Words into Action Guidelines

# National Disaster Risk Assessment

## Hazards

2017-UNISDR

In support of the Sendai Framework
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UNISDR
United Nations Office for Disaster Risk Reduction

Words into Action Guidelines

# National Disaster Risk Assessment

## Hazard Specific Risk Assessment

**UNISDR**
**2017** - UNISDR

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# 1. Earthquake Hazard and Risk Assessment

**Key words:**

vulnerability function, probabilistic seismic hazard analysis (PSHA), ground motion prediction equation (GMPE), exposure model, earthquake hazard map

The uncontrolled growth of the global population led to an increase in annual earthquake-related losses from US$ 14 billion in 1985 to more than US$ 140 billion in 2014. Similarly, the average affected population rose from 60 million to over 179 million within the same period.[1] Earthquakes constitute approximately one fifth of the annual losses due to natural disasters, with an average death toll of over 25,000 people per year.[2]

Earthquakes may cause liquefaction, landslides, fire, and tsunami which would lead to far higher level of damage and losses. This module is focused on assessing only earthquake shaking hazard and risk. The assessment of earthquake risk constitutes the first step to support decisions and actions to reduce potential losses. The process involves developing (a) earthquake hazard models characterizing the level of ground shaking and its associated frequency across a region, (b) exposure data sets defining the geographic location and value of the elements exposed to the hazards and (c) vulnerability functions establishing the likelihood of loss conditional on the shaking intensity.

Risk metrics can support decision makers in developing risk reduction measures that can include emergency response plans, the enforcement of design codes, the creation of retrofitting campaigns and development of insurance pools.

## Global earthquake activity

Most earthquakes are generated at boundaries where plates converge, diverge or move laterally past one another[3]. The greatest amount of seismicity occurs in regions where lithospheric plates converge. These convergent boundaries may manifest as regions of subduction, where oceanic crust is forced down beneath either the continental plate (e.g. west coast of South America) or of younger oceanic crust. Convergent boundaries may also produce regions of continental collision resulting in tectonic compression (e.g. the Himalayas).

Both types of environments are characterized by regions of high earthquake activity and host faults capable of generating very large earthquakes. Divergent plate boundaries represent areas where shallow crust is being pulled apart. These may manifest as rift zones (e.g. East African Rift), where the shallow continental crust is undergoing extension, resulting in moderate to high seismicity. Transform and transcurrent plate boundaries manifest where the relative movement of plates is lateral (e.g. San Andreas Fault in California). Because of their proximity to many large urban centres, these systems can pose a significant threat to society (e.g. Istanbul). Figure 1

1 Global Facility for Disaster Reduction and Recovery. The Making of a Riskier Future: How Our Decisions are Shaping Future Disaster Risk. Washington D.C.: World Bank.

2 EM-DAT (Emergency Events Database) (2017). www.emdat.be (last accessed on 24 Jan. 2017).

3 Bird, P. (2003). An updated digital model of plate boundaries. Geochemistry, Geophysics, Geosystems, G3, vol. 4, issue 3, doi:10.1029/2001GC000252.

illustrates the global distribution of earthquakes between 1900 and 2014, as well as the main plate boundaries.

Records of earthquake events throughout history are fundamental to our understanding of the earthquake process. Systematic recording of earthquake waves using more precise seismometry began at the end of the nineteenth century. The modern era of instrumental seismology was transformed, however, in the early 1960s with the establishment of the World-Wide Network of Seismograph Stations, which deployed over 120 continuously recording stations. The International Seismological Centre maintains the most comprehensive bulletin of parameterized earthquake events since 1964. The bulletin defines the location and size of earthquakes from an integrated network of approximately 14,500 earthquake stations.[4]

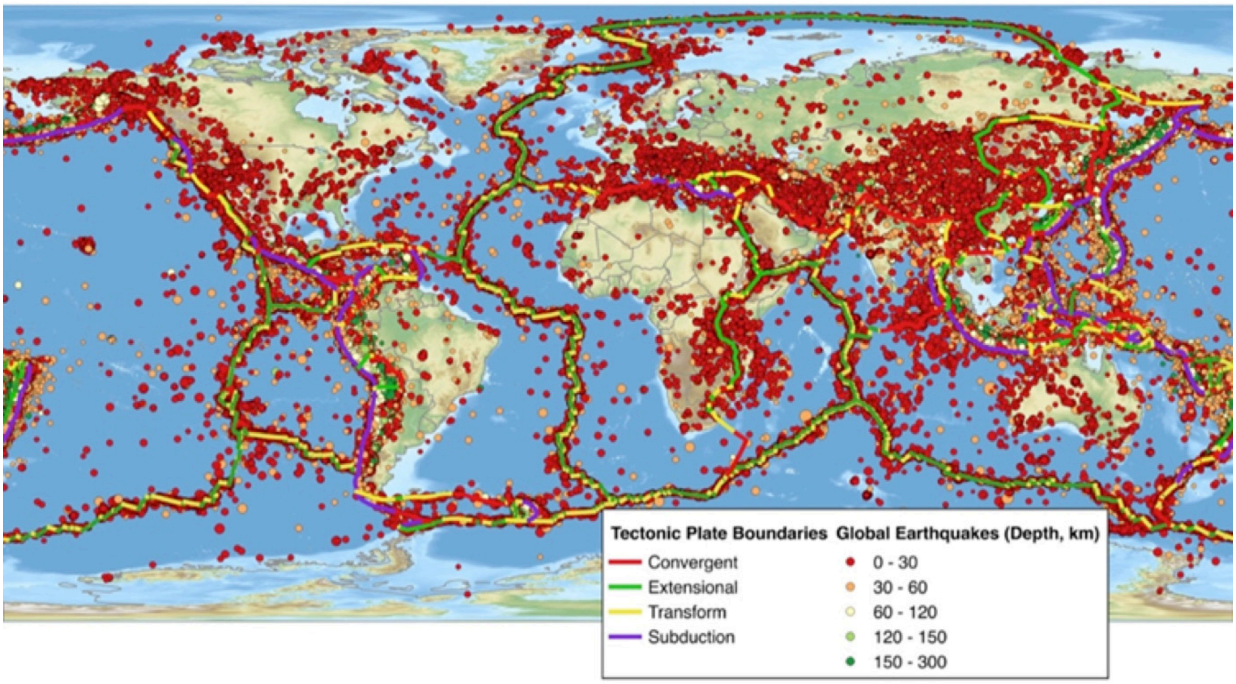


**Figure 1** - The global distribution of earthquakes in the period from 1900 to 2014, and global plate boundaries

[4] Storchak, D. and others (2015). The ISC-GEM Global Instrumental Earthquake Catalogue (1900-2009): Introduction. Physics of the Earth and Planetary Interiors, vol. 239, pp. 48-63.

## Earthquake hazard assessment

Earthquake hazard assessment enables the likelihood of ground shaking across a region to be calculated, which is a fundamental component in earthquake risk assessment or hazard mapping for design codes. The process may require several components, such as earthquake catalogues (historical and instrumental), active geological faults, geodetic estimates of crustal deformation, seismotectonic features and paleoseismicity.

Earthquake hazard may be analysed in two main ways: deterministically, in which a single (usually) most adverse earthquake scenario is identified, or probabilistically, in which all-potential earthquake scenarios are explicitly considered along with their likelihood of occurrence. Deterministic approaches may be perceived as conceptually simpler and more conservative.

The development of a probabilistic earthquake hazard analysis (PSHA) model requires complex mathematical formulations to account for uncertainties in earthquake size, location and time of occurrence, and the outputs relate various levels of ground shaking that may be observed at a site with a corresponding exceedance probability in a given time period.

This relation between ground shaking and probability constitutes a hazard curve. The expected ground shaking for a probability of exceedance within a time span (e.g. 10 per cent in 50 years) or a return period (e.g. 475 years) can be calculated for a given region, leading to a hazard map. Figure 2 shows a fault data set, an earthquake catalogue and a earthquake hazard map for a return period of 475 years for Colombia.

Since the inception of PSHA by Cornell (1968)[5] and McGuire (1976)[6], several critical developments can be identified such as the complex representation of the earthquake source, the derivation of new models to describe the recurrence of earthquakes, sophisticated ground motion prediction equations (GMPE) and the use of logic trees for the propagation of epistemic uncertainties.[7]

Probabilistic earthquake hazard analysis typically follows two main approaches: time-independent – incorporating geological and geodetic evidence with both instrumental and historical earthquake catalogues to derive a seismogenic model covering earthquake cycles up to thousands of years; and time-dependent – accounting for periodic trends in earthquake recurrence to predict the likelihood of earthquakes occurring in a source given the time elapsed since the previous event.

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5 Cornell, C. (1968). Engineering seismic risk analysis. *Bulletin of the Seismological Society of America*, vol. 58, pp.1583-1606.

6 McGuire, R. (1976). FORTRAN computer program for seismic risk analysis. *United States Geological Survey open-file report*, pp. 76-67.

7 Bommer, J. and F. Scherbaum (2008). The use and misuse of logic trees in probabilistic seismic hazard analysis. E*arthquake Spectra,* vol. 24, pp. 997-1009.

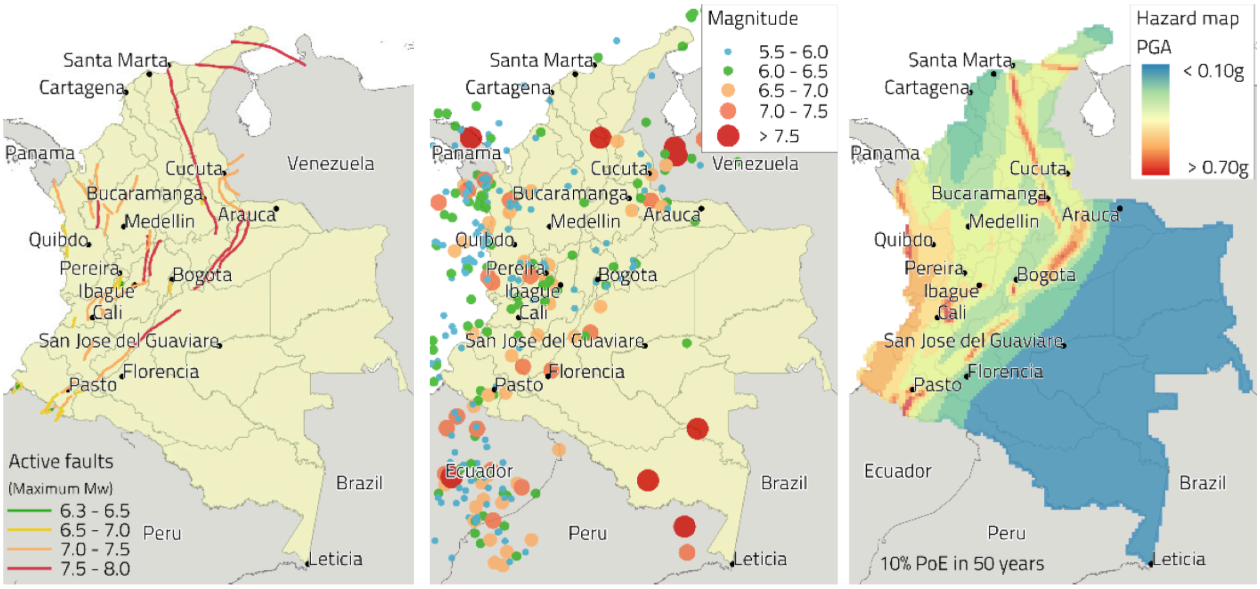


**Figure 2** – Fault data set (left), earthquake catalogue (centre) and earthquake hazard map (right) in terms of peak ground acceleration for a return period of 475 years for Colombia[9]

As time-dependent approach requires detailed information concerning the past earthquakeity in the region andfault rupture history application of time-dependent earthquake hazard analysis is still limited to only a few places in the world with well-studied active faults (e.g. California, Japan). Various software packages are available for calculating earthquake hazard using deterministic or probabilistic approaches. OpenQuake[8] is one such package and has been adopted in recent regional projects for earthquake hazard assessment in Europe, the Middle East, Latin America, the Caribbean and Africa.

## Assessment of earthquake expected losses

Carrying out an assessment of the impact of single earthquake events (deterministic approach) is a useful tool for developing risk reduction measures. For example, Anhorn and Khazai (2014)[9] investigated the need for shelter spaces in Kathmandu (Nepal) considering several destructive

earthquakes. Mendes-Victor et al. (1994)[10] and the Portuguese National Civil Protection Authority (2010)11 estimated the expected losses in Lisbon and the Algarve (Portugal), respectively, for strong earthquake events. The National

8 Pagani, M. and others (2014). OpenQuake engine: an open hazard (and risk) software for the Global Earthquake Model. *Seismological Research Letters*, vol. 85, issue 3, pp. 692-702.

9 Anhorn, J. (2014). Open space suitability analysis for emergency shelter after an earthquake. *Natural Hazards and Earth System Sciences Discussions,* vol. 1, issue 2, pp. 4263-4297.

10 Mendes-Victor, L. and others (1994). Earthquake damage scenarios in Lisbon for disaster preparedness. In: Tucker B.E., M. Erdik and C.N Hwang, eds. Issues in urban earthquake risk. NATO ASI series E, *Applied Science*, vol. 271, pp. 265-289. Dordrecht: Kluwer Academic Press.

11 National Civil Protection Authority (2010). Estudo do risco sísmico e de tsunamis do Algarve. ISBN: 978-989-8343-06-2. Autoridade Nacional de Protecção Civil, Carnaxide, Portugal (in Portuguese).

Civil Protection Authority used these results to develop emergency response plans.

This analysis requires the definition of an earthquake rupture, which can be a hypothetical event (defined based on historical earthquakes or a PSHA model[12, 13]) or a recent earthquake (whose parameters can be computed using inversion analyses[14]). In the former approach, the ground shaking is calculated using one or multiple GMPEs. In the latter, the ground shaking can be calculated using GMPEs and recordings from earthquake stations.15 In general, this distribution of ground shaking can be used to calculate damage or losses, using an exposure model and a set of fragility or vulnerability functions.

An exposure model describes the spatial distribution of the elements exposed to the hazards, as well as their value and vulnerability class.16 A fragility function establishes the probability of exceeding a number of damage states conditional on a set of ground shaking levels, whereas a vulnerability function relates the probability of loss ratio for a set of ground shaking levels.17, 18 The ground shaking, exposure model and fragility/vulnerability functions can be combined to calculate the distribution of damage or losses,19 as illustrated in figure 3 for a region around Bogotá, Colombia.

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12 Bendimerad, F. (2001). Loss estimation: a powerful tool for risk assessment and mitigation. *Soil Dynamics and Earthquake Engineering*, vol. 21, issue 5, pp. 467-472.

13 Ansal, A. and others (2009). Loss estimation in Istanbul based on deterministic earthquake scenarios of the Marmara Sea region (Turkey). *Soil Dynamics and Earthquake Engineering*, vol. 29, pp. 699-709.

14 Ji, C., D. Wald and D. Helmberger (2002). Source description of the 1999 Hector Mine, California earthquake; Part I: Wavelet domain inversion theory and resolution analysis. *Bulletin of the Seismological Society of America,* vol. 92, issue 4, pp. 1192-1207.

15Worden, B. and D. Wald (2016). *ShakeMap Manual.* United States Geological Survey technical report, dx.doi.org/10.5066/F7D21VPQ.

16 Yepes-Estrada, C. and others (2017). A uniform residential building inventory for South America. *Earthquake Spectra*. doi: 10.1193/101915EQS155DP.

17 Rossetto, T., I. Ioannou and D. Grant (2015). Existing Empirical Fragility and Vulnerability Functions: Compendium and Guide for Selection. *Global Earthquake Model (GEM) technical report. Pavia, Italy*: GEM Foundation. doi:10.13117/GEM.VULNSMOD.TR2015.01.

18 D'Ayala, D. and others (2015). Guidelines for analytical vulnerability assessment of low/mid-rise buildings. *GEM technical report* 2015-08 v1.0.0, GEM Foundation, Pavia, Italy. doi: 10.13117/GEM.VULN-MOD.TR2014.12.

19 Silva, V. (2016). Critical issues in earthquake scenario loss modeling. *Journal of Earthquake Engineering*, vol. 20, issue 8, pp.1322-1341.

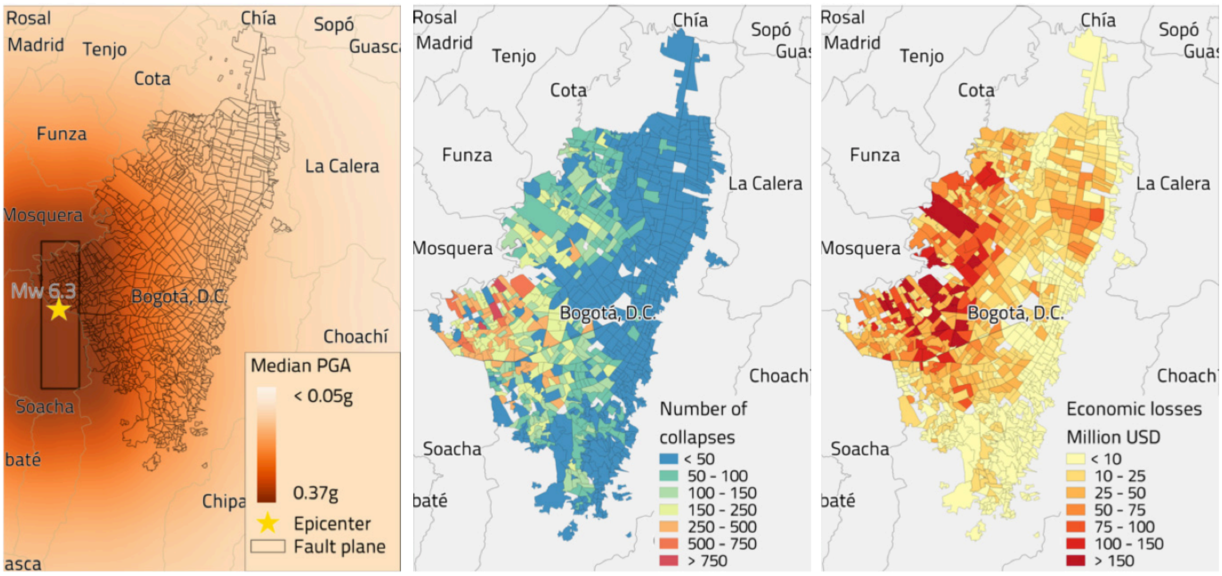


**Figure 3** – Mean ground shaking in terms of peak ground acceleration for a M6.5 event west of Bogotá (left), and resulting mean number of collapses (centre) and mean economic losses (right)

Certain risk reduction measures may require the consideration of all of the possible earthquake scenarios along with their frequency of occurrence, which can be developed using probabilistic modelling. For example, these analyses can enable the prioritization of regions or building classes in need of risk reduction interventions. Valcárcel et al. (2013)[20] explored this type of analysis to assess the effectiveness of the earthquake retrofitting of schools in South and Central America. They used a probabilistic earthquake risk model to calculate the expected annual losses considering the portfolio of schools and the savings as a result of the retrofitting or rebuilding interventions.

