1

Governance Challenges Facing Hydrometeorological Extreme Events

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After the preamble on the complementarity of the six volumes of the series on hydrometeorological extreme events edited by Philippe Quevauviller, this chapter aims to provide the readers with two main reading grids. First, it proposes some definitions of the hydrometeorological extreme events considered in this book. Second, it refers to the concept of adaptive governance to introduce the framework proposed for the governance analysis of the three hydrometeorological extreme events considered in this book, namely floods, droughts, and coastal storms.

1.1 Introduction

Introducing this book on the governance of hydrometeorological extreme events necessitates, first of all, defining what is meant by hydrometeorological extreme events for societies and what they are forecast to be in the context of climate change. Then we will introduce the governance issue related to hydrometeorological events in order to frame the specific situations set out throughout this book, which sketch the specific geographical and political contexts within which these governance issues take place.

1.2 Facing hydrometeorological extreme events

Hydrometeorological variability is inherent to terrestrial climate. Hydrometeorological extreme events are part of this variability. Societies are thus naturally exposed to hydrometeorological extreme events and have, through history, developed different strategies to manage their vulnerabilities. Each year, millions of people are affected by hydrometeorological extreme events all over the world, including Europe, with an

Facing Hydrometeorological Extreme Events: A Governance Issue, First Edition.
Edited by Isabelle La Jeunesse and Corinne Larrue.
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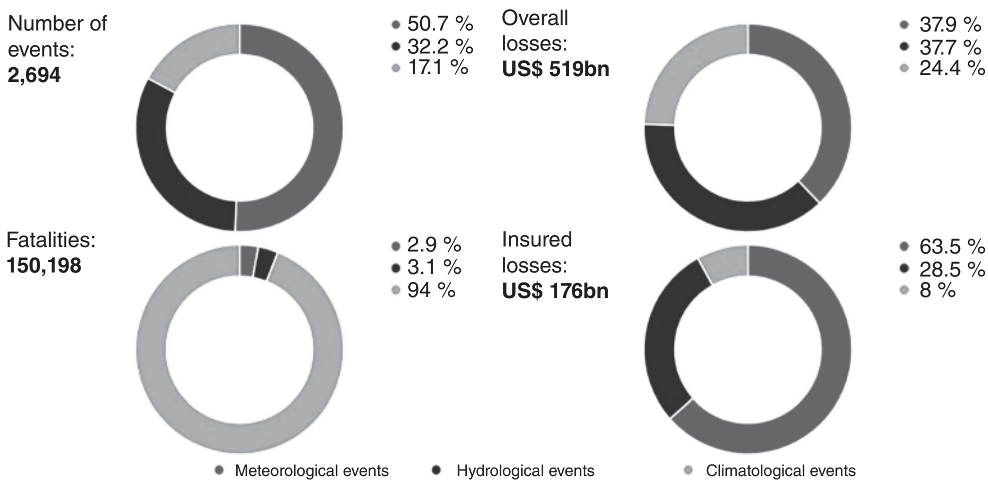

Figure 1.1 Percentage distribution for relevant weather-related losses in Europe over the 1980–2017 period © Munich Re reinsurance database.

observed and reported increase in severity and frequency (Harding et al. 2015). The total amount of floods and economic losses associated with these events have increased over the past decades (Bates et al. 2008; Kundzewicz et al. 2014), as confirmed by the NatCat SERVICE[1] – a database on natural disasters managed by the Munich Re reinsurance agency (Figure 1.1). Overall losses have been assessed to represent more than USD 500 billion.

In 2012, the Intergovernmental Panel on Climate Change (IPCC) produced a Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. This report is commonly referred to as the SREX report. Its main objective is to prevent hydrometeorological extreme events by exploring the physical and social dimensions of weather- and climate-related disasters. Thus, hydrometeorological extreme events must be considered in the context of global warming and its impacts.

According to the IPCC report on extreme events, climate extremes (extreme weather or climate event) means the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of values observed for the variable (IPCC 2012). To simplify, both extreme weather events and extreme climate events are referred to collectively as ‘climate extremes’ (IPCC 2012). These include any rare, intense, and severe extreme events (Beniston et al. 2007).

All these extreme events – floods, droughts, and coastal storms – originate from climate-system extremes such as persistent anticyclonic conditions or strong gradients in atmospheric pressure and temperature. Thus, if the climate changes, as a consequence, extreme events can also change. Scenarios proposed by the IPCC report on extreme events predict an increase in these events, both in frequency and intensity.

