

## Chapter 2

# Hazards, Vulnerability and Risk

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**Abstract** The hazards and vulnerability concepts are introduced after a brief review of the definition of risk. Hazards are essentially associated with any natural phenomenon investigated, while vulnerability is primarily a socioeconomic parameter influenced by other drivers of change such as demography. The risk concept derives from these two parameters. Given that there is no such thing as a zero risk situation, it is essential to introduce the idea of an acceptable level of risk which must be determined through a participatory process set in motion by society. Knowledge regarding these two risk components is dependent on the methods used to assess them and associated levels of uncertainty. The impact of climate change on hazards is hard to quantify because, under a constant climate, it is generally an order of magnitude below the natural existing uncertainty. Conversely, vulnerability is not well understood and few rigorous methods are available to quantify this factor. Clarifying hazards thus may seem to enhance the risk assessment but this is illusory since the less understood vulnerability factor is overlooked, which may lead to too much attention being focused on the hazards factor to the detriment of vulnerability management. This may also apply to other climate risks such as drought, although flooding risk is better understood. These considerations may be useful for the agricultural community which, besides its production function, could offer society other services of territorial scope, encompassing different areas, while in return benefitting from support measures that would make the risks more acceptable.

### 2.1 Brief Review of Cyndinics—The Science of Risk

In the field of cyndinics, especially for natural disaster experts, from a conceptual standpoint, hazards and vulnerability elements are distinguished when analysing risk (Gilard 1998b). Under this conceptual rationale, hazards are random factors

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resulting from natural phenomena that cause a danger when they arise. Hazards are characterized by a relatively well known probability law. They are mainly dependent on ‘natural’ factors that human interventions can help change via development projects or by the impact of certain practices (e.g. runoff on sealed surfaces). Conversely, from this conceptual standpoint, vulnerability is viewed as a socio-economic factor that characterizes foreseeable damage when a phenomenon occurs (Goutx 2012; Veyret and Reghezza 2006; Weiss et al. 2011), without any presumptions regarding the probability of occurrence of the phenomenon. For both concepts, the spatial distribution is heterogeneous and differs from one plot to another. They can be extended to different spatial scales depending on the targeted analysis accuracy and use. These concepts are illustrated hereafter on the basis of examples regarding natural climate-related phenomena.

The first example is from a flood risk analysis. On a given piece of land, floodwater intrusion resulting from a river overflow is the considered hazard. It can be quantified by a series of physical characteristics, combining water level, current velocity and flooding duration, with a probability of occurrence assigned to each of these three factors ( $l$ ,  $v$ ,  $d$ ) (Gilard 1998b). Although this hazard can best be described by a probability value because of its progressive and continuous nature, a hydrometeorological measurement network, with long-term monitoring data, is required to obtain accurate knowledge on such phenomena. The same plot of land can be characterized in terms of its vulnerability to the flood phenomenon. The susceptibility of the plot may differ depending on its use—a plot with an agricultural use will not have the same vulnerability as that with an urban use. Different crops do not have the same susceptibility to flooding, i.e. perennial crops are generally less susceptible than annual crops, at least for short-duration floods. Similarly, in urban environments, the vulnerability of a school is not identical to that of a residential area, industrial zone or recreational area, etc. Construction regulations may even modify the vulnerability of a given building or piece of land—a house with a mezzanine is less vulnerable than one at ground level. Independent plots can thus be characterized by a specific level of vulnerability. Risk is usually defined as the product of a hazard (probability of occurrence) and a vulnerability (estimated cost of foreseeable damage). This definition mistakenly always generates a positive result, thus tending to minimize the risk in the illusory quest for a risk-free situation. The risk concept can however, be defined differently through an additive combination of hazards and vulnerability levels (Gilard 1998a, b), whereby the risk may be positive or negative, and therefore acceptable when the hazards level is consistent with the vulnerability level, or unacceptable in the reverse situation (Figs. 2.1 and 2.2).