Another risk reduction measure that requires a probabilistic approach is the creation of insurance pools. These financial mechanisms reduce the economic burden of the reconstruction on local governments and householders by transferring the financial risk to the international insurance market. A good example of such a measure is the Turkish Catastrophe Insurance Pool (TCIP).[21] It was created after the Kocaeli and Düzce earthquakes in 1999, following which the reconstruction costs had to be covered mostly by the Government. These additional funds can also reduce the time to recover from the earthquake.

PSHA model can be used to generate large sets of stochastic events, each representing a possible realization of the seismicity within a given time span (e.g. 10,000 years). For each event, several GMPEs can be used to calculate the spatial distribution of the ground shaking at the location of the assets within the exposure models. Then, using the set of vulnerability functions, the losses for the entire portfolio can be calculated. This distribution of losses can

20 Valcárcel, J.A. and others (2013). Methodology and applications for the benefit cost analysis of the seismic risk reduction in building portfolios at broadscale. *Natural Hazards,* vol. 69, issue 1, pp. 845-868. doi:10.1007/s11069-013-0739-2.

21 Bommer, J. and others (2002). Development of an earthquake loss model for Turkish Catastrophe Insurance. *Journal of Seismology,* vol. 6, pp. 431-446.

be used to calculate the average annual losses or the aggregated losses for specific return periods.[22]

These metrics can be compounded with the local socioeconomic conditions in order to provide a holistic representation of the earthquake risk.[23, 24, 25] To this end, the risk metrics can be aggravated or attenuated according to a social vulnerability index. The index is derived from a large number of socioeconomic indicators such as education, poverty, crime, age or unemployment.

Figure 4 presents an exposure model for the residential building stock for Colombia, along with the associated average annual economic losses and socio-vulnerability index at the second administrative level. Such calculations can be performed using the OpenQuake engine26 from the Global Earthquake Model.

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22 Silva, V. (2017). Critical issues in probabilistic seismic risk analysis. *Journal of Earthquake Engineering.*

23 Carreño, L., O. Cardona and A. Barbat (2007). Urban seismic risk evaluation: a holistic approach. *Natural Hazards,* vol. 40, pp.137-172.

24 Khazai B. and F. Bendimerad (2011). Risk and resilience indicators. *Earthquakes and Megacities Initiative (EMI) topical report*, vol. 565, TR-1 03.

25 Burton, C. and V. Silva (2016). Assessing integrated earthquake risk in OpenQuake with an application to mainland Portugal. *Earthquake Spectra,* vol. 32, issue 3, pp.1383-1403.

26 Silva, V. and others (2014). Development of the OpenQuake engine, the Global Earthquake Model's open-source software for seismic risk assessment. *Natural Hazards*, vol. 72, issue 3, pp. 1409-1427.

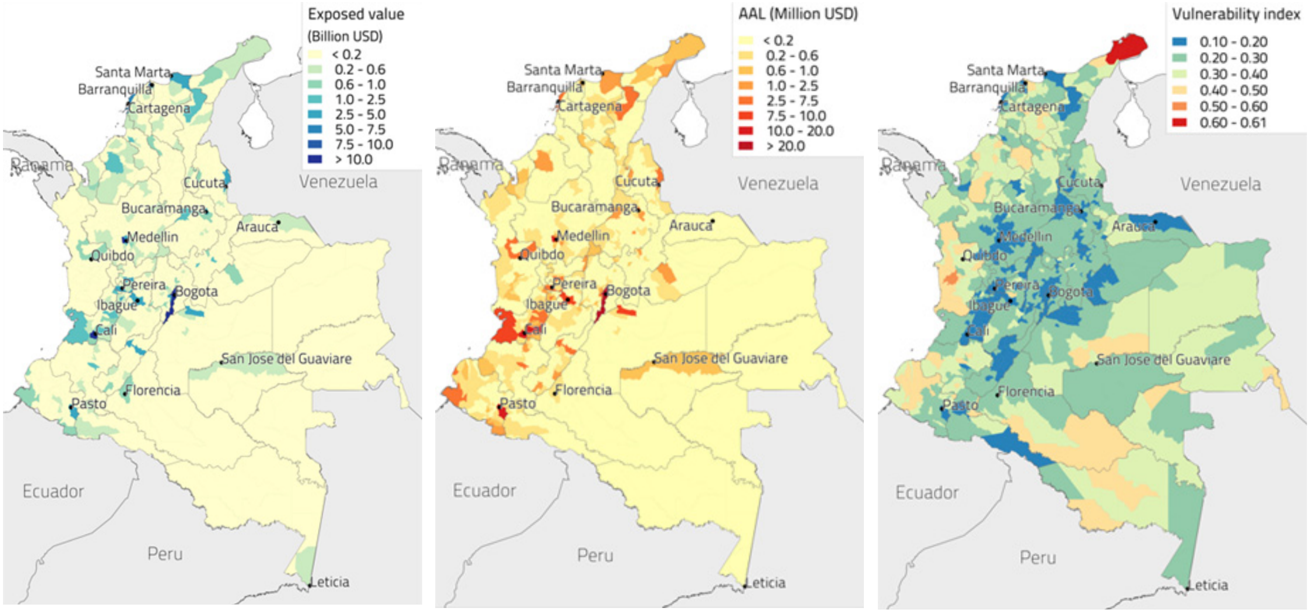


**Figure 4** – Exposure model (left), average annual economic losses (centre) and socioeconomic vulnerability index (right) for the residential building stock in Colombia[28, 29]

## Conclusion

Earthquakes can cause large economic and human losses, and represent a serious impediment to socioeconomic development, creation of jobs and availability of funds for poverty reduction initiatives. Earthquake hazard and risk assessment are fundamental tools for developing risk reduction measures. This process involves collecting earthquake catalogues and fault data, developing seismogenic models, selecting ground motion prediction equations, creating exposure models and deriving sets of fragility or vulnerability functions.

Combining these components for assessing earthquake hazard and risk requires complex software packages, some of which are currently publicly available. Several examples around the world have demonstrated how earthquake hazard and risk information can be used to develop risk reduction measures and ultimately mitigate the adverse effects of earthquakes.

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# 2. Tsunami Hazard and Risk Assessment

**Key words:**
tsunami hazard, physical vulnerability, probabilistic tsunami hazard analysis (PTHA), tsunami early warning systems

Globally, tsunami risks are dominated by rare but often very destructive events. Assessment of tsunami hazard and risk is required to support preparedness measures and effective disaster reduction. In most coastal locations, highly destructive tsunami events are not well represented in historical records, which tend to be short compared to the return period of large tsunamis (hundreds to thousands of years). In this way, tsunamis are different from more frequent hazards (such as floods or cyclones) for which historical records often provide a more useful reference for understanding the hazard and its impacts.

The "low frequency/high consequences"character of tsunamis induces considerable uncertainty into tsunami hazard and risk assessments. Recent history highlights that these uncertainties are commonly underestimated. The 2004 Indian Ocean tsunami and the 2011 Tohoku tsunami caused more than 225,000 and 19,800 fatalities, and US$ 9.9 billion and US$ 210 billion in direct monetary losses, respectively.[27] But the impact of those events was not widely anticipated or planned for,[28] in spite of the fact that these two events constituted a major proportion of the global fatalities and economic losses due to natural hazards in the last 100 years.

## Sources and setting

Submarine earthquakes have generated about 80 per cent of all tsunami events recorded globally. The majority of tsunamigenic earthquakes occur at subduction zones along the Ring of Fire in the Pacific Ocean, while other important source regions include the Sunda Arc and the Makran subduction zone in the Indian Ocean, the northeastern Atlantic, Mediterranean and connected seas,[29] eastern Indonesia and the Philippines, and the Caribbean Sea.

Subduction zone earthquakes with magnitudes above M9 cause the largest tsunamis and these can propagate across oceans. Smaller earthquakes can also generate locally damaging tsunamis. Finally, a class of earthquakes termed "tsunami earthquakes" generate more intense tsunamis than expected from their seismic moment magnitude. Considering that recent events in all of these categories were not fully anticipated and integrated in pre-existing tsunami hazard assessments, we must be cautious in future hazard assessments, accounting for: (a) the possibility that M9 earthquakes might occur on virtually every major subduction zone[30] and (b) the complexity of

27 Centre for Research on the Epidemiology of Disasters (CRED). 2009. Emergency Events Database (EM-DAT). Available from www.emdat.be

28 Synolakis, C. and U. Kanoglu (2015). The Fukushima accident was preventable. *Philosophical Transactions of the Royal Society.*

29 Papadopoulos G. A. and others (2014). Historical and pre-historical tsunamis in the Mediterranean and its connected seas: geological signatures, generation mechanisms and coastal impacts. *Marine Geology*, vol. 354, pp. 81-109.

30 Kagan, Y.Y and D.D. Jackson (2013). Tohoku Earthquake: A Surprise? Bulletin of the Seismological Society of America, vol. 103, pp.1181-1194.

recent earthquakes and tsunamis in terms of tsunami generation and resulting impacts.

The second most important sources of tsunamis are volcanoes and landslides. Tsunamigenic landslides often trigger earthquakes but other mechanisms can also trigger them. Tsunami hazard and risk assessment methods for these sources are less well established than those for earthquakes because they are less frequent and because their tsunami generation mechanisms are complex and diverse. Some of the most powerful tsunamis in history, however, have been caused by these sources, such as the seventeenth century B.C. Santorini (Greece) and the 1883 Krakatau (Indonesia) volcanic tsunamis, or the 1958 Lituya Bay (Alaska) earthquake-triggered landslide. Compared with earthquakes, landslides and volcanoes tend to produce tsunamis that are more spatially localized, although they can result in much higher run-up. Tsunamis from these tsunami sources are also more difficult to warn against effectively. Thus they should be considered at least for local tsunami hazard assessments.

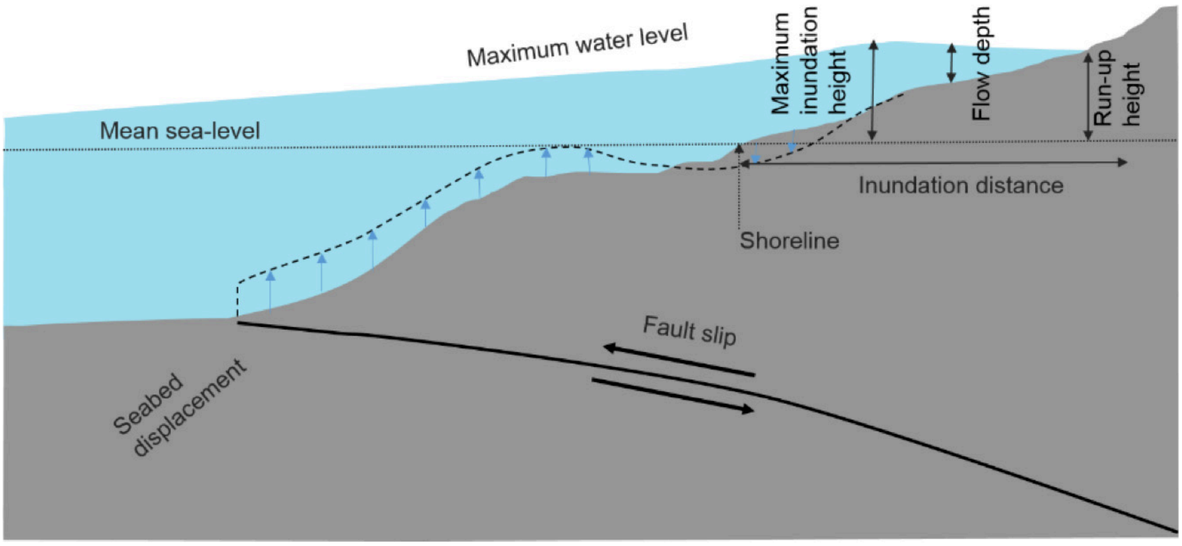


**Figure 1** - Sketch showing main features of tsunamis induced by earthquake slip. The fault slip causes a seabed displacement that generates the tsunami. Shoaling gives rise to increased maximum water levels towards the coast.

## Tsunami hazard assessment

While tsunami hazard assessments were previously routinely developed using worst-case scenarios, probabilistic approaches for estimating tsunami hazard and risk are progressively becoming the new standard.

In a probabilistic tsunami hazard analysis (PTHA), parameters that describe all possible tsunami sources and their occurrence rates are established first. Subsequently, tsunami propagation and inundation metrics are modelled, most often by means of numerical models combined with high-resolution bathymetry and topography. The results are then aggregated according to the source probability and modeled tsunami impact, providing hazard curves describing the exceedance probability for different tsunami intensity thresholds.

PTHA explicitly addresses different types and sources of uncertainty, caused by lack of knowledge of the source mechanism and the frequency of the largest events, limitations of input data, and modelling approximations. As a consequence, different alternative models are usually developed to quantify the uncertainty.

Another source of uncertainty derives from the lack of sufficiently accurate high-resolution digital elevation models and the computationally intensive nature of tsunami propagation modelling, which together limit the model resolution and the number of scenarios that can be simulated. When available, empirical tsunami data can be integrated into the analysis or be used for checking PTHA results.

| Description of input data | National entities that most commonly have these data | Examples of open databases available from international sources |
|---|---|---|
| Bathymetry and topography | national mapping agencies; geological survey; marine science institutions; meteorological, marine, environmental protection agencies | GEBCO, ETOPO, SRTM (not suitable for high-resolution inundation modelling). |
| Tsunamigenic sources | geological survey; earth science, geophysical institutions | ISC-GEM Catalogue; global CMT Catalog;GEM faulted earth; literature |
| Past tsunami observations | meteorological, marine, environmental protection agencies; geophysical institutions | NOAA NGDC; Euro-Mediterranean Tsunami Catalogue, HTDB/WLD Database; literature |
| Exposure | local government; national agency responsible for census; various ministries, private sector,<br>United Nations | WorldPop, Landscan, or GPW Global Population Data<br>Global Exposure Database |
| Vulnerability models | engineering community; academia | Literature (e.g. reporting post-tsunami surveys or laboratory testing); Geoscience Australia; Comprehensive Approach for Probabilistic Risk Assessment (CAPRA) |

**Table 1 -** Sources of data at each stage of the probabilistic tsunami hazard analysis

## Exposure and vulnerability assessment

Tsunami inundation will vary according to the topography and surface roughness, but is limited to within a few kilometres of the coastline. In the inundation zone, the exposure encompasses both the population and the built-up environment (buildings, infrastructure and critical facilities).

The possible effect of a tsunami is quantified by measures of vulnerability – the relationship between tsunami flow depth or velocity, and the resulting damage or loss. Vulnerability is often divided into the study of (a) the probability of human casualties, influenced by a population's risk awareness and behaviour during a tsunami, (b) structural damage and the resulting economic loss, influenced by building type and construction material and (c) social vulnerability, which deals with damage to livelihoods and communities and their post-event recovery.

Socioeconomic vulnerability is influenced by socioeconomic factors, gender, availability of infrastructure, and coping capacity. Assessing impacts entails very large uncertainty; even the most common damage metric, probability of structural damage is not yet very well understood. The landmark 2004 and 2011 tsunamis are relatively recent events, and the tsunami community is still in the early stages of understanding how to quantify both the physical and the societal vulnerability.

## Tsunami risk assessment use in national DRR measures

Local- and regional-scale risk assessments should combine the modelled hazard (e.g. overland flow depths, velocities) with exposure databases and vulnerability models, ideally using a probabilistic approach to risk quantification. Regional and global assessments are generally broad-scale and hence are not suitable to directly perform local-scale decision making; but rather they can serve as a guide to understanding national level tsunami risks to prioritize regions requiring more detailed site-specific studies.[31]

Long-term tsunami risk reduction measures can be devised based on local or regional scale risk assessments through approaches such as land-use planning, tsunami building codes, early warning systems and evacuation planning, installation of engineered defenses, and specific measures for nuclear and non-nuclear critical infrastructure.

Several tsunami DRR measures are now implemented worldwide. Regional Tsunami Early Warning Systems (TEWS) are today operational almost everywhere and provide regional scale warnings for any Member State of the

31 Løvholt, F., J. Griffin and M.A. Salgado-Gálvez (2015). Tsunami hazard and risk assessment on the global scale. *Encyclopedia of Complexity and Systems Science*. Meyers R.A., ed. Berlin and Heidelberg: Springer.

CASE STUDY

## Box 1 - Master Plan for Reducing Tsunami Risk

**Indonesia**

Following the 2004 Indian Ocean Tsunami, Indonesia invested heavily in disaster management. In 2007 it passed a Disaster Management Law, establishing the National Disaster Management Agency (BNPB).

This was followed in 2008 by the establishment of the multi-agency Indonesian Tsunami Early Warning System (InaTEWS), with the support of international partners. Investment in the full warning chain, from monitoring, decision support and warning systems through to "last mile" dissemination and evacuation planning has been critical, especially due to the short time frames for evacuation in many parts of the country.

A first national scale PTHA was undertaken in 2012 and incorporated into the national Master Plan to spatially prioritize where to invest in tsunami mitigation. Technical guidelines defining minimum standards for hazard and risk assessment have been written to support implementation of the Master Plan, assisting local governments in implementing informed tsunami risk reduction activities such as evacuation planning and tsunami shelter construction.

In line with a strong political agenda to develop Indonesia's maritime-based economy, tsunami risk assessment is identified as an important tool for safeguarding development investments and coastal industries, including fishing and tourism, and for building resilient coastal villages. Although challenges remain, Indonesia demonstrates how a robust understanding of tsunami risk can underpin tsunami risk reduction measures at national and local level.

Indian Ocean Commission. However, they might be ineffective without one of the most important DRR measures at the national level: the local scale assessment of the regional warning and the implementation of "last mile" actions in response – rapid alert dissemination and evacuation on pre--established evacuation routes.

However, in many countries with tsunami risk, these elements are not in place. Engineered mitigation measures such as breakwaters and seawalls are even less common globally because of the cost of constructing and maintaining them, but they have been built along the coastlines of Japan. Tsunami evacuation buildings have also been implemented, although in limited areas. These enable vertical evacuation of people in flat or isolated locations with few options to evacuate inland during near-field tsunamis. Although the physical measures may be effective in places, in general they cannot eliminate the risk. Even with warning systems and engineered solutions, risk awareness among the population is necessary for reducing casualties.