These extreme events are expected to have major impacts throughout Europe, including on water management. However, as regards the impacts on societies, it is always necessary to set these events in a historical context. As shown through the work of climate historians, history testifies to series of extreme events having taken place in

Europe between the sixteenth and twentieth centuries (Garnier 2015). The impacts of past extreme events on societies (Le Roy Ladurie, Rousseau, and Vasak 2011) give important information on what current governance could consider in its risk-assessment process. The Sendai framework for Disaster Risk Reduction, which was established by the UN General Assembly in March 2015 (as a follow up to the Hyogo framework), aimed at increasing the preparedness for climate change impacts through a framework supporting the 'substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries' (Sendai Framework 2015). In order to achieve this overall outcome by 2030, the Sendai working groups focused on the following goals: 'Prevent new and reduce existing disaster risks through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience'. These efforts are expected to: (i) generate the information base for the development of Sendai Framework implementation strategies, (ii) facilitate the development of risk-informed policies and decision-making processes, and (iii) guide the allocation of appropriate resources.[2] This must be based on efficient governance for integrated risk management.

This being said, as an introduction to this book on the governance of hydrometeorological extreme events, it seems necessary to provide an overview of the main characteristics of the hydrometeorological extreme events presented and the main impacts and adaptation strategies proposed at European level. Since the main hydrometeorological extreme events occurring in Europe are floods, droughts, and coastal storms, this book focuses on these three types of extreme event.

1.3 Floods

In Europe, flooding is probably the leading natural hazard. Flood lists are mentioned in several webpages and commonly engraved on the piers of river bridges. The European Environment Agency provides a datasheet containing information on past floods in Europe since 1980,[3] based on the reporting of European Union (EU) Member States for the EU Floods Directive (2007/60/EC), along with information provided by relevant national authorities and global databases on natural hazards. The summer of 2016 was the scene of major floods throughout Europe, where Germany and France, along with Austria, Belgium, Romania, Moldova, the Netherlands, and the United Kingdom were highly impacted.

1.3.1 Definition and characteristics

In English, the word flood describes both the natural variability of a river with a maximum flow during the wet period, and the inundation phenomenon due to the river coming out of its bed and filling the floodplains. Thus, a flooding event, as an extreme hydrometeorological event, is a situation in which water temporarily covers land not frequently flooded.

Flood can be described by hydrological characteristics such as:

1. *Flood intensity*, which is characterized by inundation depth and volume;
2. *Flood frequency*, which represents the number of times an area is inundated during a particular time interval; and
3. *Flood duration*, which is the length of time during which a particular area is inundated.

These hydrological characteristics of floods are used to study the series of historical data and to forecast flooding events. Also, in flood management, hydrological characteristics are linked with their consequences both on natural systems and human societies so as to prevent flood damage and design alert systems. Following this, floods can be described according to flow speed, the physical characteristics of the catchment area, and the main causes of flooding. We can distinguish:

1. *Riverine flooding* – the slow increase of the height of the water in the riverbed due to an unusual rainfall event, in spring with snowmelt or in summer if glaciers melt. It occurs in river floodplains in areas with low topographic elevation when the upstream basin experiences heavy rainfalls. With large rivers, the flow speed and rising speed processes are relatively slow. This type of flood can be due to an obstruction in the flow path. These types of floods last the longest amongst flooding events.
2. *Mudflow* – any type of flooding that engages high quantities of sediments. Flash floods due to heavy rainfalls in upper parts of catchments usually mobilize a large quantity of mud. However, mudflow usually concerns steeper watersheds with poor soils highly sensitive to erosion. The impacts are comparable to snow avalanches.
3. *Coastal flooding* – flooding due to particular concomitant physical conditions where the river is in flood and the pressure on the sea does not enable the water to flow into the sea. This usually occurs close to the mouth of the river and the delta area. However, this type of flooding can be induced by storm surges, which are described later.
4. *Urban flooding* or *urban drainage flooding* – is specific as the cause is usually aggravated by a lack of drainage and infiltration in partially impervious urban areas and all these areas are highly vulnerable. This occurs when the drainage infrastructure becomes blocked or overwhelmed due to high-intensity rainfall. Thus, this type of flooding impacts areas close to drainage channels and house basements.
5. *Flash flooding* – a localized flood where water flows in at great speed. The flow speed of the water is mainly determined by the slope of the terrain rained on. The steeper the slope, the faster the water flows. This usually concerns mountain and hilly areas, as well as highly impervious catchments after heavy and localized rainfall. The warning time is very short, less than one hour for some hydro systems. Flash floods can also be induced by structure failures, such as for instance, when a dike or a dam breaks and a large amount of water is released suddenly. The water speed at the breach is similar to the speed of a flash flood, but sometimes involves much larger volumes.
6. *Pluvial flooding or water logging* – due to an accumulation of water exceeding saturation conditions and forming a layer – on agricultural fields and streets alike – provoking significant and unusual runoff. These events are due to excessive rainfall. This issue concerns both urban and agricultural land.

With all this, the height of surface waters, which leads to flooding when a defined threshold is exceeded, can be exacerbated by different natural and anthropogenic factors. Most of the time, floods are caused by an unusual duration of rainfall. However, in some conditions, torrential rains or storms cause flooding. In the summer season, in hydro systems linked to mountain areas, a high average temperature can also result in increased snowmelt with, hence, a high discharge downstream.