The same type of analysis could apply to drought risk. Here again, hazards caused by a shortage of water can be described by a rainfall probability distribution, generally with a seasonal adjustment. The duration parameter is crucial to determine the drought severity. The vulnerability in turn reflects the potential impact of this lack of rain on the use of a given plot, irrespective of the probability of occurrence of the phenomenon or the crop cycle period concerned by the hazard. The extent of the risk depends on the relevance of these parameters. By the acceptable risk



**Fig. 2.1** Flooded street, Hanoi (© O. Gilard)



**Fig. 2.2** Risk—a combination of hazards and vulnerability (Gilard 1998a, b). In *red*, unacceptable risk situations when hazards are greater than the vulnerability and, in *green*, acceptable risk situations when hazards are less than the vulnerability. This comparison may be made for each territorial unit

concept, the risk occurrence could be offset by other regulation or compensation mechanisms (e.g. through an insurance scheme covering the agricultural impact of the risk).

Let us now consider the often overlooked principle that zero risk situations do not exist! Regarding the flood example (Vinet 2010), a flooding river does not have a maximum value, i.e. a flood could be more intense and therefore more infrequent than previously monitored floods. When a dike is built, despite the low probability, a flood that would overflow the dike could occur at any time. Similarly, with regard to droughts, a drought could last longer and be more intense than previously observed. These natural phenomena are not ‘bounded’. We thus conclude that there are no zero risk situations and full protection against any phenomenon is impossible. So it is essential to set an acceptable risk level, which could in turn be used to determine exactly what could be managed by development projects or infrastructures, or by other measures, such as insurance schemes, crisis management, etc. Clearly, this acceptability notion is by necessity delineated collectively, while also including economic, sociocultural and psychosociological considerations, as we shall see later with the more precise definition of vulnerability.

## 2.2 How Does This Apply to Climate Change?

Quantifying hazards—what does that mean? A brief update on a few operational hydrology facts will help differentiate intrinsic climatic variations from the impact of changes in the same climate. Climate change, resulting from the impact of a rise in temperature due to greenhouse gas build-up, leads to modifications in climate-related hazards, particularly all hydrometeorological phenomena. These modifications are nevertheless very hard to predict since the phenomena involved are inherently highly variable, both spatially and temporally. They are generally described in terms of a ‘regime’ (rainfall, flow rates, low flows, etc.), i.e. a probabilistic representation of the overall range of possibilities, with a margin of uncertainty, in a recognized stable climate setting. The impact of climate change should be determined in terms of modifications in the regime (Renard et al. 2006). This is just a secondary factor as compared to the primary variability in the measured phenomena.

To gain a clear understanding of the above and draw relevant conclusions, it is useful to briefly outline a few baseline operational hydrometeorological principles. Hydrometeorological phenomena are monitored by available relevant networks that measure different parameters such as rainfall and river flow rates. Just measuring the different parameters is in itself a difficult task. For rainfall, we actually only know how to measure a quantity of water over a given time step. Similarly, water level at a given time enables us to determine a flow rate on a rating curve (which is hard to plot and a source of uncertainty, especially for measured flood and low flow extremes). The flow of a flooded river is currently determined with a margin of

uncertainty of over 10–20 %<sup>1</sup> (Alliaud et al. 2013; Chastan et al. 1993; Gilard and Mesnil 1994). Progress has been achieved in recent years on normal river flow measurements based on radar and Doppler effects, but these methods are generally impractical during major floods, so we have to rely on indirect estimation methods with their associated margins of uncertainty. The same problem arises when assessing severe low flow events, which are very hard to accurately measure.