In countries such as Chile and Japan, the relatively high rate of self-evacuation in recent events is likely to have reduced the overall death tolls. Tsunami educational programmes have been implemented across the world to expand this awareness.

## Resources for further information

Freely available software exists for simulating tsunami propagation and inundation. Some widely used open source or community models include ComMIT (National Oceanic and Atmospheric Administration, United States), GeoClaw (University of Washington, United States), ANUGA (Australian National University and Geoscience Australia) and TUNAMI (Tohoku University, Japan). However, these models require appropriate skills and training to be used effectively.

It is also crucial that such codes be validated and verified. Relevant information about models, past events, etc. can be found through national stakeholders, such as the Pacific Marine Environmental Laboratory (PMEL) (United States).[32] Others include the International Tsunami Information Center (ITIC),[33] the North-Eastern Atlantic and Mediterranean Tsunami Information Center (NEAMTIC)34 and the Indian Ocean Tsunami Information Center (IOTIC).

In contrast, there are no comparable widely used models for quantifying tsunami frequencies or vulnerability because of the diversity of approaches used to model these factors. Notwithstanding, new guidelines from the American Society of Civil Engineers (ASCE) for assessing forces due to tsunami loads have recently become available.

General open risk assessment modules and initiatives, such as CAPRA,[35] can combine the hazard, exposure and vulnerability, to quantify commonly known risk metrics such as average annual losses, probable maximum losses and loss exceedance curves, as done at the global level for UNISDR's GAR15.[36] We also refer to the tsunami risk guidelines of UNESCO-IOC.[37]

At present, the approaches for tsunami risk analysis are not well standardized. Therefore, current methods, some of which are described in the online references, need guidelines accepted by the tsunami community.

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32 NOAA Center for Tsunami Research (2017). Pacific Marine Environmental Laboratory. United States Department of Commerce. Available from http://nctr.pmel.noaa.gov

33 International Tsunami Information Center. 2017. Intergovernmental Oceanographic Commission of UNESCO. Available from http://itic.ioc-unesco.org/index.php

34 North-Eastern Atlantic, Mediterranean and connected seas Tsunami Information Centre. 2017. Intergovernmental Oceanographic Commission of UNESCO. Available from http://neamtic.ioc-unesco.org

35 Indian Ocean Tsunami Information Center (2017). *Intergovernmental Oceanographic Commission of UNESCO.* Available from http://iotic.ioc-unesco.org

36 United Nations Office for Disaster Risk Reduction (2015). *Global Assessment Report on Disaster Risk Reduction* 2015.

37 Chock, G. and others (2016). Target structural reliability analysis for tsunami hydrodynamic loads of the ASCE 7 standard. *Journal of Structural Engineering,* vol. 10, 1061/(ASCE) ST. 1943-541.

To organize and focus efforts on such issues, a Global Tsunami Model has been proposed to provide coordinated action for tsunami hazard and risk assessment. While the Model is not yet fully operational, many publications illustrate methods that can be adapted for future hazard and risk analysis in the Model.[38,39 40]

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38 United Nations Educational, Scientific and Cultural Organization and Intergovernmental Oceanographic Commission (2009). *Tsunami Risk Assessment and Mitigation for the Indian Ocean: Knowing Your Tsunami Risk and What to Do About It.* Paris: UNESCO.

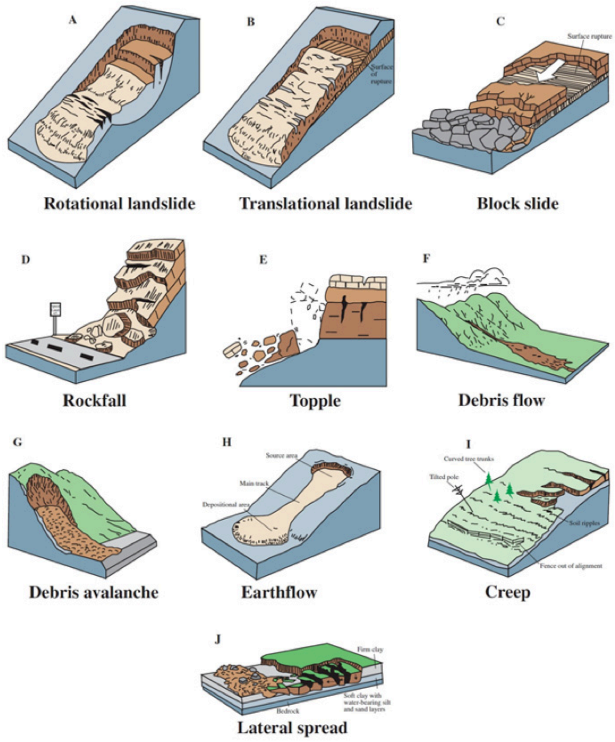
39 Geist, E. and T. Parsons (2006). Probabilistic analysis of tsunami hazards. *Natural Hazards*, vol. 37, pp. 227-314.

40 Davies G. and others (2017). *A Global Probabilistic Tsunami Hazard Assessment* from Earthquake Sources. Geological Society of London Special Publications, 456.

# 3. Landslide Hazard and Risk Assessment

**Key words:**
landslide, landslide hazard, landslide vulnerability, landslide hazard map, risk management

The term "landslide" refers to a variety of processes that result in the downward and outward movement of slope-forming materials, including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing. The schematics in figure 1 illustrate the major types of landslide movement.




In many parts of the world, landslides are a frequent natural hazard and a major threat to humans and the environment. According to the International Disaster Database of the Centre for Research on the Epidemiology of Disasters (CRED) (EM-DAT)[42], since 1900 some 130,000 persons have lost their lives because of landslides and flash floods; and the economic losses amounted to over US$ 50 billion. In the period from 2000 to 2014, the corresponding figures were around 26,000 deaths and US$ 40 billion in losses. The actual figures are, however, much higher.

In the CRED-EM database, the losses due to earthquake-triggered landslides are attributed to earthquakes, and many landslide events with no casualties, but significant material losses are not reported. For example, 20-25 per cent of the 87,000 casualties (69,000 confirmed killed and 18,000 missing) caused

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41 United States Geological Survey (2004). Landslide types and processes. Fact sheet 2004-3072. Available from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

42 Guha-Sapir, D., R. Below and P. Hoyois. The CRED/OFDA *International Disaster Database*. Université catholique de Louvain. Belgium.

by the Sichuan (or Wenchuan) Earthquake of 12 May 2008 were the result of the landslides triggered by that event.[43] Recent catastrophic landslides in Afghanistan, United States, the Philippines and India illustrate that landslides are still a major threat in developed as well as developing countries.

The volume of soil and rock mobilized in a landslide can vary from a small individual boulder to millions, and in rare cases billions, of cubic metres. Generally, the potential destructiveness of a landslide is a function of the volume of the masses that are mobilized, and their velocity. But even a single boulder can cause several fatalities.

## Sources and setting

The primary driving factor of landslides is gravity acting on a portion of a slope that is out of equilibrium. The following are some of the major landslide triggering mechanisms:

- River erosions, glaciers, or ocean waves
- Weakening of rock and soil slope proprieties through water saturation by snowmelt or heavy rains
- Stresses, strains and excess of pore pressures induced by the inertial forces during an earthquake (earthquakes of magnitude greater than or equal to 4.0 can trigger landslides)
- Volcanic eruptions with the production of loose ash deposits that may become debris flows (known as lahars) during heavy rains
- Stockpiling of rock or ore, from waste piles, or from man-made structures
- Changes of the natural topography caused by human activity.

43 Zhang, L.M., S. Zhang and R.Q. Huang (2014). Multi-hazard scenarios and consequences in Beichuan, China: the first five years after the 2008 Wenchuan earthquake. *Engineering Geology*, vol.180, pp. 4-20.

## Landslide hazard assessment

Landslide hazard is a function of susceptibility (spatial propensity to landslide activity) and temporal frequency of landslide triggers, and its assessment may be done on local (individual slope), regional, national, continental, or even global scales. The most appropriate method in each scale depends on the extent of the study area and on the available data. Examples of various methodologies for landslide hazard assessment on different scales can be found in the literature.[44,45,46,47]

In any type of landslide hazard assessment, there is a need to consider topography and other factors that influence the propensity to landslide activity (susceptibility factors), as well as landslide triggering factors (precipitation, earthquakes, human activity). Table 1 lists the input data typically required for landslide hazard assessment at regional to national scales.

44 Nadim, F. and others (2006). Global landslide and avalanche hotspots. *Landslides*, vol. 3, issue 2, pp. 159-173.

45 Nadim, F., H. Einstein and W.J. Roberts (2005). Probabilistic stability analysis for individual slopes in soil and rock. *Proceedings of the International Conference on Landslide Risk Management.*

46 Norwegian Geotechnical Institute (2010). SafeLand project. *Overview of landslide hazard and risk assessment practices.*

47 Corominas, J. and others (2014). Recommendations for the quantitative analysis of landslide risk. *Bulletin of Engineering Geology and the Environment,* vol. 73, issue 2, pp. 209-263.

| Description of input data | National entities that most commonly have this data | Examples of open databases available from international sources |
|---|---|---|
| Digital elevation model | National mapping and cartography authority | SRTM30 (NASA) |
| Lithology | National geological survey | UNESCO (CGMW, 2000), One Geology initiative |
| Vegetation cover | National agriculture/ environment and/or national forest agency | GLC2000 database |
| Soil moisture factor | National agriculture/ environment and/or national meteorological agency | Climate Prediction Center |
| Hourly, daily and monthly precipitation | National meteorological agency | Global Precipitation Climatology Centre of the German National Meteorological Service, DWD |
| Seismicity | National building code(s) | Global Seismic Hazard Program, Global Earthquake Model |
| Infrastructure and road/railway network in mountainous regions | National road and/or railway authority | Google maps |

**Table 1 -** Sources of data for landslide risk assessments at regional and national scale

There are many sources and types of uncertainty in landslide hazard assessment. By far the main source of uncertainty is the epistemic uncertainty related to our limited knowledge about the materials that make up the slope(s), their response under various external perturbations, and the characteristics of the triggering factors.

Soils, rocks and other geomaterials exhibit significant spatial variability (aleatory uncertainty) and their properties often change markedly over small distances. Many non-local scale landslide hazard assessment models are empirical and should be calibrated/validated with regional and/or national database(s) of previous landslide events. Landslide inventory maps are often an important input for the landslide susceptibility/hazard assessment and/or validation.

However, even in developed countries, the databases of landslide events are usually far from complete. Often they only cover the events from the recent past, and/or have an over-representation of landslides triggered by a single extreme event, and/or are heavily biased towards the events reported by a single source, such as the national road or rail authority.

Climate change increases the susceptibility of surface soil to instability because of abandoned agricultural areas, deforestation and other land-cover modifications. Anthropogenic activities and uncontrolled land-use are other important factors that amplify the uncertainty in landslide hazard assessment.

## Exposure and vulnerability assessment

Exposure of the population and/or the built environment to landslide risk can be assessed by superimposing landslide hazard map(s) on maps of population density, the built environment and infrastructure. However, this type of assessment provides only a qualitative picture of the exposure. Landslides vulnerability assessment is a complex process that should consider multiple dimensions and aspects, including both physical and socioeconomic factors. Physical vulnerability of buildings and infrastructure is a function of the intensity of the landslide event and the resistance levels of the exposed elements.[48,49,50,51,52,53]

Societal vulnerability and resilience of a community, on the other hand, are related to factors such as demographics, preparedness levels, memory of past events, and institutional and non-institutional capacity for handling natural hazards. Although a significant amount of literature exists[54] on the assessment of societal vulnerability to natural hazards, few studies specifically address the social and economic vulnerability to landslides.

In the SafeLand project, an indicator-based methodology was developed to assess the (relative) societal vulnerability levels. The indicators represent the underlying factors that influence a community's ability to deal with and

48 Uzielli, M. and others (2008). A conceptual framework for quantitative estimation of physical vulnerability to landslides. *Engineering Geology,* vol.102, issues 3-4, pp. 251-256.

49 Norwegian Geotechnical Institute (2011). SafeLand project. *Physical vulnerability of elements at risk to landslides: methodology for evaluation, fragility curves and damage states for buildings and lifelines.*

50 ___________ Case studies of environmental and societal impact of landslides – Part A: Rev. 1. Case studies for environmental (physical) vulnerability.

51 Papathoma-Köhle, M. (2016). Vulnerability curves vs. vulnerability indicators: application of an indicator-based methodology for debris-flow hazards. *Natural Hazards and Earth System Sciences*, vol. 16, pp. 1771-1790.

52 Eidsvig, U.M.K. and others (2014). Quantification of model uncertainty in debris flow vulnerability assessment. *Engineering Geology*, vol. 181, pp.15-26.

53 Winter, M.G. and others (2014). An expert judgement approach to determining the physical vulnerability of roads to debris flow. *Bulletin of Engineering Geology and the Environment,* vol. 73, issue 2, pp. 291-305.

54 Cutter, S., J. Boruff and L. Shirley (2003). Social vulnerability to environmental hazards. *Social Science Quarterly,* vol. 84, issue 2, pp. 242-261.

recover from the damage associated with landslides.[55,56] The proposed methodology includes indicators that represent demographic, economic and social characteristics such as the human development index and gross domestic product, and indicators representing the degree of preparedness and recovery capacity. The purpose of the societal vulnerability assessment is to set priorities, serve as background for action, raise awareness, analyse trends and empower risk management.

## Risk assessment use in national DRR measures

Studies on global distribution of landslide hazard,[57] as well as detailed assessment of the reported occurrence of landslide disasters in the CRED-EM database, suggest that the most exposed countries to landslide risk are located in south Asia, along the Himalayan belt, in east Asia, south-eastern Asia, and in Central and South America.

In most developed countries with high landslide hazard, landslide events rarely end up as disasters. This is mainly due to the low exposure in the most landslide-prone areas, as well as the increasing ability to identify the landslide-prone areas and to implement appropriate landslide risk management actions.

Many countries that have areas with high landslide hazard lack the necessary legislation and regulations to prioritize and implement a landslide risk mitigation plan. Often it is asserted that it "takes a disaster to get a policy response", and case studies of landslide risk management in different countries show a relationship between the incidence of disasters, and progress and shifts in landslide risk management.[58]

Disasters can catalyse moments of change in risk management aims, policy and practice. Increasingly, the decision-making processes of the authorities in charge of reducing the risk of landslides and other hazards are moving from "expert" decisions to include the public and other stakeholders.[59]

In practice, effective landslide risk mitigation should be implemented at local (individual slope) or regional level. On the local scale, the design of a risk

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55 Norwegian Geotechnical Institute (2012). SafeLand project. M*ethodology for evaluation of the socio-economic impact of landslides (socio-economic vulnerability)*.

56 Eidsvig, U.M.K. and others (2014). Assessment of socioeconomic vulnerability to landslides using an indicator-based approach: methodology and case studies. *Bulletin of Engineering Geology and the Environment,* vol. 73, issue 2, pp. 307-324.

57 Nadim, F. and others (2012). *Assessment of Global Landslide Hazard Hotspots*. Berlin and Heidelberg: Springer.

58 Norwegian Geotechnical Institute (2011). SafeLand project. *Five scoping studies of the policy issues, political culture and stakeholder views in the selected case study sites – description of methodology and comparative synthesis report.*

59 Scolobig, A., M. Thompson and J. Linnerooth-Bayer (2016). Compromise not consensus: designing a participatory process for landslide risk mitigation. *Natural Hazards,* vol. 81, supplement 1, pp. 45-68.

mitigation measure, for example an early warning system, can be based on a number of reasonable scenarios and may involve the following steps:

- Define scenarios for triggering the landslide(s) and evaluate their probability of occurrence
- Estimate the volume and extent of the landslide and compute the run-out distance for each scenario
- Estimate the losses for all elements at risk for each scenario
- Compare the estimated risk with risk acceptance/risk tolerance criteria
- Implement appropriate risk mitigation measures if required.

It is not clear that this level of rigour is always practised in landslide risk management, especially in poor countries where resources are limited.

## Good practice of landslide risk management

One of the best examples of good landslide risk management practice is found in Hong Kong, China. Hong Kong is situated on the south-eastern coast of China, has a subtropical climate with an average annual rainfall of 2,300 mm, peaking in the summer, with regular rainfall events of intensities exceeding 100 mm/hour.

Hong Kong has a small land area of about 1,100 km2, over 60 per cent of which is located on hilly terrain. Its population has increased steadily from 2 million in 1950 to over 7 million today. This has led to a huge demand for land for residential use and infrastructure, and resulted in a substantial portion of urban development located on or close to man-made slopes and natural hillsides. Man-made slopes that are not properly designed and steep hillsides are susceptible to landslides during heavy rainfall, and debris flows are common in natural terrain. As a result, landslides are a large natural hazard in Hong Kong, where they can cause significant casualties and socioeconomic impacts.

On 18 June 1972, after days of heavy rainfall, two destructive landslides in Sau Mau Ping and at Po Shan Road in Hong Kong killed one hundred and thirty-eight people, covered a resettlement area with landslide debris and caused a high-rise building to collapse. In 1977, in the aftermath of these and other fatal landslide disasters, the Geotechnical Control Office (now the Geotechnical Engineering Office (GEO)) was set up to strategically implement a comprehensive system to maintain slope safety.

The Slope Safety System it developed comprises several initiatives to reduce landslide risk in a holistic manner.  The key components of the system are comprehensive enforcement of geotechnical standards, community participation for slope safety, systems for early warning and emergency response, and comprehensive databases of landslide events and implemented risk mitigation measures. Several studies show that the implementation of the Slope Safety System has reduced the annual fatalities due to landslides by over 50 per cent since the late 1970s.[60] There have now been no fatalities in almost a decade.

Programmes that have achieved this level of success are rare and are obtained at considerable cost. In developing countries, few, if any, examples exist of successful countrywide reduction in landslide losses as a result of such initiatives. Landslides are among the most potentially manageable of all natural hazards, given the range of approaches and techniques that are available to reduce the level of hazard. There is much scope to reduce their impacts.

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60 Malone, A.W. (1997). *Risk Management and Slope Safety in Hong Kong*. The Hong Kong Institution of Engineers.

