.

Turkey

Reducing seismic risk to public buildings

Turkey has substantial seismic risk and vulnerable building stock. A seismic risk analysis in 2002 suggested that in earthquakes of magnitude 6.9 to 7.7, some 7-8 per cent of buildings would be heavily damaged, 87,000 people could be killed, and 135,000 severely injured. Istanbul’s schools, hospitals and other public buildings had high potential for collapse.

The assessment recommended urgent review and retrofits of 635 hospitals and 2,000 schools, and the creation of a disaster management centre and educational programmes to raise awareness.

In 2012 the Istanbul Metropolitan Municipality and the Government of Turkey used these recommendations as a basis for the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP). The project has improved seismic resilience in Istanbul through better emergency preparedness, reduced risk at over 700 public facilities and made improvements in building code enforcement.

CASE STUDY

Pacific Islands

Pacific Catastrophe Risk Assessment and Financing Initiative

The Pacific Islands are extremely exposed to multiple natural hazards. With rising populations, increasing urbanization and changes in climate, the impact of these hazards is growing. In 2007, the World Bank created the Pacific Catastrophe Risk Assessment and Financing Initiative to develop disaster risk assessment tools and practical technical and financial applications to reduce and mitigate the vulnerability of Pacific Island countries to natural disasters.

The largest regional collection of geospatial information on disaster risks was created for 15 Pacific Island countries and is hosted by the Pacific Islands Applied Geoscience Commission. It comprises the following four databases:

- Historical tropical cyclones and earthquakes (hazard database)
- Accumulated losses (consequence database)
- Assets (exposure database)
- Modelled probabilistic losses.

Catastrophe risk profiles were developed, quantifying economic losses caused by earthquakes and tropical cyclones. This analysis determined that the average annual loss caused by natural hazards across the 15 countries is about US$ 284 million, or 1.7 per cent of regional gross domestic product (GDP). Vanuatu, Niue and Tonga experience the largest average annual losses, equivalent respectively to 6.6 per cent, 5.5 per cent and 4.4 per cent of their national GDP.

The analysis also found that in a given year, there is a 2 per cent chance that the Pacific region will experience disaster losses in excess of US$ 1.3 billion from tropical cyclones and earthquakes. Not only did this effort quantify risk on a regional basis in the Pacific for the first time, benefitting DRM and development planning, it also led to the establishment of a regional catastrophe risk pool (Pacific Catastrophe Risk Insurance Pool). This pool facilitates risk transfer between member countries and pays claims rapidly on a parametric trigger basis, such as cyclone intensity.

Netherlands

Flood risk protection

The Netherlands is vulnerable to flooding from the sea and from large rivers, such as the river Rhine. Dikes have been built throughout the ages to control the risk of flooding, often in response to a flood disaster. After the 1953 floods, standards for flood protection were introduced. These standards were partly based on an economic optimization of investment costs and the benefits of damage reduction.

As the standards were in need of updating, taking into account newest insights into flood probability, vulnerability of infrastructure and loss of life, new standards were developed based on a cost-benefit analysis that used a variety of models to determine an optimal investment strategy for dike reinforcements.

This strategy minimizes the discounted investment cost and residual flood damages over a long time horizon. The impacts of economic growth and climate change on flood risk are taken into account. The cost-benefit analysis uses information on flood probabilities, flood consequences and the costs of investments in dike reinforcement. The consequences consist not only of direct flood damages but also of an estimate of immaterial damages such as loss of life and indirect damages.

This was the first and most complete analysis to determine economically efficient flood protection standards in the world and included all areas in the Netherlands exposed to flooding. It provided policy makers not only with the expected economically efficient flood protection standard, but also with confidence intervals around those economically optimal standards.

The main conclusion from the cost-benefit analysis was that from an economic point of view, the current safety standards for the coastal areas (1/4.000 to 1/10.000 per year) are sufficiently high and that the safety standards for dikes along the major rivers (1/1250 to 1/2000 per year) should be increased. These standards were accepted and confirmed by parliament and became operational as of 1 January 2017. To reach the new standards, an initial amount for investment is needed of more than 5 billion of euros in the period up to 2028.

Terminology

Probability: likelihood of an event occurring compared to all the possible events that might occur. The exceedance probability is the likelihood of one event of a given intensity 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% chance to occur or be exceeded every year.

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

Annual Average Loss (AAL): The long-term expected loss per year, averaged over many years. While there may be little or no losses, over a short period of time, the AAL accounts for 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 1,000 year return period, there is still a 5% probability of a PML being exceeded over a 50-year time frame.

Resources for further information

International communities of practice focused on probabilistic modelling of various hazards:

- Global Earthquake Model: globalquakemodel.org
- Global Volcano Model: globalvolcanomodel.org
- Global Tsunami Model: http://globaltsunamimodel.rm.ingv.it/
- Global Flood Partnership: http://portal.gdacs.org/Global-Flood-Partnership
- Global Landslide Model: https://pmm.nasa.gov/applications/global-landslide-model
- Understanding Risk: www.understandrisk.org

Other substantial peer-reviewed guidelines

- GFDRR (2016). The Making of a Riskier Future: How our Decisions are Shaping Future Disaster Risk. www.gfdrr.org/sites/default/files/publication/Riskier Future.pdf
- GFDRR (2014). Understanding Risk in an Evolving World. Emerging Best Practices in Natural Disaster Risk Assessment. www.gfdrr.org/understanding-risk-evolving-world-emerging-best-practices-natural-disaster-risk-assessment
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- United States Environmental Protection Agency (2014). Probabilistic risk assessment to inform decision making: Frequently asked questions. www.epa.gov/sites/production/files/2014-11/documents/raf-pra-faq-final.pdf
- United States Department of Energy (2013). Development of Probabilistic Risk Assessment for Nuclear Safety Applications. www.standards.doe.gov/standards-documents/1200/1628-2013/@@images/file
- United States Environmental Protection Agency (2009). Probabilistic Risk Assessment White Paper and Supporting Documents. www.epa.gov/osa/probabilistic-risk-assessment-white-paper-and-supporting-documents
- CAPRA Probabilistic Risk Assessment Platform. Documents. www.ecapra.org/documents

BOX 2.

Global Facility for Disaster Risk Reduction has been supporting many countries in conducting national hazard and risk assessments that have incorporated probabilistic modelling. Below are few examples:

- Dozens of case studies included in publication: GFDRR. 2014. Understanding Risk in an Evolving World. Emerging Best Practices in Natural Disaster Risk Assessment. www.gfdrr.org/understanding-risk-evolving-world-emerging-best-practices-natural-disaster-risk-assessment
- A detailed disaster risk assessment for Afghanistan has been published highlighting the risk from drought, river flood, landslide, avalanche and earthquake annually (average annual loss) and for different return periods under current and future socioeconomic and climate conditions www.gfdrr.org/sites/default/files/publication/drp_afghanistan.pdf
- South West Indian Ocean Country Risk Profiles
  www.gfdrr.org/disaster-risk-profiles
- Rwanda Risk Atlas
  http://midimar.gov.rw/uploads/tx_download/National_Risk_Atlas_of_Rwanda_electronic_version.pdf

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