The rainfall regime is characterized by three main parameters, i.e. the intensity, duration and frequency, at least for small time steps (e.g. daily). More integrative parameters may also be considered, such as decadal rainfall rates (useful for agriculture) or seasonal rainfall patterns (useful for estimating available resources), etc. The point-specific nature of these measurements is somewhat problematic—a rain gauge records local characteristics of a rain storm whereas spatial variability in the rainfall pattern is often noted. Have we not all crossed a rainy area and then come upon an adjacent area that is still completely dry? Rain gauges therefore have to be well distributed throughout the concerned area to encompass this spatial variability, while also accounting for orographic factors such as the terrain. Recorded data may now be supplemented with indirect radar measurements, thus improving the representativeness of point measurements obtained. The descriptive accuracy of the rainfall regime depends on the duration of the time series measurements, especially for integrating so-called extreme events in the probability distributions of these parameters, which is essential for gaining full insight into potentially associated risks. Longer series enable more reliable estimates of the ‘natural’ frequency of these events, while in addition enhancing the capacity to consider them when making development decisions (size of hydrological structures, estimating agricultural production failures, etc.).

The hydrological regime of rivers is also characterized by three main parameters, i.e. flow, duration and frequency (Galéa et al. 2000; Javelle et al. 1999; Mar et al. 2003). The most relevant parameter should be defined according to the phenomena studied, i.e. the water volume when available quantities are sought (e.g. the mean monthly volume over a given month) or the flow rate when studying the intensity of a phenomenon (e.g. maximum instantaneous flow to characterize the flood intensity). The relevant parameter is not monitored directly but instead is obtained by processing baseline measured data. However, the prediction quality of the models used is degraded by the many measurement uncertainties (Renard et al. 2006; Sauquet et al. 2012).

Climate change, the effects of which have already been observed on the temperature variable, inevitably has an impact on other climate variables such as rainfall, and consequently river flow (Redaud et al. 2002), etc. But it is complicated (Sauquet et al. 2012), if not impossible, to assess these changes due to the

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<sup>1</sup>The 1992 historic flood of the Ouvèze River at Vaison-la-Romaine (France) is edifying in this respect—it was not possible to reduce the assessment range (found to be between 800 and 1200 m<sup>3</sup>/s) even after a year of research (Chastan et al. 1993; Gilard and Mesnil 1994). Similarly, inclusion of a single especially dry year in the 1986 Niger River flow record prompted a review of all probabilistic flood frequency estimates for this large river.

complexity of the prevailing phenomena. Such assessments have to take into account the overall rainfall and hydrological regimes and local features (geology, orography, land cover, etc.), which in turn may independently undergo changes.

This scenario can be illustrated by assessing the impact of climate change on the centennial flood of the Seine River in Paris (France). Such assessments are, however, complicated by changes related to control dams and their management, by changes in runoff and flow conditions, etc. If it were necessary to decrease the return period from 100 to 80 years due to climate change, would that fundamentally alter the centennial flood hazard?

## **2.3 What About Vulnerability?**

### ***2.3.1 What Are the Current and Future Adaptation Margins?***

Vulnerability is far more complex to characterize, and especially to quantify, than hazards because a full set of economic, social, cultural, psychological, etc., factors have to be taken into consideration. This characterisation and quantification is multi-levelled and involves individual to political perceptions. The latter ultimately determine the operational choices made by a country or society to ensure protection from foreseen risks which, as already noted, must be defined by a level of acceptability. Moreover, to be effective, this vulnerability assessment should be spatialized on a scale that is suitable for fine-tuned land management. This is the only way to obtain sufficient leeway to minimize the impacts of the most exceptional events, which certainly will both technically and financially exceed the structural protection resources at our disposal.

It is only in the last 20 years that vulnerability analysis studies (Veyret and Reghezza 2006; Weiss et al. 2011) have been under way in some developed countries. Moreover, the topic has still far from been thoroughly investigated regarding some natural risks. Vulnerability quantification is thus still highly tentative. However, working on this risk component increases the leeway for making it acceptable (Goutx 2012). Concerning the flood risk, infrequent floods could be acceptable in some urban areas if they are of limited duration and if houses are built with a sufficiently elevated mezzanine. Moreover, concerning floods, for rare flood events, decisions could be made to flood agricultural areas in order to reduce the risk in urban areas, but financial compensation would have to be arranged for this ‘risk exchange’, thus making it possible to reduce the size of protective structures. In urban areas, it could be acceptable that some roadways and recreational zones are temporarily flooded in order to better protect hospitals and fire stations, etc. Drought risk to agricultural activities could be made acceptable by selecting resistant crop varieties and setting up insurance mechanisms that are less expensive than building water infrastructures (which could also fail in the event of exceptional droughts).