## Resources for further information

The following sources provide useful information and tools for landslide hazard and risk assessment, and landslide risk management:

- European Commission FP7 Project SafeLand[61]
- Geological Survey of Canada landslide guidelines[62]
- International Consortium on Landslides[63]
- United States Geological Survey landslide hazards programme[64]
- Geotechnical Engineering Office, Hong Kong slope safety[65]
- UNISDR global assessment reports on disaster risk reduction[66]
- MoSSaiC: Management of slope stability in communities[67]

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61Norwegian Geotechnical Institute (2012). SafeLand project. R&D program Safeland. Abstract available from www.ngi.no/eng/Projects/SafeLand

62 Government of Canada (2017). Hazards: Landslides. Available from www.nrcan.gc.ca/hazards/landslides

63International Consortium on Landslides. Available from http://icl.iplhq.org/category/home-icl/

64 Landslide Hazards Program. Available from http://landslides.usgs.gov/

65 Geotechnical Engineering Office (2012). Hong Kong Slope Safety. Available from http://hkss.cedd.gov.hk/hkss/eng/index.aspx

66 United Nations Office for Disaster Reduction (2015). Global Assessment Report. Available from www.preventionweb.net/english/hyogo/gar/

67 Anderson, M. and L. Holcombe. Management of Slope Stability in Communities. Available from www.bristol.ac.uk/geography/research/hydrology/research/slope/mossiac/

# 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)

## 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,[68] 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 that 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.

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68 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)[69] and a final, more detailed, flood risk assessment (FRA).

PRFA 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"(APSFR). 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)70 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

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

70 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.[71]

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.

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71 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

| Description of input data | National entities that most commonly have these data | Examples of open databases available from international sources |
|---|---|---|
| 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

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 floods[72] 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 people that need to be managed. This results in a more organized and refined loss data collection.

72 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.ijdrr.2015.09.013

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.

## 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.[73]

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

73 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

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 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.

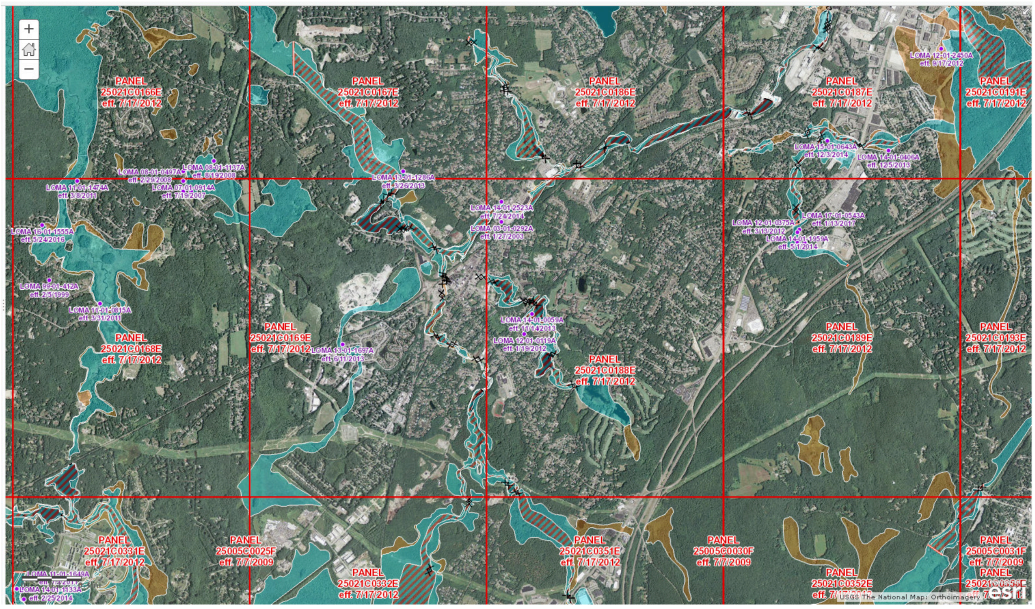

**Figure 1 -** GIS viewer showing the FEMA's national flood hazard layer (Official)

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.

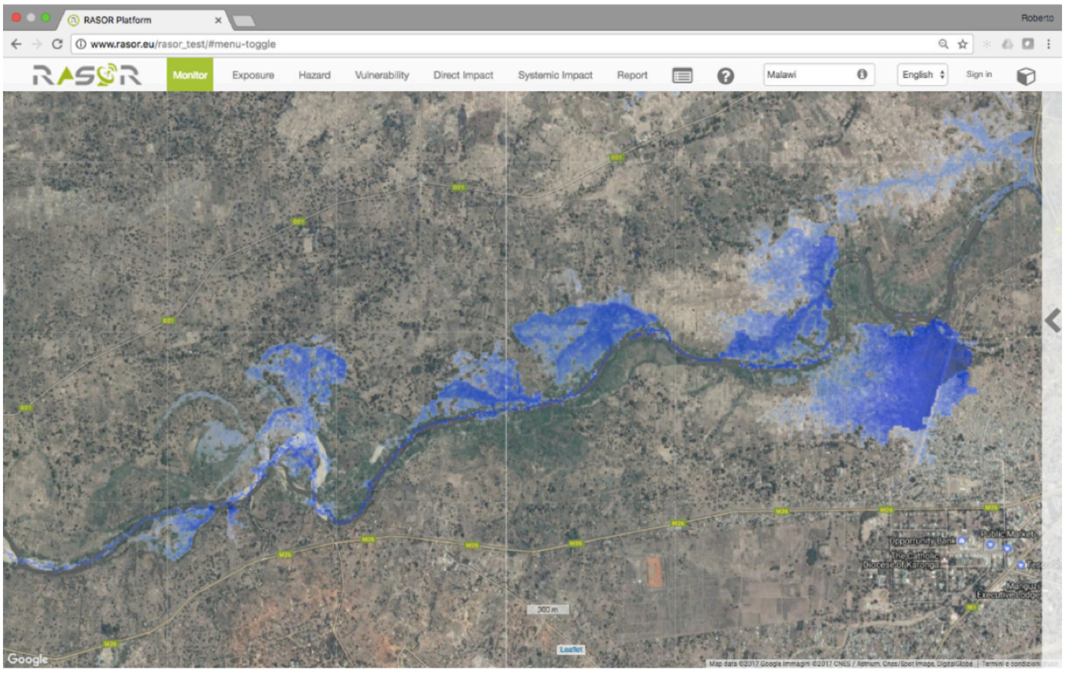


**Figure 2 -** 100-year flood map depicting maximum water depth for the river flowing into Karonga city in Malawi

## Resources for further information

- International community of practice focused on this hazard
  - preventionweb.org
  - gfdrr.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

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# 5. Biological Hazards Risk Assessment

Biological hazards are a major source of risk that may result in emergencies and disasters. They cause significant loss of life, affect many thousands of people, have the potential for major economic losses through loss of livestock and crops, and may also cause damage and loss to the natural heritage, including to endangered fauna and flora.

The management of risks due to biological hazards is a national and community priority. It has been recognized as part of the Sendai Framework, and is globally addressed under the International Health Regulations (IHR).

## Biological hazards – what are they?

Biological hazards are of organic origin or conveyed by biological vectors, including pathogenic microorganisms, toxins and bioactive substances. Examples are bacteria, viruses or parasites, as well as venomous wildlife and insects, poisonous plants, and mosquitoes carrying disease-causing agents [1].[74] These hazards are usually the result of a natural occurrence, but can also result from deliberate or accidental release.

Biological hazards also pose a risk to animals, including livestock, and to plants. However, we are focusing here on human health. The consequences of a biological hazardous event may include severe economic and environmental losses. Some examples of recent large outbreaks,[75] epidemics[76] or pandemics[77] due to biological hazards either on their own or following a disaster are:

- The Ebola Virus Disease outbreak in West Africa in 2013-2016, the largest epidemic of its kind to date in the populations of Guinea, Liberia, and Sierra Leone.
- The ongoing outbreak of Zika virus infection in the Americas and the Pacific region, associated with congenital and other neurological disorders.
- Significant increase in diarrheal disease incidences following recurrent floods in most African countries or significant increase following the 2004 tsunami in Indonesia and Thailand [2].
- Outbreaks of yellow fever in Angola, the Democratic Republic of Congo and

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74 http://preventionweb.net/go/488

75 A disease outbreak is the occurrence of cases of disease in excess of what would normally be expected in a defined community, geographical area or season. An outbreak may occur in a restricted geographical area, or may extend over several countries. It may last for a few days or weeks, or for several years. A single case of a communicable disease long absent from a population, or caused by an agent (e.g. bacterium or virus) not previously recognized in that community or area, or the emergence of a previously unknown disease, may also constitute an outbreak and should be reported and investigated. www.who.int/topics/disease_outbreaks/en/

76 Epidemic: The occurrence in a community or region of cases of an illness, specific health-related behaviour, or other health-related events clearly in excess of normal expectancy. http://www.who.int/hac/about/definitions/en/

77 A pandemic is the worldwide spread of a new disease. www.who.int/csr/disease/swineflu/frequently_asked_questions/pandemic/en/

Uganda in 2016.

- Outbreaks of Middle East Respiratory Syndrome – Coronavirus (MERS CoV), an emerging disease identified in 2012.

Assessing the risk of biological hazards can be challenging owing to their unique characteristics:

- **Agent diversity.** Biological hazards range from microorganisms such as bacteria or viruses, to toxins to insect infestations. They can be transmitted to humans from the environment, from animals, from plants, and from other humans.
- **Routes of transmission.** These include airborne transmission, ingestion, absorption (through the skin, eyes, mucous membranes, wounds), animal vectors (e.g. mosquitos or ticks), and bodily fluids (e.g. blood, mother-to-child transmission, sexual transmission).
- **Pathogenicity and virulence.** Some biological hazards can cause severe disease in extremely low concentrations and can multiply quickly once within its host. For example, 1-10 aerosolized organisms of Lassa virus or Ebola are sufficient to cause severe disease in humans.
- **Hazard identification.** As microbes are not visible to the naked eye, they are often not easy to identify on the basis of epidemiological information derived from clinical signs and symptoms. They therefore require specific diagnosis techniques, including polymerase chain reaction (PCR), to amplify a single copy or a few copies of a piece of DNA, microbial cultures, whole genome sequencing.
- **Endemic diseases with potential for epidemic transmission.** Unlike some other hazards (e.g. earthquakes or floods), biological hazards can be present in the community (i.e. they are endemic) and usually pose low risk when the population is largely immune. The risk may change when crises or emergencies arise, exacerbating the conditions favourable for disease transmission, or when people migrate from disease-free areas to endemic regions typically lacking immunity, making them susceptible to infection and transmission of the disease resulting in cases in excess of normal expectancy. Biological hazards, which are not endemic also pose a risk when they are introduced to a new host community with no immunity.
- **Sensitivity to climate, environmental or land use changes.** Biological hazards – particularly zoonoses[78] and vector-transmitted diseases such as malaria, dengue, Zika and Ebola – may increase in incidence, lethality or change geographic distribution or seasonal patterns directly due to climate and weather sensitivity, environmental or land-use changes, or mediated

78 Zoonoses are diseases and infections that are naturally transmitted between animals and humans. A zoonotic agent may be a bacterium, a virus, a fungus or other communicable disease agent. www.who.int/neglected_diseases/diseases/zoonoses/en/

through changes in ecosystems resulting from human activities, thus changing human exposures and susceptibility to these hazards. An estimated 75 per cent of emerging infectious diseases of humans that have evolved from exposure to zoonotic pathogens [3] warrant risk assessments for health threats at the interface between animal, human and ecosystems.

## Assessing the risk of biological hazards

Approaches in assessing the risks of biological hazards differ according to the purpose of the assessment:

- **Strategic Risk Assessmen**t is used for risk management planning with a focus on prevention and preparedness measures, capacity development and medium- to longer-term risk monitoring and evaluation.
- **Rapid Risk Assessment** is used to determine the level of risk associated with detected events and to define response interventions accordingly.
- **Post-event assessment** is used for recovery planning, updating and strengthening the overall risk management system.

### Pre-event: Strategic Risk Assessments

Strategic Risk Assessments are used for risk management planning with a focus on prevention and preparedness and capacity development before events occur. They can be used for medium- to longer-term risk monitoring and evaluation, which tracks changes in risk over time. They catalyse targeted action to reduce the level of risk and consequences for health based on assessment of the hazard, exposure, vulnerabilities and capacities.

In relation to addressing the risk of biological hazards, the term vulnerability refers to the risk factors that exist in exposed populations, such as the burden of endemic diseases, living conditions (e.g. overcrowding) and environment (e.g. favourable environment for the growing of the pathogen). This is in addition to factors that are addressed in risk assessments for other hazards, such as demographics (e.g. age or gender), the availability of health services to those populations and the degree of resilience of the health systems.

Some examples of strategic risk assessment methods for biological hazards are outlined below.

A quantitative microbiological risk assessment (QMRA) is an example of a strategic risk assessment for prevention and mitigation of risks. The hazard identification includes identifying the characteristics of the pathogen/microbial agent (i.e. case fatality ratios, transmission routes, incubation times…) and the human diseases associated with the specific microorganism. This information can be found in the literature and it could be also helpful to search for similar outbreaks as references.

The exposure assessment of the QMRA measures the dose of the pathogen that an individual ingests, inhales or comes in contact with. It also requires data on the concentration of the pathogen in the source, route of transmission and timing of the exposure.

For this purpose, the QMRA Wiki [4] is a community portal with evolving knowledge repository for the QMRA. In addition, some other available and free access QMRA tools are E3 Geoportal (European Environment and Epidemiology Network) QMRA for Food and Waterborne Diseases [5] and the QMRA spot for drinking water [6].

To prepare for an event involving biological hazards, different approaches to ranking risks could be used, including multi-criteria decision analysis (MCDA) and burden of diseases. These approaches allow for better risk prioritization and planning of public health preparedness.

The World Health Organization (WHO) STAR approach to strategic risk assessment enables countries to incorporate an evidence-based approach to strategic risk assessments. The approach is designed to: engage multisectoral stakeholders around a risk assessment developed for risks affecting public health; provide a systematic, transparent and evidence-based approach to identify, rank and classify priority hazards by level of risk; and for each hazard, to define the level of national preparedness and readiness required to mitigate its risk. The tool is available from WHO on request.

Multi-Criteria Decision Analysis (MCDA) is a stochastic/randomized approach in which several criteria with their levels are identified according to the outcome of interest. Criteria may include information on epidemiological, economic and perception data of the diseases. The criteria can have equal or different weights depending on their relative importance for the outcome. These data can be collected from literature, databases from the official sources, prevalence studies or studies in the field, and from expert consultations. An example is a tool developed by the European Centre for Disease Prevention and Control (ECDC) for ranking infectious diseases to support preparedness planning in the European Union/European Economic Area countries with two versions: a qualitative and less detailed version and a semi-quantitative and more detailed version. Both versions are developed in a flexible way, allowing the users to modify the weighting factors to their own countries. MCDA has also been applied in the WHO Research and Development Blueprint for action to prevent epidemics, which utilizes a combination of the Delphi technique, questionnaires and multi-criteria decision analysis to review and update the Blueprint's priority list of diseases [7].

The Global Burden of Disease (GBD) estimates provide comprehensive and comparable assessment of mortality and loss of health due to diseases, injuries and risk factors, examining trends from 1990 to the present and making comparisons across populations. The estimates provides an understanding of the changing health challenges facing people across the world [8]. GBD research incorporates both the prevalence of a given disease or risk factor and the relative harm it causes. The tools allow decision makers to compare the effects of different diseases and use that information for policymaking. The flexible design of the GBD machinery allows for regular updates as new data and epidemiological studies are made available. In that way, the tools can be used at the global, national and local levels to understand health trends over time [9-10].

The Burden of Communicable Disease in Europe toolkit [11] estimates the burden for 32 communicable diseases and six healthcare-associated infections, applying composite health measures – disability-adjusted life years (DALYs) – to summarize the overall burden in one single metric and compare the relative burden of each communicable disease.

## Detection and response: Rapid Risk Assessment

When an event occurs, and in order to inform early warning and response measures, the level of risk posed by the event itself is assessed on a continuous basis through rapid risk assessments [12,13]. The key parameters to take into account in the risk assessment of communicable diseases are the probability (likelihood of transmission in the population) and the impact (severity of the disease), as well as the context in which the disease occurs.

The initial rapid risk assessment must be generated within a short time period when information is often limited and circumstances can evolve rapidly. The assessment should be undertaken in the initial stages of an event or of an incident being reported and verified, and should ideally be produced within 24 to 48 hours. The level of risk should be re-assessed based on evolving information on the event and disease pattern. Risk assessments will help determine whether a response is indicated, the urgency and magnitude of the response, the design and selection of critical control measures; and they will inform the wider implications and further management of the incident.

In the light of time constraints, the assessment generally relies on published research evidence, on specialist expert knowledge, and on experience gathered through previous similar events. Some sources for identifying outbreaks and obtaining disease information are listed in the WHO Rapid Risk Assessment manual [12], and in appendix 3 of the ECDC operational guidance on rapid risk assessment methodology [13]. The principles of transparency, explicitness and reproducibility strictly apply to a rapid risk assessment. In addition, uncertainties must be identified, clearly documented and communicated.

It is important for the public health team in charge of risk assessment to have the following available:

- A repository of events that occurred in the past
- Evidence-based protocols and guidance ready to use for responding to incidents
- Protocols for identifying sources of key information for rapid risk assessment
- Strategies for rapid literature searches
- Lists of experts who can be consulted.

## Post-event or post-disaster assessments and after-action reviews

As health needs might not be immediately apparent, it is important to assess the risk of biological hazards after natural or human-induced disasters. Damage to health-care facilities and diagnostic and treatment equipment and interruption of services such as power cuts can have long-reaching consequences affecting the proper functioning of health facilities, including the preservation of the vaccine cold chain.

The availability of safe water, sanitation facilities and hygiene conditions before, during and after a disaster can greatly determine the impact on a community's health and can result in water-related communicable diseases or vector-borne diseases. Other diseases such as tetanus are also associated with natural hazardous events, where contaminated wounds – particularly in populations where vaccination coverage levels are low – are associated with illness and death from tetanus.

Population displacement is also associated with outbreaks of diseases associated with overcrowding. Disasters can also exacerbate non-communicable diseases and mental health needs and increase demands for sexual and reproductive health services.

Post-disaster assessments also inform the implementation of recovery, reconstruction, rehabilitation and restoration of services and other health-related activities, including plans for ongoing and latent risks to population health, and the application of "build back better" principle to ensure that future risks of emergencies and disasters are reduced.

Health impact assessments include identifying existing and latent risks to population health. A rapid risk assessment of these potential risks to human health, and reports on the acute event and syndromic surveillance indicators are needed. As an example of how to implement a syndromic surveillance in a specific population, ECDC launched a handbook and supporting tool for implementing syndromic surveillance in migrant centres and other refugee settings [14].