Land use and land cover in watersheds are also highly implicated in the variability of the hydrological responses of the catchment to rainfall. The proportion of forest areas in the upper parts of the catchment decreases the runoff generated by heavy rainfalls in these upper parts. Downstream, wetlands buffer the volumes of water and thus have a significant impact on flow peaks. Moreover, depending on how natural meanders have been managed throughout the river's history, the linearity of the river is highly efficient in decreasing flow speed in the riverbed. Last but not least, the proportion of impermeable areas versus soil infiltration capacity has an impact on the height of water runoff and flow peak volumes.

1.3.2 Impacts and adaptation

Both during and after floods, any kind of economic activity may be impacted due to disruptions or possible damage to infrastructure and transportation networks. In many cases, residents of flooded houses are invited to move. It is also well-known that floods have a significant psychological impact, since when someone's house or work place is flooded they can lose everything. However, the impact is considered only if it is negative for the environment and/or human activities. And it all depends on where and when the flooding took place. For instance, flooding has higher impact in cities than in wetlands and is more or less significant in agricultural areas depending on the time of the year and stage of crop growth.

To reduce the impact of flooding, the management options vary from environmental actions to flood defence infrastructures. These may include, for example building a storm basin, restoring river banks, dredging rivers, rehabilitating drained or inefficient wetland areas, and increasing the surface of forests in the upper parts of the catchment. The hydrological modelling facilities are used by national/regional/local communities to assess the effects of either option (e.g. river flow, volume stored in storm basins, and inundated areas).

To prevent flood damage, and in particular to avoid loss of life, authorities need to anticipate and communicate to citizens and economic agents at different decisional levels on the state of the flooding event. In fact, whilst the water level slowly rises in large rivers, officials can first inform citizens as well as decide to evacuate people before the river overflows. However, the area that is flooded can be huge and require local communities, included isolated ones, to be highly organized. Many prevention systems exist, depending on national incentives and local community investment. At the European level, the European Flood Awareness System (EFAS)[4] – developed in the context of several European research projects, is now a single operational European monitoring and forecasting system for floods across Europe. It provides complementary information to the National and Regional Hydrological Services and to the European Response and Coordination Centre operating within the European Commission's Humanitarian Aid and Civil Protection department.

1.4 Drought

1.4.1 Definition and characteristics

Drought refers to a period of abnormally dry weather long enough to cause serious hydrological imbalance (IPCC 2012). Considering this, any region of the globe can suffer from drought. However, drought is a relative term and therefore needs to be clarified. In this book, 'drought', as a hydrometeorological extreme event, refers to the impact of an exceptional lack of rainfall. In contrast to aridity, which is a permanent feature of the climate and is restricted to low rainfall areas, drought is a temporary water shortage condition compared to the average situation. It is usually the consequence of a natural reduction in the amount of rainfall received over an extended period of time, which can be caused or aggravated by other climatic factors, such as high temperatures, high winds, or low relative humidity. Based on this, and depending on the main causes or impacts, some definitions of droughts have been proposed. These are usually grouped into five types (Wilhite and Glantz 1985):

1. *Meteorological drought*, which is mainly due to a long period of no or very low rainfall;
2. *Hydrological drought*, which is characterized by below average river flows;
3. *Agricultural drought*, which refers to a soil moisture deficit affecting crops;
4. *Mega drought*, which is a persistent and extended drought that lasts for a much longer period than normal; and
5. *Socioeconomic drought* has also been considered in order to name droughts induced by human factors, causing, for instance, excessive demands on a supply-demand system. These occur when the demand for water exceeds the supply (Wilhite and Glantz 1985).

The last type of drought makes it possible to distinguish between drought (and drought impacts) and water scarcity. Thus, water scarcity and drought (WS&D) are two interrelated but distinct concepts. Water scarcity may result from a range of phenomena, which may either be produced by natural causes – such as drought, or can also be induced by human activities alone, or, as is usually the case, may result from the interaction of both (Pereira, Cordery, and Lacovides 2002). This explains why the relevant policy at European level is called 'water scarcity and drought policies'.

1.4.2 Impacts and adaptation

Over the past four centuries, Europe has been affected by severe droughts (Garnier 2015). No later than 1921, a severe drought occurred with rainfalls 40% lower than usual, from England to Italy. It affected a large part of Europe and even provoked a famine in Eastern Europe. Later on, the 1976 drought was especially severe in the Northern half of France and affected other parts of North-western Europe (Le Roy Ladurie et al. 2011).

Since then, both policy literature and the popular press have pointed out in the 1990s the potential water wars that reduced water availability, resulting from climate-induced changes, could generate in parallel with demographic growth. Indeed, water scarcity is often cited as a cause of water conflicts, which in turn can threaten water security, enabling us to draw a link between droughts and water security in Europe (Liberatore 2013).