**Fig. 2.3** Market near a flooded road after heavy rain, Cameroon (© L. Parrot/CIRAD)

Support measures could be effectively identified by focusing studies on enhancing vulnerability assessment and management. This could help gain further insight into the risk, to come up with non-structural solutions that do not involve infrastructures and that indirectly boost the efficiency of structural measures, while drawing up land use plans that take all of these risk factors into account (Figs. 2.2 and 2.3).

### ***2.3.2 To Avoid Addressing the Issues Inefficiently***

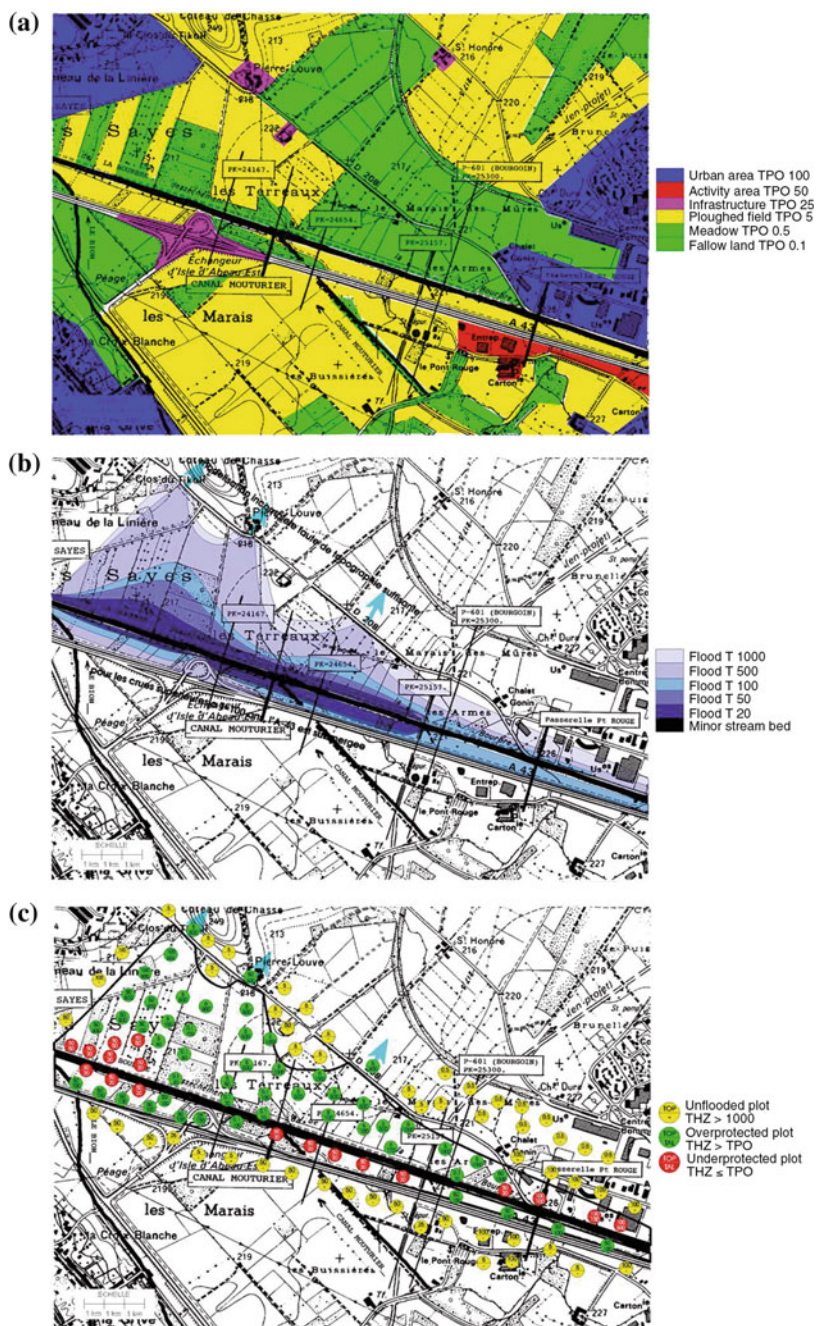
A few conclusions could be drawn on taking climate change into consideration in natural risk analyses related to climate change.