Post-event reviews (e.g. after-action reviews (AAR) or critical incident reviews) are qualitative reviews of actions at any level, usually focused on the response to an event, as a means of identifying best practices and lessons learned [15]. An AAR seeks to identify what worked well and how these practices can be institutionalized and shared with stakeholders; and what did not work and requires corrective action. AARs can be used as an evaluation of the real response capacities and processes in place.

AARs following epidemics and pandemics usually include evaluations of the capacity of the organization and health and multisectoral systems to deal with the risk, the availability and the enforcement of legal instruments, and issues of leadership and coordination. For example, several reviews have been conducted following the Ebola outbreak in West Africa 2013-2016 [16-18]. A typical review looks at the scale of the epidemic, origins of human infection, spread patterns of the infection, the effects of the interventions taken in both timing and magnitude, the declaration of the end of the epidemic, and finally lessons learned for future preparedness and response.

## Risk assessment and use in national DRR measures

Risk assessment will inform policymaking of the management of the risks, including biological hazards, by answering the following important questions:

- Who is at risk? Who is more exposed or in vulnerable situations?  What is the level of exposure and the rate of assumed risky behaviours?
- What are the routes of transmissions within and between communities?
- What is the level, severity and scale of the risks? What are the established thresholds that apply to this particular pathogen based on past and present disease incidence?
- What is the risk of international spread that warrants reporting the event under the International Health Regulations (2005) and which may lead to a declaration by WHO of a Public Health Emergency of International Concern?
- What are the effective treatment and control measures available to use to contain and stop the risk?
- What are the environmental and ecological factors or drivers affecting the risk? What is the likelihood and impact of emerging or evolving health threats? How can they be mitigated?
- What are the contextual factors to take into account when managing the risks? These include public perception and behaviour, media interest and political and economic issues.

Policy makers and DRR practitioners use this information to trigger actions that reduce risk of biological hazards i.e. effective and timely prevention, preparedness and response actions, including measures to reduce exposure of groups at increased risk of infection due to biological hazards, contain the spread of the risk, and eventually stopping it.

Measures include protective equipment, behaviour-change practices by raising awareness and education of the public through appropriate communication channels, and effective treatment and/or vaccine if and when available.

Risk information is also used to inform preparedness and contingency planning at various levels and capacity-development measures for health workers to match the full risk profile of the community, including for biological hazards.

Risk assessment information provides the foundation for investment in measures to reduce the risk. For example, identification and mapping of hazardous areas inform the decisions for building critical infrastructure such as water, sanitation and health systems and services to manage the risks of biological hazards as well as other types of emergencies. They also provide the foundation for developing financial applications to manage or transfer the risk.

Impact modelling and rapid risk assessment inform early and rapid estimates of impacts on the populations, on services in health and other sectors, and provide critical information for recovery and rehabilitation reconstruction when needed.

# Case studies of a country good practice

## Case study: Rapid Risk Assessment of a severe respiratory disease

**Event:** A cluster of 22 cases of severe respiratory disease with seven deaths in country X were admitted to hospital over the past 17 days. The event is occurring 8 km from the border and cases have been reported from three villages by a local health-care worker. The area is the poorest in the country and health infrastructure is limited.

Many of the health-care facilities charge a consultation fee and consequently the local population self-medicates during mild illness. There are also strong beliefs that "strange diseases" are caused by sorcery.

**Risk question:** What is the likelihood of further spread of severe cases of respiratory disease and what would be the consequences (type and magnitude) to public health if this were to occur?

Information used to assess the likelihood of further spread:

- Cases are still being reported 17 days after the first known cases were detected
- The specific hazard and mode(s) of transmission have not been identified
- It is also likely that some cases are not being detected (e.g. mild cases are less likely to seek care from health services and are therefore not included in the official reports).

Therefore, if nothing is done, it is highly likely that further cases will occur.

Information used to assess the consequences of further spread:

- The disease has a high case fatality ratio (even when underreporting is taken into account)
- The health-care system is poor and the ability to treat the cases is already limited; new

admissions will further stress acute care services and lead to worse clinical outcomes for hospitalized patients

- Negative economic and social impact of the cases and deaths in the affected communities
- Potential for unrest in communities because of cultural belief that sorcery is causing the deaths
- The event is occurring in a border area and could affect the neighbouring country.

Therefore, if further cases occur, the consequences will be severe.

Using the risk matrix to combine the estimates of likelihood and consequences leads to an estimate of the overall risk. In this case, the overall level of risk is high. The confidence in the risk assessment is low to medium.

Although the report is from a local health-care worker, the information is limited and it is not clear if that person has examined the suspect cases or is merely reporting a rumour.

Source: http://apps.who.int/iris/bitstream/10665/70810/1/WHO_HSE_GAR_ARO_2012.1_eng.pdf

## Case study – Collaboration between the Chief Epidemiologist and Civil Protection in Iceland on risk assessment

An island country located in the North Atlantic Ocean, Iceland has a population of some 330,000 inhabitants and an area of 103,000 km2, making it one of the most sparsely populated countries in Europe. Over two thirds of the population live in the southwest part of the country, which makes up the Reykjavik area, while the rest are scattered along the coastal area.

Iceland's Chief Epidemiologist and the Civil Protection service of the National Commissioner of Police are responsible for the national preparedness planning for communicable diseases, as well as chemical, biological and radio-nuclear hazards and events where the source is unknown. Additionally, the Chief Epidemiologist, in cooperation with the Civil Protection service, is responsible for the national risk assessment, risk reduction and response management for these types of events.

In times of crisis, the risk assessment is performed in cooperation with responders and scientists at formal meetings at the National Coordination Centre. Meetings are scheduled as often as needed and a press release issued after each meeting. The objective of the meetings is to share information, assess the risk and decide whether preparedness plans should be activated.

The preparedness plans in Iceland are all-hazard plans and involve the following sectors [19]: primary health care and hospitals, ambulance services, distributors of medicines, Icelandic Medicine Agency, Icelandic Food and Veterinary Authority, food suppliers and distributors, the Farmers Association of Iceland, Icelandic Transport Association, Icelandic Tourist Board, the financial sector, Icelandic Environmental Agency, Icelandic federation of energy and utility companies, Icelandic road and coastal administration, prisons, Red Cross and rescue services, Icelandic National Broadcasting Service and the Evangelical Lutheran Church of Iceland.

The main health hazards in Iceland result from natural hazards such as volcanoes, earthquakes, avalanches and severe weather. Hazards from volcanoes have been a great concern in Iceland for years. These hazards can result from heavy ash fall and various gases being emitted from eruptions, the main one being sulphur dioxide (SO2).

The evaluation of possible health effects involves various agencies but the final risk assessment, risk mitigation and communication to the public is the responsibility of the Chief Epidemiologist and Civil Protection. Several Icelandic studies have been published that describe the health effects of volcanic eruptions in Iceland. These studies are invaluable in the making of preparedness plans for hazards due to volcanic activities in Iceland as well as for carrying out risk assessment and risk reduction.

# Resources for further information

## Open-source modelling tools available

- E3 Geoportal (E3 tools): Vibrio, West Nile, E3 map viewer (Dengue, Chikungunya, mosquitoes), Quantitative Microbial Risk Assessment for food and waterborne diseases (QMRA).
- ECDC Legionnaires' disease GIS tool. "It allows field epidemiologists to quickly plot cases and potential outbreak sources, and to make a basic spatial analysis to support the source identification".
- European Up–Front Risk Assessment Tool (EUFRAT). "Quantification of the risk of infection transmission by blood transfusion in an outbreak-affected region, or the risk from a stream of donors who have visited such a region".
- Global Burden of Disease Data Tool. "[…]tool to quantify health loss from hundreds of diseases, injuries, and risk factors, so that health systems can be improved and disparities can be eliminated".
- Burden of Communicable Disease in Europe toolkit. "[…] stand-alone software application which allows calculation of disability-adjusted life years (DALYs) for a selection of 32 communicable diseases and six healthcare-associated infections".
- Joint External Evaluation Tool. "[…] is intended to assess country capacity to prevent, detect, and rapidly respond to public health threats independently of whether they are naturally occurring, deliberate, or accidental".

## List of entities to consult for more guidance on health risk assessment

- Departments of health at national, provincial and municipality levels
- Health emergency management sections
- Civil protection agencies
- Food safety agencies
- Vector control agencies
- Water and sanitations agencies
- Civil society organizations working on health: including NGOs, associations of doctors, nurses, public health professionals and foundations on health
- International and regional organizations working on health, such as WHO and ECDC.

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14. (2016). *Handbook on implementing syndromic surveillance in migrant reception/detention centres and other refugee settings.* Stockholm: ECDC. Available from http://ecdc.europa.eu/en/publications/_layouts/forms/Publication_DispForm.aspx?List=4f55ad51-4aed-4d32-b960-af70113dbb90&ID=1589

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16. WHO Ebola Response Team (2016). After Ebola in West Africa – unpredictable risks, preventable epidemics. *New England Journal of Medicine,* 375(6): pp. 587-596.

17. World Health Organization (2015). *Report of the Ebola Interim Assessment Panel.* Available from www.who.int/csr/resources/publications/ebola/report-by-panel.pdf

18. United Nations (2016). Protecting Humanity from Future Health Crises. Report of the High-level Panel on the Global Response to Health Crises. Available from www.un.org/News/dh/infocus/HLP/2016-02-05_Final_Report_Global_Response_to_Health_Crises.pdf

19. Influenza Pandemic National Plan (2016), (in Icelandic). Available from www.landlaeknir.is/servlet/file/store93/item29596/2016_áætlun vegna heimsfaraldurs inflúensu- útgáfa 2.pdf

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# 6. Wildfire Hazard and Risk Assessment

**Key words:**

wildfires, wildfire hazard, risk assessment, wildfire exposure, wildfire vulnerability, risk mitigation, wildland-urban interface

Globally, the occurrence of vegetation fires is common in all continents. Natural vegetation fires have been documented since prehistoric times and have significantly shaped the composition and dynamics of some ecosystems, including forests and open landscapes.

Since the beginning of land cultivation by early humans, the use of fire has contributed to the evolution of humanity and the formation and productivity of cultural landscapes. Today, the vegetated area annually affected by fire globally may range between 300 million and 600 million hectares (3 million-6 million square kilometres).[79]

While some natural ecosystems and land-use systems are dependent, adapted or tolerant to fire, other ecosystems are highly susceptible. With increasing human population and expanding land-use change, the interfaces between vegetation fires and vulnerable human assets are becoming more abundant, critical and conflicting.

And scientific evidence reveals that the indirect effects of vegetation fires have significant impacts on the environment and society. Most importantly, the fire emissions (gas and particle emissions) influence the composition of the atmosphere and thus affect the global climate, as well as human health and security.[80]

Wildfires in wildland-urban interfaces (WUIs) pose a serious threat to communities in many countries worldwide as they can be extremely destructive, killing people and destroying homes and other structures, as happened in California in 2003 and 2007, Greece in 2007, Australia in 2009, Israel in 2016 and Chile in 2017.[81,82,83,84] According to the fire fatalities database of the Global Fire Monitoring Center, an annual average of 297 fatalities caused by wildfires (both civilians and firefighters) was reported globally between 2008 and 2015.[85]

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79 Mouillot, F. and C. Field (2005). Fire history and the global carbon budget: A 1×1 fire history reconstruction for the 20th century. *Global Change Biology*, vol. 11, pp. 398-420.

80 Goldammer, J.G., ed. (2013). *Vegetation Fires and Global Change: Challenges for Concerted International Action*. A white paper directed to the United Nations and international organizations. Global Fire Monitoring Center publication. Remagen-Oberwinter: Kessel Publishing House. www.fire.uni-freiburg.de/latestnews/Vegetation-Fires-Global-Change-UN-White-Paper-GFMC-2013.pdf

81 Haynes, K. and others (2010). Australian bushfire fatalities 1900–2008: exploring trends in relation to the 'Prepare, stay and defend or leave early' policy. *Environmental Science & Policy*, vol. 13, pp. 185-194.

82 Mell, W.R. and others (2010). The wildland-urban interface fire problem – current approaches and research needs. *International Journal of Wildland Fire*, vol. 19, pp. 238-251.

83 For the wildfire situation in Israel in November 2016, see an exemplary report on WUI fires and damages:
www.chabad.org/news/article_cdo/aid/3503826/jewish/Damage-and-Destruction-as-75000-Return-Home-from-Raging-Fires-in-Israel.htm

84 For the wildfire situation in Chile in February 2017, see www.fire.uni-freiburg.de/GFMCnew/2017/01/20170125_cl.htm

85 Global Fire Monitoring Center, Global Wildland Fire Fatalities and Damages Annual Reports 2008-2015, GFMC / IWPM / UNISDR Global Wildland Fire Network Bulletins Nos. 13 to 21: www.fire.uni-freiburg.de/media/bulletin_news.htm

Wildfires also affect the ecological functioning of many ecosystems, as they partially or completely burn the vegetation layers and affect post-fire soil and vegetation processes such as soil erosion, debris flow, flooding and vegetation recovery.[86]

**Figure 1** - Wildfire burning at the Wildland-Urban Interface

In addition to global impacts, fires also have serious local impacts, which are commonly associated with fire frequency and intensity, and imply loss of life and infrastructure, soil degradation, and changes in vegetation and biodiversity. These changes can also affect ecosystem services such as food production and stocks of fresh water or wood products. This process particularly affects tropical rain forest, which has little adaptability to fire.

## Wildfire hazard assessment

The term "hazard" is considered a process, a phenomenon or a human activity that may cause loss of life, injury, or other health impacts, property damage, social and economic disruption or environmental degradation. Wildfire hazard is usually computed or expressed as potential fire behaviour (e.g. fireline intensity) or fuel physical and chemical properties (e.g. loading or biomass).

Land managers and firefighting officials need to consider the wildfire hazard potential in order to (a) identify local wildfire threats and assess the risks to

86 Morgan, P. and others (2014). Challenges of assessing fire and burn severity using field measures, remote sensing and modeling. *International Journal of Wildland Fire*, vol. 23, pp. 1045-1060.

communities, (b) educate and motivate homeowners and landowners and increase community involvement with wildfire awareness and preparation, (c) assist land managers and planners in making appropriate decisions about land management and development in fire-prone areas and (d) assist local fire protection districts in pre-attack planning.[87]

The spatial estimation of wildfire hazard can be difficult owing to the complexity of fire occurrence across multiple spatiotemporal scales.[88] The dominant factors determining wildfire behaviour, or the fire spread and intensity in space and time, are fuel availability and fuel conditions, topography, atmospheric conditions and the presence of firefighting. Wildfire hazard has been estimated through a variety of approaches considering some or several of these drivers, including expected fire behaviour, spatial arrangement of fuels, topography variables, and expert knowledge.

## Wildfire Risk Assessment

Wildfire risk is the likelihood of a fire occurring, the associated fire behaviour, and the impacts of the fire. Risk mitigation is achieved when any of the three parameters (likelihood, behaviour and/or impacts) are reduced. Wildfire risk has been defined in a variety of ways. However, most of them refer only to wildfire likelihood and behaviour and do not take into consideration the expected fire impacts.[89,90,91,92]

Recent advances in landscape wildfire behaviour modelling have led to a number of new tools and approaches for applying risk frameworks to wildfire management problems which allow land managers to estimate all of the above-mentioned primary wildfire risk components to a number of high-value resources located within forest stands and lands.

Computer models can now perform spatially explicit fire simulations over heterogeneous fuels and map wildfire behaviour characteristics across large landscapes. These approaches have been recently incorporated as a key

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87 Calkin, D.E. and others (2011). A comparative risk assessment framework for wildland fire management: the 2010 cohesive strategy science report. *General Technical Report RMRS-GTR* 262. United States Department of Agriculture Forest Service Rocky Mountain Research Station.

88 Keane, R. and J. Menakis (2014). Evaluating wildfire hazard and risk for fire management applications. Making *Transparent Environmental Management Decisions* (K. Reynolds, P. Hessburg and P. Bourgeron, eds.), 111-135. New York: Springer.

89 Hardy, C. (2005). Wildland fire hazard and risk: roblems, definitions, and context. *Forest Ecology and Management*, vol. 211, 73-82.

90 Chuvieco, E. and others (2012). Integrating geospatial information into fire risk assessment. *International Journal of Wildland Fire*, vol. 2, pp. 69-86.

91 Blanchi R., M. Jappiot and Alexandrian D. (2002). Forest fire risk assessment and cartography. A methodological approach. In: Viegas, D., ed. *Proceedings of the IV International Conference on Forest Fire Research.* Luso, Portugal.

92 Carmel, Y. and others (2009). Assessing fire risk using Monte Carlo simulations of fire spread. *Forest Ecology and Management*, vol. 257, pp. 370-377.

element for assessing risk in wildfire management in the United States[93] on a national scale and in Euro-Mediterranean countries on a regional scale.[94] They are also used to support tactical and strategic decisions related to the mitigation of wildfire risk, the post-fire impacts, the forest carbon pools estimation, the forest restoration, and the post-fire soil erosion.

## Wildfire Exposure and Vulnerability

Wildfire exposure defines the situation of people, infrastructure, housing, production capacities and other tangible human assets located in wildfire-prone areas.[95] Wildfire exposure is simply the spatial juxtaposition of wildfire likelihood and intensity metrics with the location of Highly Valued Resources and Assets (HVRAs) found in a specific area. Wildfire vulnerability expresses the potential damage from wildfires and it may be defined as: "The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging impacts of a hazard".[96] The assessment of vulnerability to wildfire should consider the expected damage caused by wildfire, which is a critical part of an integrated wildfire risk assessment.

The combination of wildfire exposure, vulnerability and risk assessment has been widely used as an integrated framework for holistic fire management in many fire-prone parts in the world. [97, 98, 99, 100]

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93 Scott, J., M. Thompson and D. Calkin (2013). A wildfire risk assessment framework for land and resource management. United States Department of Agriculture Forest Service, Rocky Mountain Research Station, *General Technical Report RMRS-GTR 315.*

94 Mitsopoulos, I., G. Mallinis and M. Arianoutsou (2015). Wildfire risk assessment in a typical Mediterranean Wildland–Urban Interface of Greece. *Environmental Management,* vol. 55, pp. 900-915.

95 Fairbrother, A. and Turnley, J. (2005). Predicting risks of uncharacteristic wildfires: application of the risk assessment process. *Forest Ecology and Management*, vol. 211, pp. 28-35.

96 United Nations Office for Disaster Risk Reduction (UNISDR) (2009). UNISDR terminology on disaster risk reduction. Available from www.unisdr.org/we/inform/terminology

97 Calkin, D.C. and others (2011). Progress towards and barriers to implementation of a risk framework for US Federal wildland fire policy and decision making. Forest Policy and Economics, vol.13, pp. 378-389.