We can already note that the number of people and areas in Europe affected by drought and water scarcity has increased by 20% between 1976 and 2006 (European Commission [EC] 2007). The total cost of these 30 years of drought amounts to € 100 billion (EC 2007). This makes it crucial to deal with drought and water scarcity now, and increase drought resilience before the problem grows even larger. In its 2007 Communication Report, the EC clearly stated that devising effective drought risk management strategies must be regarded as an EU priority.

Out of all hydrometeorological extreme events, drought is undoubtedly the most complex as both its causes and impacts are not very well known or understood, nor are they described and modelled. This partly explains why overall losses are usually more significant than insured losses for climatological events whereas for hydrological events (floods) these losses are very similar, as shown by the extractions of Munich Re's reinsurance database. This can be demonstrated by the two graphs presenting natural disaster losses for Europe in 2016 and 2017. In 2016 there were major floods, mainly in France, Germany, and the Netherlands (Figure 1.2). In 2017, Europe was more affected by freezing events and droughts, where mainly Spain, Italy, and Serbia were affected by dry conditions and heatwaves with low water levels in rivers and reservoirs, which affected crops, fruits, vineyards, and pasture land (Figure 1.3).

In fact, although a lack of rainfall is a frequent phenomenon from a climatic point of view, drought and its socio-economic impacts depend not only on the severity and the spatial extent of the rainfall deficit, but also on several factors such as the state of the environment, as well as social and economic vulnerabilities. Some authors have pointed out that inadequate land use practices, unsustainable management of water resources, and inadequate risk management are key factors in explaining the drought impacts (Vogt and Somma 2000).

The impacts on socio-economic activities are mainly due to losses in agricultural production, which mostly concerns wheat in Europe as it is a non-irrigated crop

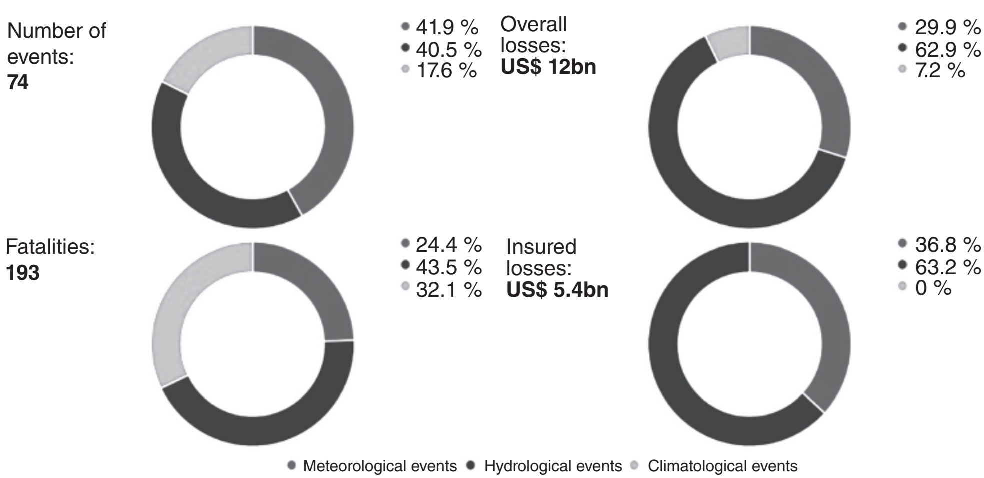

Figure 1.2 Percentage distribution for relevant weather-related loss events in Europe in 2016.

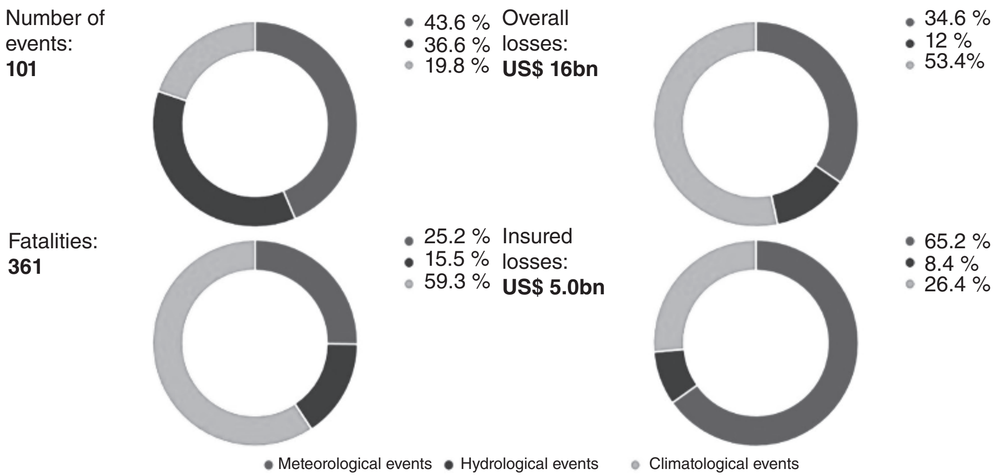

Figure 1.3 Percentage distribution for relevant weather-related loss events in Europe in 2017.