The vulnerability assessment uncertainty is an order of magnitude greater than that of hazards. The risk resulting from looking simultaneously at these two parameters (Gilard 1998a, b) is thus estimated with an even greater uncertainty, which could be summed up by the following equation:

$$\text{Risk}(\pm \text{uncertainty}) = \text{hazard}(\pm \text{uncertainty}) - \text{vulnerability}(\pm \text{uncertainty})$$

As the impact of climate change on the hazard parameter is an order of magnitude lower than the uncertainty regarding knowledge on this parameter, the risk







◀ **Fig. 2.4** Vulnerability (a), hazards (b) and risk (c) maps for the same area. The vulnerability spatial distribution is based on a tailored quantification method that includes economic and sociological factors. The hazards distribution is based on hydrological and hydraulic modelling of the studied river regime. The risk map shows plots with acceptable or unacceptable levels of risk, where the former offer leeway for tailored development projects (Gilard 1998a, b).  $T$  = return period,  $THZ$  = return period of the hazard,  $TPO$  = return period of the protection objective; the figures represent years

assessment is not fundamentally improved by taking the impact of climate change on the hazard factor into account, which is a complicated task (Renard et al. 2006; Sauquet et al. 2012):

$$\Delta Risk(CC) = hazard(\pm uncertainty \pm \Delta CC) - vulnerability(\pm uncertainty)$$

where  $\Delta CC < hazard\ uncertainty \ll vulnerability\ uncertainty$  and  $\Delta CC$  = assessment of the impact of climate change on the hazard factor.

Costly studies that focus on hazards factor without concomitantly addressing the vulnerability factor are not useful in the quest for tailored solutions. They might even channel research towards structural measures associated with hazards instead of measures that could ultimately be more effective—even though they would likely be harder to implement—especially those related to land-use management. Risk maps are thus based on associated vulnerability and hazards maps, which enable simulation of development projects geared towards modifying either of these two parameters (Fig. 2.4).

Showcasing climate change induces a distorting prism focused on hazards, while diverting attention from the demographic factor which otherwise would clearly increase the vulnerability overall. This demographic change should be accompanied by land-use planning to manage these risks. Such planning is not directly associated with climate change, with the noteworthy exception of coastal areas which are directly susceptible to the temperature parameter and to the impacts of the rise in average sea level.

## 2.4 What Relevance for Rural Areas?

Natural climate-related risks can only be managed on a tailored territorial scale—rivers for floods and a wider region for drought, especially if water resources are required that are not locally available. This territorial scale includes different types of urban or rural land use, each subject to different possible climate hazards, especially floods and drought. Collective management of these risks by society could generate opportunities in agricultural areas which, in exchange for services (in addition to the production function), could in turn benefit from compensation from other society members, thus potentially enabling them to boost their efficiency, including production efficiency (Fig. 2.5).



**Fig. 2.5** Vegetable gardening adapted to a flood zone, Inle Lake, Burma (© O. Gilard)

Regarding the drought risk in agriculture, these concepts could be applied when seeking to reduce crop vulnerability by using varieties or cropping systems that are less vulnerable to drought, such as conservation agriculture, rather than trying to reduce hazards by expensive irrigation investments requiring more water, a locally rare resource. Public funding should also be directed towards vulnerability management rather than investing in hazards reduction.

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