98 Acuna, M.A. and others (2010). Integrated spatial fire and forest management planning. Canadian Journal of Forest Research, vol. 40, pp. 2370-2383.

99 Alcasena, F.J., M. Salis and C. Vega-García (2016). A fire modeling approach to assess wildfire exposure of valued resources in central Navarra, Spain. European Journal of Forest Research, vol. 135, pp. 87-107.

100 Plucinski, M. and others (2017). Improving the reliability and utility of operational bushfire behaviour predictions in Australian vegetation, *Environmental Modelling & Software*, vol. 91, pp. 1-12.

Recently, the concepts of wildfire risk transmission and human and natural systems have been studied in the United States in order to create assessment methods that can advance concepts for cross-boundary wildfire risk governance and facilitate the development of more effective policies and practices for fire-prone landscapes.[101, 102]

101Ager, A. and others (2017). Network analysis of wildfire transmission and implications for risk governance. PLOS ONE 12 (3): e0172867.

102 Spies, T. A. and others (2014). Examining fire-prone forest landscapes as coupled human and natural systems. Ecology and Society, vol.  19, No. 3, art. 9.

## Risk Assessment and Use in National DRR measures

A critical component of effective wildfire prevention policies and strategies is a long-term wildfire risk assessment, based on robust methods accounting for the spatial and temporal nature of wildfire risk.[103, 104] On a local scale, such wildfire risk assessment could be used for areas to be treated for wildfire risk reduction, fuel treatment practices implementation, fire towers and water tank construction. This information is extremely useful in implementing efficient preventive strategies and measures, since fire prevention is not only preferable but also a cost-effective way to manage forest fires when compared to fire fighting and suppression. Availability of information on wildfire risk assessment on a regional scale supports optimal allocation of fire-fighting personnel and the protection of critical infrastructure.[105]

Holistic wildfire management and implementation plans at landscape level should be based on wildfire risk scenarios that take into consideration wildfire danger warning systems, coupled with physical and socioeconomic parameters.[106]

For global scale wildfire risk assessment, the focus is shifted towards identifying supra-national patterns of similarities and differences, developing and coordinating effective prevention and response mechanisms, identifying areas where more detailed risk assessment models should be implemented, and facilitating research on the context of climate change. Global wildfire risk assessment also is necessary for comprehensive wildfire protection and policy development.

## A Regional Case Study

Wildfires constitute a severe threat to cultural heritage and archaeological sites, particularly in countries where most of these sites are covered with vegetation or situated close to forests and other flammable vegetation. Reports of damage caused to historical sites by wildfires are becoming more frequent and alarming. Wildfire events in recent years have threatened UNESCO Natural World Heritage Properties in recent years, including Garajonay National Park (Canary Islands, Spain), Nea Moni Monastery (Chios Island, Greece), Olympia (Greece), and Laurisilva (Madeira Island, Portugal).

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103 Chuvieco, E. and others (2010). Development of a framework for fire risk assessment using Remote Sensing and Geographic Information System technologies. *Ecological Modelling*, vol. 221, pp. 46-58.

104 Jones, T. and others (2012). Quantitative bushfire risk assessment framework for severe and extreme fires. *Australian Meteorological and Oceanographic Journal*, vol. 62, pp.171-178.

105 Kalabokidis, K. and others (2012). Decision support system for forest fire protection in the Euro-Mediterranean region. *European Journal of Forest Research*, vol. 131, pp. 597-608.

106 Morgan, P., Hardy, C.C., Swetnam, T.W., Rollins, M.G. and Long, D.G. (2001). Mapping fire regimes across time and space: understanding coarse and fine-scale fire patterns. International Journal of Wildland Fire, vol. 10, pp. 329-342.

In 2016, a regional wildfire risk and exposure assessment was carried out at Mount Athos in Greece, a UNESCO World Heritage Site. This case study is an example of the use of satellite remote sensing and geographic information system (GIS) for wildfire risk assessment on a regional and local scale (Figure 1).[107]

The special characteristics of the surroundings, the monasteries and their architecture, the relatively limited human activity, and the singular and isolated location of the peninsula have combined to make Mount Athos one of the most unique and important coastal landscapes in Greece and the Mediterranean area as a whole. Mount Athos includes 20 monasteries and other structures that are threatened by increasing frequency of wildfires. Assessing wildfire risk and exposure enabled fire management plans to be developed and implemented for this region, supporting the management of its important cultural heritage.

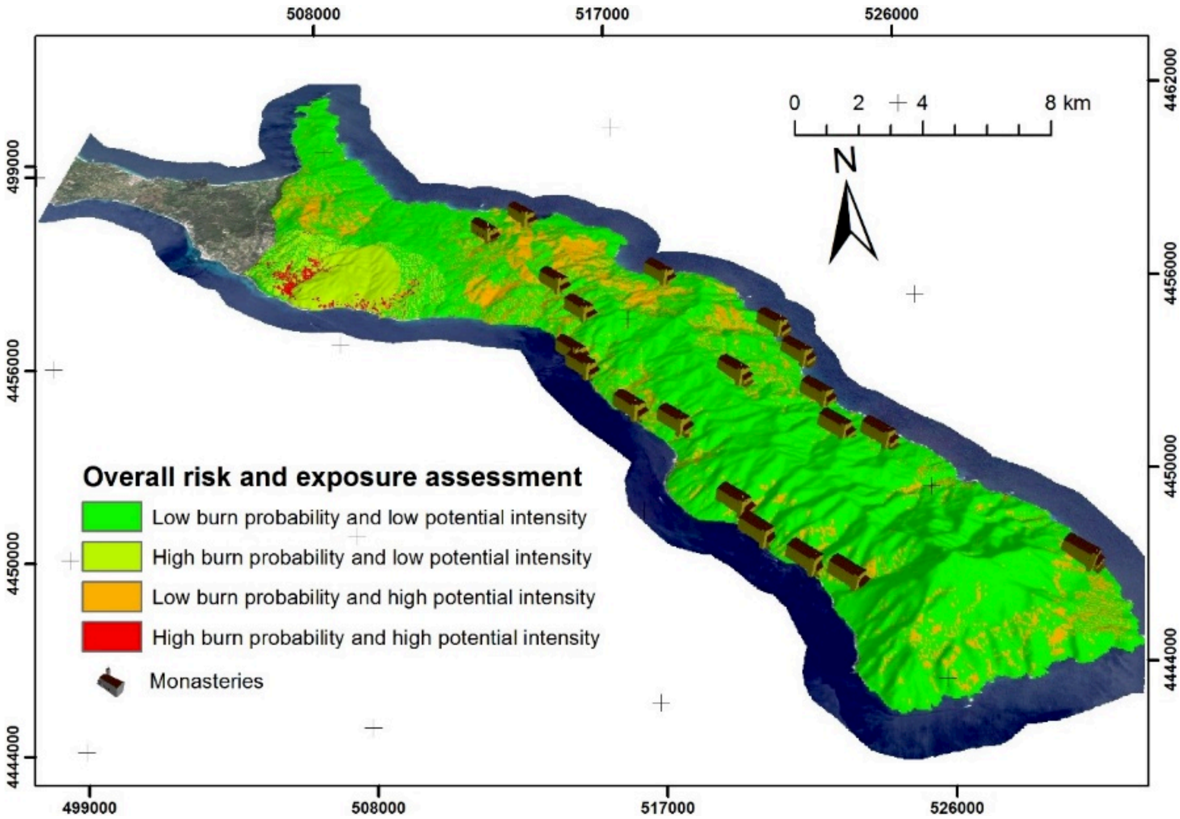


**Figure 2** - Fire risk and exposure assessment at Mount Athos, Greece

107 Mallinis, G. and others (2016). Assessing wildfire risk in cultural heritage properties using high spatial and temporal resolution satellite imagery and spatially explicit fire simulations: the case of Holy Mount Athos, Greece. Forests, vol. 7, issue 2.

## Resources for Further Information

Freely available software tools exist for simulating wildfire propagation and wildfire impacts on different temporal and spatial scales. Some widely used models include BehavePlus, FlamMap, FARSITE and FOFEM. These models require appropriate skills, training and adequate knowledge of GIS and wildland fuel modelling to be used effectively. Most of the software and tools have been validated against prescribed fires and medium-low intensity wildfires.

Relevant information about models and the software tools can be found through the Fire, Fuel, and Smoke Science Program web portal.[108] ArcFuels is a streamlined fuel management planning and wildfire risk assessment toolbar implemented in ArcMap GIS software that creates a trans-scale (stand to large landscape) interface to apply various forest growth (e.g. Forest Vegetation Simulator) and fire behaviour models (e.g. FlamMap).[109]

Methods for enhancing capacities of local communities in wildfire disaster risk reduction are provided by numerous initiatives.[110] The FireWise USA community programme is a collaborative approach that encourages local solutions for safety by involving homeowners in taking individual responsibility for protecting their homes against the threat of wildfire.[111] FireSmart is a Canadian initiative that provides to communities and individuals across Canada the information and tools they need to confront interface fire protection issues.[112]

The Global Fire Monitoring Center (GFMC) provides a global portal for wildland fire documentation, information and monitoring and is publicly accessible through the internet.[113] The regularly updated national to global wildland fire products of GFMC are generated by a worldwide network of cooperating institutions.

Web-based information and GFMC services include:

- Early warning of fire danger and near-real time monitoring of fire events, including the Global Wildland Fire Early Warning System.[114]
- Interpretation, synthesis and archive of global fire information.
- Support of countries and international organizations to develop long-term strategies or policies for wildland fire management, including community-

108 Rocky Mountain Research Station Fire Sciences Laboratory www.firelab.org

109 Software and functional tutorial www.fs.fed.us/wwetac/tools/arcfuels/

110 Portal of global initiatives in participatory/community-based fire management www.fire.uni-freiburg.de/Manag/CBFiM.htm

111 FireWise community programme http://firewise.org/

112 FireSmart Canada www.firesmartcanada.ca/

113 www.fire.uni-freiburg.de

114 www.fire.uni-freiburg.de/gwfews/index.html

based fire management approaches and advanced wildland fire management training for decision makers, especially in preventing and preparing for wildfire disasters.

- Serve as advisory body to the United Nations system through the coordination of the UNISDR Wildland Fire Advisory Group and the UNISDR Global Wildland Fire Network.[115]
- Emergency hotline and liaison capabilities for providing assistance for rapid assessment and decision support in response to wildland fire emergencies under cooperative agreements with the Emergency Services Branch of the United Nations Office for the Coordination of Humanitarian Affairs.[116]

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115 www.fire.uni-freiburg.de/GlobalNetworks/globalNet.html

116 www.fire.uni-freiburg.de/emergency/un_gfmc.htm

# 7. Coastal Erosion Hazard and Risk Assessment

**Key words:**
Coastal erosion hazard and risk assessment, built environment, risk mitigation

## Description of the Hazard, Sources and Setting

Coastal erosion (or shoreline retreat) is the loss of coastal lands due to the net removal of sediments or bedrock from the shoreline. Erosion is typically driven by the action of waves and currents, and by mass wasting processes on slopes, and subsidence (particularly on muddy coasts). Significant episodes of coastal erosion are often associated with extreme weather events (coastal storms, storm surge and flooding) but also with tsunami, both because the waves and currents tend to have greater intensity, and because the associated storm surge or tsunami inundation may allow waves and currents to attack landforms that are normally out of their reach.

On coastal headlands, such processes may lead to the undercutting of cliffs and steep slopes and contribute to mass wasting. In addition, heavy rainfall can enhance the saturation of soils, with high saturation leading to a reduction in the shear strength of the soil and a corresponding increase in the chance of slope failure. Coastal erosion is a natural process that occurs whenever the transport of material away from the shoreline is not balanced by the deposition of new material onto the shoreline. Many coastal landforms naturally undergo quasi-periodic cycles of erosion and accretion on timescales of days to years – this is especially evident on sandy landforms such as beaches, dunes, and intermittently closed and open lagoon entrances.

However, human activities can also strongly influence the propensity of landforms to erode. For example, the construction of coastal structures (e.g. breakwaters, groynes (coastal barriers) and seawalls) can lead to changes in coastal sediment transport pathways, resulting in erosion in some areas and accretion in others.117 The removal of sediments from the coastal system (e.g. by dredging, sand mining), or a reduction in the supply of sediments (e.g. by the regulation of rivers) may also be associated with unintended erosion.

117 Cooper, A. and O.H. Pilkey (2012). *Pitfalls of Shoreline Stabilization. Selected Case Studies.* Coastal Research Library 3, DOI 10.1007/978-94-007-4123-2_1. Dordrecht : Springer Netherlands.

Shoreline retreat in the highly populated mega-deltas of Asia is partly attributed to regulation of rivers, reducing the sediment supply to the shoreline and associated deltaic plains, in addition to groundwater extraction, which has increased subsidence rates118. On larger scales, natural and human-induced climate change can modulate the likelihood and rate of coastal erosion. For example, mean sea level is predicted to increase in the coming decades/centuries due to anthropogenic climate change, and this is expected to increase the frequency of coastal inundation events and thus opportunities for shoreline erosion.[119]

Coastal erosion becomes a hazard when society does not adapt to its effects on people, the built environment and infrastructure. Many human settlements are constructed in areas vulnerable to coastal erosion, with early estimates suggesting that around 70 per cent of the global coastline is eroding.[120] But it is difficult to accurately quantify the global distribution of the hazard and risk, since coastal landforms and human settlements can vary significantly over spatial scales of metres to kilometres, and current global scale data sets are inadequate for assessments at this scale. National scale assessments[121] highlight that there is considerable spatial variability in the risk at these fine scales.

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118 Queensland Government (2013). Coastal hazard technical guide: Determining coastal hazard areas (last accessed 26 Jan. 2017
www.ehp.qld.gov.au/coastalplan/pdf/hazards-guideline.pdf)

119 Intergovernmental Oceanographic Commission (2012). Guide on adaptation options in coastal areas for local decision makers: Guidance for decision making to cope with coastal changes in West Africa. IOC Manual and Guide No. 62, ICAM Dossier No. 7 (last accessed 26 Jan. 2017 www.accc-africa.org/sites/default/files/documents/2012/09/14/une-guide_acca_en_bd.pdf)

120 Bird, C. F. (1985). *Coastline Changes*. New York: John Wiley.

121 Department of Climate Change (2009). Climate Change Risks to Australia's Coast: A First Pass National Assessment. Department of Climate Change, Australia. Available from www.environment.gov.au/climate-change/adaptation/publications/climate-change-risks-australias-coasts, last accessed 16 Feb. 2017)

## Examples of coastal erosion

Rapid:

- **Storm surge:** Australia has experienced a number of coastal erosion events, some dating from the 1800s. One of Australia's most damaging storms was the 1974 sequence, impacting Queensland and New South Wales.[122]
- **Tsunami:** The 2004 Indian Ocean Tsunami caused severe coastal erosion in a number of locations, including Thailand.[123] Impact was also observed on coral reefs, sea grass and mangroves.[124]

Slow (sea-level rise):

- Happisburgh (United Kingdom), on Norfolk's North Sea coast, was once some distance from the sea. Historic records indicate that over 250m land was lost between 1600 and 1850. It is likely that the Norfolk cliffs have been eroding at the present rate for about the last 5,000 years when the sea level rose to within a metre or two of its present elevation.
- From most countries in the Pacific region there are many anecdotal reports that sea-level rise is already causing significant erosion and loss of land. Evidence of erosion includes beach scarps, undercutting of vegetation, including coconut palms, and outcrops of beach rock that have become uncovered by shoreline changes.
- The coastline of Tongatapu (Tonga) is subject to a range of coastal protection studies and works. The Ministry of Meteorology, Energy, Information, Disaster management, Climate Change and Communications has recognized the vulnerability of that coastline to coastal erosion processes, launching the Coastal protection Project in 2015.

## Hazard assessment

A wide range of methodologies have been applied for coastal erosion hazard assessment. The key factors influencing these methodologies include:

- The spatial and temporal scale of the analysis. This may range from an entire continent as part of a national assessment to a regional analysis at local government level or a single sediment compartment to inform a particular erosion issue.

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122 Callaghan, J. and P. Helman (2008). Severe storms on the east coast of Australia 1770-2008. Griffith Centre for Coastal Management (last accessed 26 Jan. 2017 www.goldcoast.qld.gov.au/documents/bf/storms-east-coast-1770-2008.pdf)

123 Choowong, M. and others (2007). Erosion and Deposition by the 2004 Indian Ocean Tsunami in Phuket and Phang-nga Provinces, Thailand. *Journal of Coastal Research*, vol. 23, issue 5, pp. 1270-1276.

124 Thom, B. (2014) Coastal Compartments Project - Summary for policy makers. (last accessed 24 April 2017 www.environment.gov.au/climate-change/adaptation/publications/coastal-compartments-project-summary-policy-makers)

Likewise, the timescale of analysis can range from short-term (subannual) to better understand coastal behaviour across the seasonal weather cycle or long-term (decadal) to incorporate climate variability and inform planning decisions.

Geological timescales are also relevant on those coasts where sea-level rise is ongoing due to natural subsidence (e.g. deltaic coasts such as in the Gulf of Mexico) or continued adjustments of land masses following deglaciation after the last ice age (e.g. eastern Canada and northeastern United States).

These natural changes across various timescales provide important context for understanding coastal erosion processes on short time scales and when making planning decisions (see figure 1 in [18]).[125] The timeline then defines the range of events that should be considered. For example, residential buildings in Australia (life of asset expected to be at least 50 years) are designed for events with an annual probability of exceedance of 1/500 (for wind and earthquake).

- The nature of the coastal landforms and the offshore environment in the area of interest. At a general level, the form and composition of coastal landforms and the presence of barrier islands and reefs in the offshore environment determines the sets of physical processes that should be considered in an erosion assessment. Sandy shorelines, coastal cliffs, fringing reef coasts and deltaic coasts are each affected by somewhat different processes.

- The nature of the sea action being considered. The underlying driver for erosion (e.g. sea-level rise, storms or tsunami) will determine the types of analysis or modelling that will inform an assessment. In addition, future trends associated with climate change are critical and the event being considered (e.g. design event (specified event possibly based on consequence or likelihood criteria) or extreme event (largest event believed possible) or the full range of events (e.g. via a probabilistic analysis).

Our understanding of the coastal environment, and particularly how and where sediment is transported (i.e. the sediment budget) will critically affect the appropriate choice of spatial scale for the study. Data availability place limitations on the nature of the hazard assessment (see table below for examples of input data for hazard assessments).