covering a large amount of agricultural areas. Affected non-irrigated crops are considered as really representative of the production impacted by rainfall deficits. However, irrigated crops are also impacted, yet it is more difficult to establish a cause–consequence relation. Drought impacts are also related to reductions in hydropower energy production and environmental degradation. Last but not least, droughts generally provoke public water supply cuts, both because of a degradation of water quality and the quantity of water available. As regards security, another major consequence of droughts is dryness and possible fire outbreaks, as well as the management of heatwave effects, which usually induce an increased water consumption.

From an historical perspective, in the first volume of this series, E. Garnier proposed an interesting drought severity index adapted to available European information from the sixteenth to the nineteenth centuries (Garnier 2015). This index is proposed to be compared to the physical drought classification mentioned above. An index scale between −1 and 5 is given according to the information available in archives. The −1 index is proposed to be used to characterize an event kept in the chronological reconstruction that has insufficient qualitative and quantitative information. Index 1 is mainly dedicated to an absence of rainfall, and thus mainly applies to meteorological droughts as per the physical definition provided earlier, with lots of evidence of the issue in historical texts and materialized by several rogations (in the Christian Church this is a solemn supplication consisting of the litany of the Saints chanted for requiring rainfall). Index 2 can be used for the observation of local low-water in rivers, with notified effects on vegetation. As far as this index concerns the vegetation, it can be compared to agricultural droughts. Index 4 expresses severe low-water marks associated with impossible navigation in rivers, wheat mill lay-offs, search for new springs, forest fire outbreaks, as well as cattle deaths. This level corresponds to a severe hydrological drought. The last index, no. 5, is proposed for exceptional droughts, also referred to as mega droughts, without any possible supply, shortages, sanitary problems, and very high wheat prices, along with several forest fires.

Above all, droughts are expected to increase in the future as a result of climate change. Amongst the impacts is an increase in the frequency and severity of drought periods and water scarcity (EC 2012). In 2007, 11% of the European population and 17% of the European territory were affected by drought (EC 2007).

In this century, despite an increased awareness of drought hazards at European level through the work on the common implementation strategy groups of the water framework directive (WFD) dedicated to drought for instance, the tools, instruments, and management strategies for capitalizing data, risk assessment, forecasting, monitoring, and adapting to potential droughts are not clearly defined. After one of the most widespread droughts affecting over 100 million people in 2003 – one-third of the EU territory, the cost of which was assessed at € 8.7 billion at EU level, the EU Council of Ministers asked the EC to address the challenges of WS&Ds in the EU. This led to the communication of several measures to integrate WS&Ds in river basin management plans in 2007. These were summarized in seven policy options[5]:

1. Putting the right price tag on water;
2. Allocating water and water-related funding more efficiently;
3. Improving drought risk management;
4. Considering additional water supply infrastructures;
5. Fostering water efficient technologies and practises;
6. Fostering the emergence of a water-saving culture in Europe; and
7. Improving knowledge and data collection.

A final report on the Review of the European WS&D Policy was completed in November 2012. This report responds to the 2007 Council request to review by 2012 whether the policy on WS&Ds has achieved its objectives of reducing water scarcity and vulnerability to droughts. It also looks into whether actions taken in the implementation of the WFD[6] helped address WS&D. This report is part of the 'Blue Print for Safeguarding European Waters' adopted by the European Commission on 14 November 2012.

1.5 Coastal storms

Coastal storms can be the most destructive natural hazards. Several coastal storms have hit the European coast over the past 50 years, such as Xynthia in 2010 or Klaus in 2009. The coastal storms, Lothar and Martin, which affected Europe in December 1999, generated such damage inland due to windstorms that the collective memory has denied the very existence of a submersion (Garnier and Surville 2010). In fact, if coastal storms originate from marine waters, the characterization of these events usually depends heavily on what generated the most impacts and what was the most destructive. Furthermore, coastal storms are a combination of multiple specific hydrometeorological conditions.

In addition, coastal storms concern the coastal zone, therefore it seems vital to first characterize the latter and delimit the areas concerned.

1.5.1 Coastal zone delimitation

Coastal zones can be delimited based on several types of criteria: physical, ecological, economical, and societal. Following a general definition proposed by the European Environment Agency on its website, coastal zones can be considered as 'the part of the land affected by its proximity to the sea, and that part of the sea affected by its proximity to the land as the extent to which man's land-based activities have a measurable influence on water chemistry and marine ecology'. However, in order to be operational as regards land use management, the coastal zone is generally defined more specifically in territorial planning documents and can even differ from regions to countries. For instance, the 1991 Planning Act in Denmark defined the landward boundary of the coastal zone as extending 3 km inland from the coast and the seaward boundary as the shoreline; whilst at the same period of time, the Spanish Shores Act (1988) considered the landward boundary extended up to 200 m from the inland limit of the shore (Lavalle et al. 2011).