Coastal compartments represent one way to define the scales that should be considered when taking actions that could affect sediment budgets. For example, construction of a groynes may protect a community as intended but cut off sediment supply to another part of the same coastal compartment, thereby leading to coastal erosion downdrift. A typical coastal compartment

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[125] Ibid.

identifying the sediment transport pathways can be found in the Climate Change Adaptation Guidelines published by Engineers Australia (see figure 4).[126]

When data are sparse or non-existent, it is helpful to understand the physical context and history of an eroding beach through available imagery (e.g. Google Earth), conduct site surveys to assess the wave climate and beach state, map coastal infrastructure (such as groynes) and features that may be controlling the sediment supply to the coastal zone of interest, and engage with the local community. Establishing a baseline may also be necessary if suitable data do not exist. For example, shoreline mapping to record erosion lines and subsequent recovery over time will assist in understanding the impact of seasonal cycles in beach dynamics.

Estimating how a shoreline will change over time is an evolving science. State-of-the-science approaches include some form of shoreline response modelling that can be applied to coastal erosion hazard assessments. Modelling can be done to provide information to address questions such as:

- How far would the shoreline retreat for the design level scenario?
- Which parts of the shoreline are more vulnerable to coastal erosion?
- Are there offshore features (e.g. reefs, barrier islands) that are vulnerable to sea-level rise?
- What is the probability of 1m, 5m or 10m of shoreline retreat (shown spatially for the region of interest)?
- What is the confidence (and uncertainty) in these estimates?
- What is the effectiveness of coastal defence options?

However, complex shoreline evolution models may not necessarily outperform simpler approaches[127] and are not suitable for national-scale assessments.

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126 Engineers Australia (2012). *Climate Change Adaptation Guidelines in Coastal Management and Planning* (last accessed 24 April 2017 www.engineersaustralia.org.au/sites/default/files/content-files/2016-12/climate_change_adaptation_guidelines.pdf)

127 Kinsela, M.A. and D.J. Hanslow (2013). Coastal erosion risk assessment in New South Wales: limitations and potential future directions. Proceedings of the NSW Coastal Conference, 2013 (last accessed 16 Feb. 2017 www.coastalconference.com/2013/papers2013/NSWCC_Kinsela_Hanslow_2013.pdf)

| Description of input data | National entities that most commonly have these data | Examples of open databases available from international sources |
|---|---|---|
| Elevation data (onshore and offshore) | National spatial agencies, local government, lands department, universities / academia | LINZ Data Service, 3DEP (USGS), US Interagency Elevation Inventory, Digital Coast (NOAA), ELVIS (onshore elevation), |
| Information on landform types (geomorphology and substrate) and sediment transport pathways | National research and development agencies (e.g. United States Army Corps of Engineers), national geological survey, local government, universities / academia | Smartline (Australia), Geomorphic classification of the coastal zone (Australia), Coastal compartments (used in Australia, United States, United Kingdom, some parts of Europe), ground-penetrating radar (to determine location of bedrock) |
| Historic shoreline positions (e.g. from aerial photographs) and/ or elevation transects | National research and development agencies (e.g. United States Army Corps of Engineers), national geological survey, local government, lands department, academia, local knowledge in community | University of California Santa Barbara Map and Imagery Laboratory (MIL) aerial photography collection includes areas of China, central Asia, Africa, and Pacific Islands, Nationwide Environmental Title Research (NETR) Online Historic Aerials, United States Geological Survey (USGS) Coastal Change Hazards Portal, Narrabeen-Collaroy historic beach profiles (Australia), historic aerial imagery |
| Exposure data (locations and characteristics of buildings, infrastructure, human population) | Local government (e.g. asset registers), bureau of statistics, lands department | National Exposure Information System (NEXIS) |
| Historic sea levels and ocean waves, forecast sea level and ocean wave scenarios (including tsunami) | Intergovernmental Panel on Climate Change (IPCC), hydrographic office national weather service, academia | Tsunami waveforms from national probabilistic tsunami hazard assessments, CAWCR Wave Hindcast 1979-2010, and 2013-2014, Manly Hydraulic Laboratory, IPCC |

**Table 1**- Sources of data for coastal erosion risk assessment

## Tsunami risk assessment use in national DRR measures

A risk assessment will typically be determined by combining the knowledge of the hazard, the elements at risk (e.g. built environment) and an understanding of the vulnerability of those elements. This vulnerability is often described by classes of damage, ranging from "no damage" through to "complete damage" (e.g. total destruction of an asset). In the case of the coastal erosion hazard, buildings (residential, commercial, public, etc.) can be considered as requiring complete replacement or as being uninhabitable where their foundations are undermined. If the risk assessment process considers other elements at risk – such as parts of the surrounding landforms and ecosystem (e.g. dunes, mangroves, saltmarsh) – vulnerability models describing the level of damage to these elements will need to be determined. Coastal inundation hazards may also be included in the risk assessment, in which case suitable vulnerability models would need to be sourced (a starting point could be to employ flood damage models).

Case study: The New South Wales (Australia) coastal erosion risk assessment[128] is a broad-scale assessment for the entire coastline of that State, (over 2,000 km) combining the elements described above. Over several decades, New South Wales has seen a number of severe coastal erosion events, and with population increasing in the coastal zone, the risk profile is changing.

The assessment led to the identification of coastal erosion hotspots, and this information allows the government to prioritize its coastal management activities. The study also suggests that the assessment should be guided by the level of risk, and that there needs to be agreement among stakeholders on the acceptable thresholds of that risk.

Recommendations to reduce risk should be based on these assessments, and may take many forms, including:

- Land-use policy and/or regulation, such as planning laws to limit development in at-risk areas (e.g. by defining coastal setback lines)
- Physical shoreline protection, such as beach nourishment, sea walls and groynes to maintain sediment volumes and help stabilize shoreline position
- Physical offshore protection, such as breakwaters and artificial reefs, to modify and redistribute the energy of storm waves
- Environmental remediation approaches, such as maintaining or restoring natural ecosystems (e.g. mangrove forests, coral reefs and dune

128 Intergovernmental Panel on Climate Change (2014). *Climate Change 2014: Impacts, Adaptation and Vulnerability.* Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

vegetation) to provide natural buffers to storm events.

Recent examples of the implementation of risk reduction measures:

- United Kingdom. Clacton coastal defences[129]
- United States. Barrier Islands, New Jersey https://toolkit.climate.gov/case-studies/restoring-natural-dunes-enhance-coastal-protection
- United States. Ventura, California https://toolkit.climate.gov/case-studies/restoring-surfers-point-partnerships-persistence-pays
- United States. Hawaii. O'ahu North Shore https://toolkit.climate.gov/case-studies/confronting-shoreline-erosion-o%E2%80%98ahu
- New Zealand, Bay of Plenty dune rehabilitation www.mfe.govt.nz/publications/climate-change/coast-care-bay-plenty-dune-restoration/coast-care-bay-plenty-dune

## National case study

The National Coastal Risk Assessment for Australia, which was conducted in 2010 and 2011,[130] identified the spatial extent of settlements and infrastructure, ecosystems and industries in the coastal zone which would be impacted from inundation and erosion for a range of sea-level rise scenarios. The infrastructure assessed included residential, commercial, light-industry buildings, and transport systems. The assessment was led by the Federal Department of Climate Change with input from a range of technical experts (government science agencies, research institutions and consultants), as well as from State government departments responsible for coastal management.

The assessment required the development of national data sets, including: the digital elevation model (necessary for inundation modelling); high water level and storm tide (necessary for inundation modelling) and coastal geomorphology (to identify segments of the coast which are susceptible to erosion).

Through the assessment, a number of key areas emerged where various kinds of data were lacking on the national scale: estuaries and knowledge of their shoreline geomorphology; national exposure of important infrastructure; regional and local influences on coastal instability (i.e. inputs for coastal erosion models) and higher resolution digital elevation models (as coarse resolution models were not suitable for modelling inundation in low gradient coastal plains).

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129 Environment Agency (2016). Managing flood and coastal erosion risks in England 1 April 2015 to 31 March 2016 (last accessed 24 April 2017 www.gov.uk/government/uploads/system/uploads/attachment_data/file/575139/National_Flood_Risk_Report_LIT_10517.pdf)

130 Kinsela, M.A. and D.J. Hanslow (2013). Coastal erosion risk assessment in New South Wales: limitations and potential future directions. Proceedings of the NSW Coastal Conference, 2013 (last accessed 16 Feb www.coastalconference.com/2013/papers2013/NSWCC_Kinsela_Hanslow_2013.pdf)

Key findings from the assessment were:

- Between $41 and $63 billion AUD (2008 replacement value) of existing residential buildings are potentially at risk of inundation from a 1.1 m sea-level rise (between 157,000 and 247,600 individual buildings of the 711,000 existing buildings).
- Nearly 39,000 buildings located within 110 m of "soft" shorelines were at risk from accelerated erosion due to sea-level rise and changing climate conditions.
- The concentration of infrastructure in the coastal zone around population centres will bring risks to those assets which could have consequences for the delivery of community and essential services, regional economies and possibly the national economy. For example, there are 258 police, fire and ambulance stations, 5 power stations/substations, 75 hospitals and health services, 41 landfill sites, 3 water treatment plants and 11 emergency services facilities located within 200 m of the shoreline.
- While there is a lack of information on social vulnerability to climate change, remote Indigenous communities in the north of Australia and communities living on the low-lying Torres Strait Islands are particularly vulnerable to sea-level rise.

The assessment provided a case for early action to reduce risk. There is a large legacy risk in the coastal zone from buildings and other infrastructure constructed in the past, without regard to climate change and the instability of some coastal landforms. For "at-risk" areas, strategies to protect, accommodate or retreat will need to be developed, as sea level is projected to continue rising for several centuries. Triggers will be needed to identify when on-ground responses are needed to manage increasing risks. State and local government, industry and communities will have a primary role to play in on-ground coastal adaptation action.

Continued work is required on developing standards and benchmarks, providing information, auditing infrastructure at risk, on-ground demonstrations of adaptation options, and local capacity-building. Areas of uncertainty for the science components also need to be addressed.

## Resources for further information

Climate change adaptation guidelines are another source of information for coastal managers:

- The Intergovernmental Oceanographic Commission (IOC) advises policy makers and managers on reducing risks from tsunamis, storm surges, harmful algal blooms (HABs) and other coastal hazards by focusing on implementing adaptation measures to strengthen the resilience of vulnerable coastal communities, their infrastructure and service-providing ecosystems. IOC is implementing the project "Adaptation to climate change in coastal zones of West Africa"[131]
- United Nations Environment Programme (UNEP)[132]
- United Nations Development Programme (UNDP) Climate change adaptation – coastal zone development programme http://adaptation-undp.org/thematic-areas/coastal-zone-development (example case studies in Africa, Samoa)

Other substantial peer-reviewed guidelines from reputable institutions:

- National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management https://coast.noaa.gov/digitalcoast/tools/hazards-portal.html
- Engineers Australia: Climate Change Adaptation Guidelines in Coastal Management and Planning, includes information on coastal processes and sediment budgets www.engineersaustralia.org.au/sites/default/files/content-files/2016-12/climate_change_adaptation_guidelines.pdf
- CATALYST project (funded by the European Commission) Capacity development for hazard risk reduction and adaptation www.catalyst-project.eu and Hare et al. 2013
- United States Army Corps of Engineers – Manuals: www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/
    - Environmental Engineering for Coastal Shore Protection
    - Design of Coastal Revertments, Seawalls, and Bulkheads
    - Coastal Engineering Manual - Part I to Part VI and Appendix A

131 Intergovernmental Oceanographic Commission (2012) Guide on adaptation options in coastal areas for local decision makers: Guidance for decision making to cope with coastal changes in West Africa. IOC Manual and Guide No. 62, ICAM Dossier No. 7 (last accessed 26 Jan. 2017 www.accc-africa.org/sites/default/files/documents/2012/09/14/une-guide_acca_en_bd.pdf)

132 United Nations Environment Programe (2010). *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding*. TNA guidebook series (last accessed 26 Jan. www.unep.org/pdf/TNAhandbook_CoastalErosionFlooding.pdf)

Open source hazard and risk modelling tools:

- United States Army Corps of Engineers (USACE) Coastal Modeling System www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/484188/coastal-modeling-system/
- USACE Beach-fx. Analyzing Evolution and Cost-Benefits of Shore Protection Projects
  www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476718/beach-fx/
- Deltares – XBeach. https://oss.deltares.nl/web/xbeach/
- University of Southampton – SCAPE+ (Soft Cliff And Platform Erosion)
- United States Geological Survey Digital Shoreline Analysis System (shoreline change) – requires ArcGIS 9.x or above
- https://woodshole.er.usgs.gov/project-pages/DSAS/
- SWAN (wave model) http://www.swan.tudelft.nl/
- NIWA Beach Profile Analysis Toolbox (BPAT) – free licence for academic (with restriction on number of regions), NZ$850 for first commercial licence https://www.niwa.co.nz/our-science/coasts/tools-and-resources/tides/bpat

Successful and well-documented national hazard and risk assessment with results used in DRR:

- The U.S. Climate Resilience Toolkit shows a number of case studies relating to coastal erosion - https://toolkit.climate.gov/topics/coastal-flood-risk/coastal-erosion

- The synthesis report[133] shows a number of case studies where assessments were made that led to adaptation measures being implemented to reduce the risk of coastal erosion.

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133 Hare, M, C., J. van Bers and J. Mysiak, eds. (2013). *A Best Practices Notebook for Disaster Risk Reduction and Climate Change Adaptation: Guidance and Insights for Policy and Practice from the CATALYST Project.* Trieste: The World Academy of Sciences (last accessed 26 Jan. www.catalyst-project.eu/doc/CATALYST_D65_Best_Practices_Policy_Notebook.pdf)

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# 8. Sea-level Rise

**Key words:**

Sea level change, glacial melting, land movement, flooding, storm surge, coastal adaptation

Global climate change is expected to impact the entire globe by the end of this century. The release of carbon dioxide and other greenhouse gases is responsible for rapidly rising global mean surface temperatures, which could increase by as much as 4.8°C by 2100.134 This warming is causing ice to melt, along with an expansion of warming waters that is expected to increase global sea levels between 0.26 and 0.82 metres according to the 2013 report of the Intergovernmental Panel on Climate Change.

These rising sea levels pose an extreme risk to many global cities135, including Shanghai (China), Mumbai (India), Rio de Janeiro (Brazil), New York (United States) and London (United Kingdom). Many global regions, such as the South Pacific island of Tuvalu and low-lying coastal areas of Bangladesh, are already experiencing significant coastal flooding and inundation due to sea-level rise.136,137 But this is merely the beginning, as it is expected that, without adaptation, 0.2 to 4.6 per cent of the global population will be flooded annually by the end of this century, costing approximately 0.3 to 9.3 per cent of global gross domestic product.138

In undertaking hazard assessment, we need to keep in mind that because sea-level rise occurs gradually, it behaves very differently from many other hazards. Its impacts may not be immediately seen or coalesce around a single sea-level rise event. Permanent flooding on land is a direct hazard caused by sea-level rise; however, a number of indirect (secondary) hazards need to be incorporated into the assessments. These include extended damage caused by storm surges or saltwater contamination of fresh water sources.

## Hazard assessment

Understanding disaster risk related to sea-level rise is essential to understanding the scale of impact this hazard could have for a particular locality. In the United States, the Mississippi River delta – including the city of New Orleans – is already experiencing severe flooding. Other regions, such as south-east Alaska, are not expected to experience rising sea levels until later in the century.

The table below lists some resources that are currently available to assess the risk of sea-level rise. It also provides links to sources on strengthening disaster risk reduction governance to manage sea-level rise, on enhancing

134 Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *Climate Change 2013: The Physical Science Basis.* Cambridge: Cambridge University Press.

135 Nicholls, R. J. and A. Cazenave (2010). Sea-level rise and its impact on coastal zones. Science, vol. 328, pp.1517-1520.

136 Church, J. A., N.J. White and J.R. Hunter (2006). Sea-level rise at tropical Pacific and Indian Ocean islands. *Global and Planetary Change,* vol. 53, issue 3, pp.155-168.

137 Hamlington, B. D. and others (2014). Uncovering an anthropogenic sea-level rise signal in the Pacific Ocean. *Nature Climate Change,* vol. 4, pp. 782-785.

138 Hinkel, J. and others (2014). Coastal flood damage and adaptation costs under 21st century sea-level rise. Proceedings of the National Academy of Sciences 111, pp. 3292-3297.

disaster preparedness for effective response and on guiding resilience investment.

The global costs of protecting the coast with dikes alone are estimated to range between US$ 12 billion and US$ 71 billion by 2100.5 While this investment in disaster risk resiliency may appear costly, it is still much less than the projected loss of gross domestic product – as forced migration of between 1.6 million and 5.3 million people caused by sea-level rise, without adaptation, is estimated to cost between US$ 300 billion and US$ 1,000 billion.[139]

| Description of input data | National entities that most commonly have this data | Examples of open databases available from international sources |
|---|---|---|
| Rates of past sea-level change from tide gauges | National Oceanic and Atmospheric Administration,<br>British Oceanographic Data Centre | www.gloss-sealevel.org/<br><br>www.psmsl.org/ |
| Sea-level altimetry data | United States National Aeronautics and Space Administration | www.nodc.noaa.gov/SatelliteData/jason/ |
| Future sea-level projections | United Nations Intergovernmental Panel on Climate Change | www.ipcc-data.org/ |
| Sea-level adaptation strategies | United States National Park Service, United States Environmental Protection Agency, Australian Government Geoscience Australia OzCoasts programme | www.cakex.org/<br><br>https://coastadapt.com.au/ |
| Examples of general adaptation projects | weADAPT, a collaborative platform supported by Sweden | www.weadapt.org/placemarks/maps<br><br>https://toolkit.climate.gov/ |

**Table 1**- Sources of data for sea-level rise risk assessment

Table 1 includes input data required for understanding disaster risk. However, uncertainties exist that could influence the outcome of risk assessment. These uncertainties can be due to the following:

- Choice of sea-level rise scenario (also known as greenhouse gas concentration representative concentration pathways)[140]

139 A global analysis of erosion of sandy beaches and sea-level rise: An application of DIVA. *Global and Planetary Change* (2013). vol. 111, pp. 150-158.

140 Van Vuuren, D. P. and others (2011). The representative concentration pathways: an overview. *Climatic Change,* vol. 109, pp. 5-31.

- Accuracy of the models used (to be specified by the authors of the models)
- Secondary hazards (e.g. storm surge and groundwater intrusion) that could provide a "tipping point" for reconstruction, adaptation, or abandonment
- Willingness across all scales (intergovernmental, within the State, community, individual) to invest in planning to manage risk.

## Exposure and vulnerability assessment

It is estimated that US$ 9.6 trillion to US$ 11 trillion in global assets and 290 million to 310 million people live within the present-day 100 year flood zone.5 This number does not include those working within the coastal zone who could be exposed to sea-level rise by 2100.

Neumann et al.141 offer four different scenarios under which demographic data are combined with sea-level rise data to identify the most vulnerable regions. People living in the coastal zone in China, India, Bangladesh, Indonesia and Viet Nam are estimated to be most vulnerable due to secondary storm surge hazards. Africa is also in a precarious position due to its rapid population growth and urbanization in the coastal zone, which will make Egypt and sub-Saharan countries in eastern and western Africa more vulnerable to sea-level rise and its associated hazards. Prevention measures and long term planning early on can help reduce vulnerabilities by retreating from any zones of potential exposure. Funds should be secured for any critical resources or infrastructure that cannot be moved but can be protected using engineered methods (e.g. elevate roads and buildings).

## Risk assessment use in national DRR measures

A number of national-level DRR measures are important for management, after the risk of sea-level rise has been assessed.142 These measures include the following:

- Promoting the collection of appropriate data and encourage the use of standardized baselines for the periodic assessment of sea-level risk and secondary hazards such as storm surge and groundwater intrusion.
- Adopting and implementing national sea-level rise plans that take into account changes in sea level across multiple timescales and climate change scenarios.
- Putting in place mechanisms to periodically assess and publicly report on progress in implementing resiliency measures to address sea-level rise.

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141 Neumann, B. and others (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding - a global assessment. PLOS ONE 10.

142 United Nations Office for Disaster Risk Reduction (2015). Sendai Framework for Disaster Risk Reduction 2015-2030, p. 37.

The reports should promote public scrutiny and be subject to institutional debates, including by parliamentarians, as well as scientists from the climate change arena.

- Promoting the mainstreaming of sea-level plans and assessments that include mapping and management strategies for rural development planning and management of wetlands, coastal floodplains areas, and any other areas prone to flooding.
- Encouraging the revision of existing building codes to include the impact of sea-level rise in designated flood and storm surge zones; and assessing buildings based on their adaptive capacity and ability to be relocated if necessary.
- Promoting cooperation among diverse institutions across multiple spatial scales.
- Promoting the inclusion of planning to adapt to sea-level rise into post-storm and other post-disaster documents. This includes rebuilding based on future shoreline positions.
- Considering the relocation of public facilities and infrastructure.

CASE STUDY

## Box 1

## A case of country good practice: Australia

The Government is actively planning for sea-level rise. In 2015 the Department of the Environment and Energy released its National Climate Resilience and Adaptation Strategy, which outlined the following four priorities for national engagement: (a) understand and communicate, (b) plan and act, (c) check and reassess and (d) collaborate and learn.

Managed retreat has been implemented in many parts of the country. Five guiding principles exist for those attempting this strategy. Managed retreat may not be an option for many less economically developed countries if they do not seek to establish and maintain protective coastal ecosystems. Sea-level rise will continue to be a hazard in regions that promote population growth along the coastline while ignoring the cumulative impacts of development and asserting political pressure for coastal development.

Liability laws that favour developers also put those at risk, since many are unaware of their potential future exposure to sea-level rise. The establishment of conditional occupancy rights (managed retreat via compensation for present-day landowners to abandon future at risk property) is one proposed technique to raise homebuyers' awareness of this issue, although stakeholder attitudes towards this approach vary.

Australia is an economically developed country, which makes adapting to sea-level rise easier because it can afford to pursue a number of strategies such as seawalls, beach sand replenishment and subsidized managed retreat to reduce the risk from sea-level rise and its associated secondary hazards.

But a number of less economically developed countries are also leading the way in creating strategies for reducing their sea-level rise risk. The Least Developed Countries Fund was established to help enhance and adapt infrastructure and develop community-based projects that build adaptive capacity across 51 least developed countries.

## Resources for further information

Further information about understanding and preparing for sea-level risk:

- The Potsdam Institute for Climate Impact Research has information on the latest sea-level science, as well as links to ongoing global projects.
- The United Nations Environment Programme offers information on various adaptation and mitigation strategies related to climate change. Links to information regarding finance tools to fund projects can be found here: http://web.unep.org/climatechange/
- The Pacific Climate Change Portal was established as a resource for planners and managers so they could get information on projects, country profiles and sources of finance for climate change-related projects in the Pacific region.
- The EcoAdapt Climate Adaptation Knowledge Exchange (CAKE) manages a global database of climate change-related adaptation case studies, and as well as providing links to various tools : www.cakeex.org

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# 9. Natech Hazard and Risk Assessment

**Key words:**

Natech, technological risk, chemical accident, industrial safety, loss of containment, cascading effect, Natech risk assessment

The impacts of natural hazard events on chemical installations, pipelines, offshore platforms and other infrastructure that process, store or transport dangerous substances can cause fires, explosions and toxic or radioactive releases.[143] Although these "Natech" accidents are a recurring feature in many natural disasters, they are often overlooked, despite the fact that they can have major social, environmental and economic impacts.

They may cause multiple and simultaneous releases of hazardous substances over extended areas, damaging or destroying safety barriers or systems, and downing lifelines often needed for accident prevention and mitigation.

In addition, emergency responders are usually neither equipped nor trained to handle several substance releases at the same time, in particular as they also have to respond to the natural hazard event consequences in parallel.[144,145,146]

Because of the inherent multi-hazard nature, Natech risk assessment concerns industry operators and authorities in charge of chemical accident prevention and civil protection. Natech risk assessment and management therefore requires a comprehensive understanding of the interdependencies of human, natural and technological systems. Successfully controlling a Natech accident has often turned out to be a major challenge – if not impossible – where no prior risk assessment and proper preparedness planning had taken place.

## Sources and setting

Examples of recent major events that highlight the importance of the serious consequences of Natech accidents include the 2002 river floods in Europe, which resulted in significant hazardous substance releases, including chlorine[147] and dioxins, the 2011 Tōhoku earthquake and tsunami, which caused a meltdown at a nuclear power plant and raging fires and explosions at oil refineries,[148] and Hurricane Sandy in 2012, which triggered multiple hydrocarbon spills.

The Tōhoku earthquake, in particular, is a textbook example of a cascading

143 Showalter, P.S. and M.F. Myers (1994). Natural disasters in the United States as release agents of oil, chemicals, or radiological materials between 1980-1989: analysis and recommendations. *Risk Analysis,* vol. 14, issue 2, pp. 169-182.

144 Krausmann, E., A.M. Cruz and E. Salzano (2017). Natech Risk Assessment and Management - *Reducing the Risk of Natural-Hazard Impact on Hazardous Installations.* Amsterdam: Elsevier.

145 Girgin, S. (2011). The natech events during the 17 August 1999 Kocaeli earthquake: aftermath and lessons learned. *Natural Hazards and Earth System Sciences*, vol. 11, issue 4, pp. 1129-1140.)

146 Krausmann, E., A.M. Cruz and B. Affeltranger (2010). The impact of the 12 May 2008 Wenchuan earthquake on industrial facilities. *Journal of Loss Prevention in the Process Industries*, vol. 23, pp. 242-248.

147 Hudec, P. and O. Lukš (2004). Flood at Spolana a.s. in August 2002. *Loss Prevention Bulletin,* issue 180. Institution of Chemical Engineers, United Kingdom.

148 Krausmann, E. and A.M. Cruz (2013). Impact of the 11 March 2011, Great East Japan earthquake and tsunami on the chemical industry. *Natural Hazards*, vol. 67, issue 2, pp. 811-828.

risk, because the earthquake itself caused only limited damage owing to the stringent protection measures in place. However, the tsunami and its impact on a nuclear power plant resulted in the most severe technological disaster ever recorded in the region and whose adverse effects still persist.

It does not necessarily require a major natural hazard event, e.g. a strong earthquake or flood, to cause a Natech accident; it can be triggered by any kind and size of natural hazard event. Consequently, Natech risks exist both in developed and developing countries where hazardous industrial sites are located in natural hazard regions. Industrial growth, climate change and the increasing vulnerability of a society that is becoming more and more interconnected will increase the likelihood and impact of such events in the future.

## Hazard assessment

Natech events are joint disasters that combine natural and technological hazards and that feature very complex consequences owing to amplifying effects between the two types of hazard. Adequate prevention, preparedness and response are specifically needed, therefore, to prevent them and mitigate their consequences.

Unfortunately, disaster risk reduction frameworks do not always consider technological hazards and chemical accident prevention and preparedness programmes often overlook the specific aspects of Natech risk. This results in a lack of dedicated methodologies and guidance for risk assessment and management for industry and authorities.

Adequate national-level Natech risk assessment is therefore important to see the overall picture and pinpoint potential risk hotspots that require detailed risk assessment. Many such potential hotspots, such as refineries, petrochemical complexes, and oil and gas pipelines, are also considered critical infrastructures. Consideration of Natech risk is required for their effective protection. In this context, it is important to consider all natural hazards that a hazardous installation can be subject to in a certain area.

Although the consequences of hazardous materials release are well known and industrial practices exist to cope with most scenarios, including major events, the cost of additional safety measures to reduce the Natech risk can result in reluctance to accept that such risks exist and to act to reduce them. This also means a limited amount of data from industry, which are required for national risk assessment. Adequate legislative frameworks and their enforcement should ensure that operators share information that is critical for Natech risk assessment.

## Exposure and vulnerability

National Natech risk assessments should consider that major natural hazards can impact large areas, affecting the population, the building stock, industry and infrastructure. Potential multiple and simultaneous releases from various installations and also from different parts of each installation, as well as the possibility of on- and off-site secondary cascading (domino) events, should be taken into account when assessing exposure.

Industrial facilities handling hazardous materials are inherent vulnerabilities for the social system in which they are nested. If not managed well, not only extreme events but also low-level hazards can generate broad chain effects if vulnerabilities are widespread in the system and the risks are not handled properly.[149]

By analysing past Natech accidents, conclusions were drawn concerning the most vulnerable types of industrial equipment per natural hazard, common damage and failure modes, and the hazardous substances mostly involved in the accidents.[150,151,152,153]

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149 Pescaroli, G. and D. Alexander (2015). A definition of cascading disasters and cascading effects. Going beyond the "toppling dominos" metaphor. Global Risk Forum, Davos, Switzerland.

150 Cozzani, V. and others (2010). Industrial accidents triggered by flood events: analysis of past accidents. *Journal of Hazardous Materials*, vol. 175, pp. 501-509.

151 Renni, E., E. Krausmann and V. Cozzani (2010). Industrial accidents triggered by lightning. *Journal of Hazardous Materials*, vol. 184, pp. 42-48.

152 Krausmann, E. and others (2011). Industrial accidents triggered by earthquakes, floods and lightning: lessons learned from a database analysis. *Natural Hazards*, vol. 59 (285).

153 Girgin, S. and E. Krausmann (2016). Historical analysis of U.S. onshore hazardous liquid pipeline accidents triggered by natural hazards. *Journal of Loss Prevention in the Process Industries*, vol. 40, pp. 578-590.

Among the process and storage units commonly used by industry, atmospheric storage tanks, especially those with floating roofs, appear to be particularly vulnerable to natural hazards. This is critical from an industrial-safety point of view, as these units usually contain large amounts of flammable liquids that may ignite and escalate into major fires or explosions during Natech accidents. The likelihood of ignition is high in earthquake- or lightning-triggered Natech events.

Oil and gas pipelines transporting vast amounts of hazardous substances are also vulnerable to natural hazards, especially at river crossings. Because the pipelines are usually located in the countryside, detection of pipeline accidents can be late, leading to major spills and significant economic damage. 6

Natech accidents may result in exposed areas that are much greater than for ordinary industrial accidents. For example, if floods cause an overflow of containment dikes at a facility, any released substances that would normally be captured within the dikes can easily be dispersed by the flood waters and contaminate the environment up to hundreds of kilometres through the river network. In the case of earthquakes, cracks that occur on dike floors as a result of ground movement may leak hazardous liquid substances that can lead to significant ground water pollution.

The vulnerability of the population may also be significantly increased during Natech conditions. For instance, when there is toxic atmospheric dispersion caused by an earthquake, shelter might not be possible because of structural damage to buildings. Also, evacuation from the location of an industrial accident might not be feasible because of the blockage of escape routes by debris or flooding. And residents might be reluctant to evacuate an area if relatives are still trapped under the debris. Such factors should be considered in undertaking exposure and vulnerability analysis.

## Natech risk assessment use in national DRR measures

Risk assessment is a powerful tool for identifying hazards and estimating the associated risk. Industrial risk assessment methodologies vary across countries, ranging from fully quantitative to qualitative approaches. For Natech risk assessment, existing methodologies need to be extended to include equipment damage models for natural-hazard impact and the possibility of multiple loss-of-containment events at several industrial units at the same time.

Unlike many natural hazards, technological hazards are usually localized – an aspect that needs to be considered in the national risk assessment. In order to assess the Natech risk to a hazardous installation, operators should determine if their site is located in a natural hazard zone and, if so, what the expected severity of the natural hazards on the site would be.[154]

This needs to be followed by an analysis of which parts of the installation would be affected and how, since not all equipment is equally vulnerable. Priority should be given to the most hazardous equipment. The natural hazard risks to these selected facilities should then be analysed. This analysis should also include an assessment of the impacts of the natural events on the prevention and mitigation measures in place. Once the potential consequences have been assessed and a need for further risk reduction identified, dedicated protection measures should be implemented. This process requires a significant amount of input data. However, as much of this information (natural risk maps, industry information) is already gathered in the framework of the national risk assessment, these data could also be used for the Natech risk assessment. Krausmann (2017)[155] provides a detailed discussion of the requirements and steps for Natech risk assessment. Risk assessment methodologies and tools have inherent uncertainties that need to be considered in the decision-making process.

A number of research and policy challenges and gaps exist that can prevent effective Natech risk reduction. These include a lack of data on equipment vulnerability against natural hazards, and the unavailability of a consolidated methodology and guidance for Natech risk assessment, which has, for instance, resulted in a lack of Natech risk maps.

The few existing Natech risk maps are usually only overlays of natural hazards with industrial site locations and are therefore only Natech hazard maps. Natech risk maps must also include an estimate of the potential

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154 Krausmann, E. (2016). Natech accidents - an overlooked type of risk? *Loss Prevention Bulletin*, vol. 250. Institution of Chemical Engineers, United Kingdom.

155 (2017). Natech risk and its assessment. In: Krausmann, E., A.M. Cruz and E. Salzano. Natech Risk Assessment and Management - Reducing the Risk of Natural-Hazard Impact on Hazardous Installations. Amsterdam: Elsevier.

consequences, which may differ significantly from site to site. Attention should be paid to the inherent limitations of existing equipment vulnerability models from non-Natech applications if these are used to substitute for the missing Natech models.

There is the misconception that engineered and organizational protection measures in place to prevent and mitigate conventional industrial accidents would be sufficient to protect against Natech events. But the very natural event that damages or destroys industrial buildings and equipment can also render unavailable the instrumentation (e.g. sensors, alarms), the engineered safety barriers (e.g. containment dikes, deluge systems) and the lifelines (e.g. power, water for firefighting or cooling, communication) needed for preventing an accident, mitigating its consequences and keeping it from escalating. Therefore, for effective Natech risk reduction, additional Natech-specific safety measures need to be put in place to accommodate the characteristics of Natech accidents.

The assessment of Natech risk can therefore be challenging, even for the impact of a single natural hazard on a hazardous installation. Consideration of multiple natural hazards and cascading events (e.g. domino effects) that may involve multiple process units or installations at the same time is much more difficult.

Currently no assessment tools exist to capture all aspects of Natech risks. Recently, however, risk assessment tools and methodologies that can rapidly estimate regional and national Natech risk have become available. These include RAPID-N for semi-quantitative risk assessment[156] based on natural hazard information and the data on hazardous industrial installations entered by the user, ARIPAR for a quantitative treatment of the problem[157] and PANR for a qualitative assessment methodology.[158] Although still limited to selected natural hazards and certain types of installations, the tools are in active development to cover additional hazards and industries, and can significantly facilitate national risk assessment studies.

Being an emerging risk – even in developed countries – national authorities are still not assessing Natech risk comprehensively. Although there are no risk assessments at country level, several national and international programmes and regulations exist that require the operators of hazardous installations to include Natech risks in their safety plans.

156 Girgin, S. and E. Krausmann (2013). RAPID-N: Rapid natech risk assessment and mapping framework. *Journal of Loss Prevention in the Process Industries,* vol. 26, issue 6, pp. 949-960.

157 Antonioni, G. and others (2009). Development of a framework for the risk assessment of Natech accidental events. *Reliability Engineering and System Safety*, vol. 94, issue 9, 1442-1450.

158 Cruz, A.M. and N. Okada (2008). Methodology for preliminary assessment of Natech risk in urban areas. *Natural Hazards,* vol. 46, issue 2, 199-220.

CASE STUDY

## Box 1
Good practices for addressing Natech risk

**European Union** - Directive 2012/18/EC on the control of major-accident hazards involving dangerous substances (Seveso III Directive), which regulates chemical accident risks at fixed industrial installations, explicitly addresses Natech risks and requires the installations to routinely identify environmental hazards, such as floods and earthquakes, and to evaluate them in safety reports.
The inclusion of Natech risks in the Seveso Directive acknowledges that awareness of this risk has been growing steadily in Europe since the Natech accidents during the 2002 summer floods.

**Japan** - The Law on the Prevention of Disasters in Petroleum Industrial Complexes and Other Petroleum Facilities was updated after the Tokaichi-oki earthquake triggered several fires at a refinery in 2003. Moreover, the amended Japanese High Pressure Gas Safety Law requires companies to take any additional measure necessary to reduce the risk of accidents, and to protect their workers and the public from any accidental releases caused by earthquakes and tsunamis.

**United States -** The State of California released the California Accidental Release Prevention (CalARP) Program, which calls for a risk assessment of potential hazardous materials releases as the result of an earthquake.

The Natech database eNatech is specifically designed for the systematic collection and analysis of worldwide Natech accident data (available at http://enatech.jrc.ec.europa.eu).

Rapid Natech risk assessment and mapping tool RAPID-N allows quick regional and local Natech risk assessment, including natural hazard damage assessment and accident consequence analysis with minimum data requirements (available at http://rapidn.jrc.ec.europa.eu). (Requires prior authorization).

The Natech addendum to the OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response contains amendments to the original guiding principles (available at www.oecd.org/chemicalsafety/guiding-principles-chemical-accident-prevention-preparedness-and-response.htm).

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# 10. Tropical Cyclone (To be completed soon)