Regarding the diversity of socio-economic activities generally concentrated in coastal zones, the EU started to define rules for Integrated Coastal Zone Management (ICZM) (Cicin-Sain and Knecht 1998), first through the WFD, which covers the transitional and coastal waters up to one nautical mile from the continental baseline. The ICZM was completed for marine waters by a marine policy initiated in 2008, the environmental part of which was represented by the Marine Strategy Framework Directive (MSFD) (Borja et al. 2010, 2013; Elliott 2013). On this occasion, a definition of the coastal zone was proposed by the European Commission Demonstration Programme on ICZM[7] (EC 1999). A common definition of the coastal zone used by the European Commission is 'a strip of land and sea of varying width depending on the nature of the environment and management needs. It seldom corresponds to existing administrative or planning units. The natural coastal systems and the areas in which human activities involve the use of coastal resources may therefore extend well beyond the limit of territorial waters, and many kilometers inland'. The following criteria – provided in order to consider both the influences of the sea inland and the impacts of human activities on coastal ecosystems – were adopted to define the geographical delimitation of coastal zones:

1. A 10 km buffer from the coastline (obtained from administrative boundaries such as the Geographic Information System of the Commission [GISCO] for the EU);
2. A 2 km buffer from the aggregation of five Corine Land Cover classes: salt marshes, salines, and intertidal flats for coastal waters; and coastal lagoons and estuaries for marine waters.

The first ICZM criterion aims to represent an influence area of the shore, in order to capture its specific ecosystems on one hand, and any urban areas that might generate pressure on the coast, on the other. The aim of the second criterion is to include all inland areas under a direct influence from the maritime environments, these being characterized by transitional waters, where valuable biophysical features (fauna, flora, and geomorphologies) are potentially present.

1.5.2 Definition and characteristics

A general definition of coastal storms could consist in an anomalous set of meteorological conditions comprising extreme winds, large waves with storm surges, and usually heavy rainfalls (Ciavola et al. 2015). Storm surges appear when the sea rises as a result of atmospheric pressure changes and winds associated with a storm. In Europe, storms forming in the ocean and entering into the continent across the North Atlantic usually create extreme sea levels.

Until now, most of the damaging windstorms in Europe have been extra-tropical cyclones. These are low-pressure systems at a synoptic scale, that is to say characterized by an extent of several hundreds to thousands of kilometres and lasting for several days. They include depressions, anticyclones, and barometric troughs. These systems will grow if there is a strong north–south temperature gradient plus pressures that create a vorticity in the unstable frontal waves. In the North Atlantic Ocean, these conditions are met during the months of October to March.[8] They enable extra-tropical cyclones to be formed and have sufficient energy to travel eastwards towards Europe. The path followed by these storms usually curves northwards, which explains why Iceland and northern European countries such as the regions of Ireland, the UK, and Scandinavia are frequently hit. When the storms finally travel further southwards, they can affect countries such as France, Portugal, and Spain.

Moreover, the Mediterranean basin can also generate convective storms and cyclones. These are called 'medicanes', or Tropical-like Mediterranean Storm (TMS), to distinguish them from the hurricanes generated in tropical oceans. These storms are warm-core, low-pressure systems, generating strong winds in the Mediterranean. They are tight, highly convective windstorms without, however, acquiring either size or power, due to the temperature gradient. In the context of climate change, these coastal storms are expected to become more frequent.

Due to climate change, regions in southern Europe are assessed to become the theatre of a gradual and strong increase in overall climate hazards (Forzieri et al. 2016).

1.5.3 Impacts and adaptation

1.5.3.1 Impacts The impacts of climate change will not be distributed evenly or equitably across the territory. With regard to natural hazards, climate change will mainly result in widespread pressure on lower coasts, through coastal erosion or submersion, due to the expected increase in sea level. The specificities of coastal storms, combining violent winds with important movements of water both from the oceans and atmosphere, explain why coastal-storm impacts are most often associated with flooding issues.

Also, so far, fast-rising coastal storms usually give little time to raise the alert and frequently engage massive volumes of water. In general, storms occur in North and North-Western Europe all year round, but mainly between October and March in central Europe, as already mentioned. Storm surges can provoke temporary increases in sea level, rising above tide level, and often cause coastal flooding. Storm events can thus have large impacts on vulnerable systems such as transport, forestry, and energy infrastructures, as well as on human safety. Recordings of storm surges causing floods in large coastal areas date back to 1953, which was the most damaging surge. In the Netherlands and in Eastern England, respectively, 1800 and 307 people died and around 200 000 ha and 160 000 ha of land was flooded (EEA 2017).

If the impacts are considered through the analysis of coastal vulnerability rather than the physical characteristics of the extreme event, these can refer to a spatial concept that considers people and places in the coastal zone likely to be impacted by coastal hazards such as coastal storms (Bevacqua, Danlin, and Yaojun 2018). Socio-economic and demographic data are usually used to assess the social vulnerability of coastal areas. In this sense, Europe's coastal vulnerability is a reality. In Europe, the length of the coastline for the 22 EU Member States with a sea border is estimated at 136 106 km. The European coastal regions account for 43% of the total EU-22 area and population (Eurostat 2009). The population living in coastal municipalities in the EU was approximately assessed at 70 million people (16% of the EU-25 population, EEA 2006).

The impacts of climate change will not be distributed evenly or equitably across the coastal zones in Europe. With regard to natural hazards, climate change will mainly result in widespread pressure on lower coasts, through coastal erosion or submersion, due to the expected increase in sea level. From a geographical point of view, some coastal regions could therefore be significantly affected by the projected changes.

However, long-term extreme sea level increase trends along the European coasts will mostly result from mean sea level changes rather than wave and storm surge changes, which mostly contribute to inter-annual and decadal variability (Weisse et al. 2014). Forzieri et al. (2016) have demonstrated that keys hotspots are located along coastlines and in floodplains because of their significant vulnerability due to high population densities and their economic pivotal role. In these areas, floods and windstorms could be critical in combination with other climate hazards. Moreover, exposure is projected to increase for very extreme events due to their increase in frequency.

1.5.3.2 Adaptation The main adaptation principles proposed for coastal zones are to:

1. Not increase the vulnerability of people, goods and economic activities;
2. Assess the resilience, that is, the ability to adapt to situations, the objective being to develop resilience in the face of climate change hazards;
3. Choose between protection, displacement, or management of temporary disturbances. Beyond the sole socio-economic analysis, these choices to which citizens will be associated will have to take into account the acceptance of the change, its environmental cost, and the available financial resources. Choosing between protection and strategic retreat requires in-depth local studies on a complex dynamic (local trend of rising sea levels, erosion, sediment inputs and availability of materials, as well as, over a slightly longer time frame, the appreciation of the causes of extreme surges);
4. Analyse the vulnerability of territories and populations. The aim being to identify all the issues likely to be damaged in areas subject to potential hazards, including areas protected by structures and territories due to be urbanized in the future. It is then necessary to assess their physical vulnerability and the associated direct and indirect costs, as well as their functional vulnerability in order to determine the

measures to be taken, according to the various hypotheses adopted, social representations, and behaviours;

5. Deploy modelling tools to represent both sea-level rises in temporary or permanent submersions, as well as account for coastal erosion causing territory losses, sediment movements, and the behaviour of existing protection elements (artificial or natural);
6. Develop methods for assessing the economic, social and environmental impact, and the effectiveness of preventive measures; and
7. Adopt a national coastline management strategy and create a national network of coastal changes observations.

National strategies for the sea and coasts and planning documents intend to provide a coastal component meeting each of these objectives, with the final objective of decreasing disaster risks along the coastlines. The main frameworks are the Sendai Framework and the European integrated coastal zone management strategies included in the WFD (2000) and the MSFD (2008).

1.6 Governance issues related to hydrometeorological extreme events

Facing hydrometeorological extreme events therefore raises interesting governance questions. This governance issue is multidimensional and depends on a combination of conditions: public policies, funding opportunities, existing authority and access to knowledge, as well as capacity building at various decision levels, from the citizens up to national and international levels. It can differ from extreme events, insofar as extreme events seem not to be perceived equally both in time and space and depend on the type of actors concerned. Thus, the governance required could be different. For instance, droughts are by definition not sudden extreme events as their severity is linked to a lack of rainfall. On the contrary, floods and coastal storms can be sudden with the necessity to anticipate in order to be ready to face such events. The impact assessment can also be radically different. It seems easier to assess flood and coastal storm impacts than droughts. Thus, the ability to delineate risks and potential impacts is still a major issue in developing governance.

1.6.1 Addressing governance issues

Faced with the rising risks associated with meteorological extreme events, the organization of public authorities and more widely, society as a whole, is a key issue in terms of their ability to cope with these events. As a matter of fact, the importance of extreme event impacts in socio-economic terms depends on how societies anticipate and prepare for these events, as well as on how they manage periods of crisis and post-crisis situations. The risk governance issue is, therefore, at the heart of responses to climate-related risks. In recent years, numerous publications have been drafted in connection with these issues, which can be grouped under the heading of environmental or risk governance.

Speaking of environmental governance first requires clarifying the notion of governance. The term 'governance' refers to the organization of actors and stakeholders involved in a problem considered as public. 'Governance can be defined as a process of coordination between actors of social groups and institutions with a view to achieving objectives defined and discussed collectively' (Le Galès 2006, p. 245). This book will, therefore, focus on the various actors involved in the preparation and management of climate events and their consequences on one hand, and on the interactions between these actors and the regulations they produce on the other hand.

In the environmental field, the concept of governance has also given rise to numerous definitions. We shall retain the one summarized in Chaffin (Chaffin, Gosnell, and Cosens 2014, p. 1) in their review paper on adaptive governance: 'In short, environmental governance is the system of institutions, including rules, laws, regulations, policies, and social norms, and organizations involved in governing environmental resource use and/or protection'. The paper groups the various approaches into three types of governance system: (i) top-down, (ii) centralized, and (iii) bottom-up. The first system is state-based, the second functions via top-down directives, and the third usually emerges through groups of local actors or social networks. The authors explain the interests and difficulties of each approach. A 'new' approach that emerged over the past ten years is called adaptive governance, in the sense of robust governance (Dietz, Ostrom, and Stern 2003). It is a theoretical approach searching for ways to manage the uncertainty and complexity of environmental issues, in other words: social-ecological systems (Berkes and Folke 1998; Costanza et al. 1998).

Applied to hydrometeorological extreme event issues, the question of governance refers first of all to the actors' ability to cope with natural events (or those considered as such). Together with Kooiman, we will consider in this book the 'interactive arrangements in which public as well as private actors participate aimed at solving societal problems' (Koimann 2003), or more precisely, to 'a range of interactions between actors, networks, organizations, and institutions emerging in pursuit of a desired state for social-ecological systems' (Chaffin et al. 2014). This book will show and illustrate the diversity of arrangements between actors in terms of their coping abilities faced with natural events through time, as well as according to the political systems specific to the countries and regions studied, the place given to citizens, and the distribution of responsibilities and resources between these different actors. This book is based on recent research outcomes stemming from European research projects implemented in the field of natural hazards studied from a geographical and/or political point of view and focusing specifically on European contexts.[9]

The question tackled in this book is thus that of the actors of this governance, their perceptions and representations of the problems to be dealt with, the instruments mobilized, as well as the coordination set up between decision and time scales. As a matter of fact, governance related to natural and especially extreme risks is specific: on the one hand it applies to problems that go beyond institutional boundaries, which traditionally organize relations between subnational and supra-national actors. On the other hand, the uncertainty that characterizes the occurrence of these events makes organizing and coordination between actors a complex process. Finally, the importance of potential damage, as well as the relative scarcity of their occurrence, reduces the capacity for anticipation and preparation.

These two last characteristics argue for the use of the notion of a social-ecological system (Berkes and Jolly 2001) to address governance issues related to hydrometeorological extreme events. The concept of the social-ecological system is based on the recognition of the relationships between social and ecological systems: Folke showed that 'social and ecological systems are deeply interconnected and co-evolving across spatial and temporal scales' (Folke 2007, pp. 14–15). Thus, Folke's analysis of the management of the social-ecological system is particularly useful for positioning the stakes of a governance able to cope with hydrometeorological extreme events. Indeed, from this approach emerged the notion of adapting institution: Boyd and Folke define 'adapting institutions' as 'those that allow a variety of actors to deal with complexity, uncertainty and the interplay between gradual and rapid change' (Boyd and Folke 2011, p. 3).

From this first approach emerged the notion of adaptive governance: 'Adaptive governance is an outgrowth of the theoretical search for modes of managing uncertainty and complexity in *Social-Ecological Systems'* (Dietz et al. 2003; Walker et al. 2004 *in* Chaffin et al. 2014; Folke et al. 2005; Folke 2006).

1.6.2 Analytical framework based on adaptive governance

This approach is based on the observation that the traditional top-down 'state-based orientated' approach is not able to address the uncertainties associated with global environmental changes and does not have the flexibility to 'provide effective solutions for highly contextualized situations'. Huitema et al. (2009) summarize the key characteristics of adaptive governance and management. These include notions of polycentricity, evidence of public participation, experimental approaches to resource management, and management at a bioregional scale to match the scale of the problem (as opposed to relying on administrative boundaries) (Fournier et al. 2016).

The analytical framework provided by the adaptive governance approach makes it possible to identify several characteristics required for this type of governance. The following will be taken into account:

1. Multilevel governance, with a balance between top-down and bottom-up decision-making processes;
2. Multi-actor (formal and informal) networks, including active participation from citizens;
3. Flexibility in governance arrangements enabling mitigation measures tailored to local conditions;
4. Governance arrangements supporting management at the appropriate scale of the problem; and
5. Opportunities for experimentation, along with social and institutional learning.

1.6.3 Analytical framework based on risk governance

Adaptation to climate change is sometimes mixed up with disaster risk reduction as they both address issues of prevention and reduction of vulnerability and impacts. Thus, the governance of hydrometeorological extreme events can also be approached through

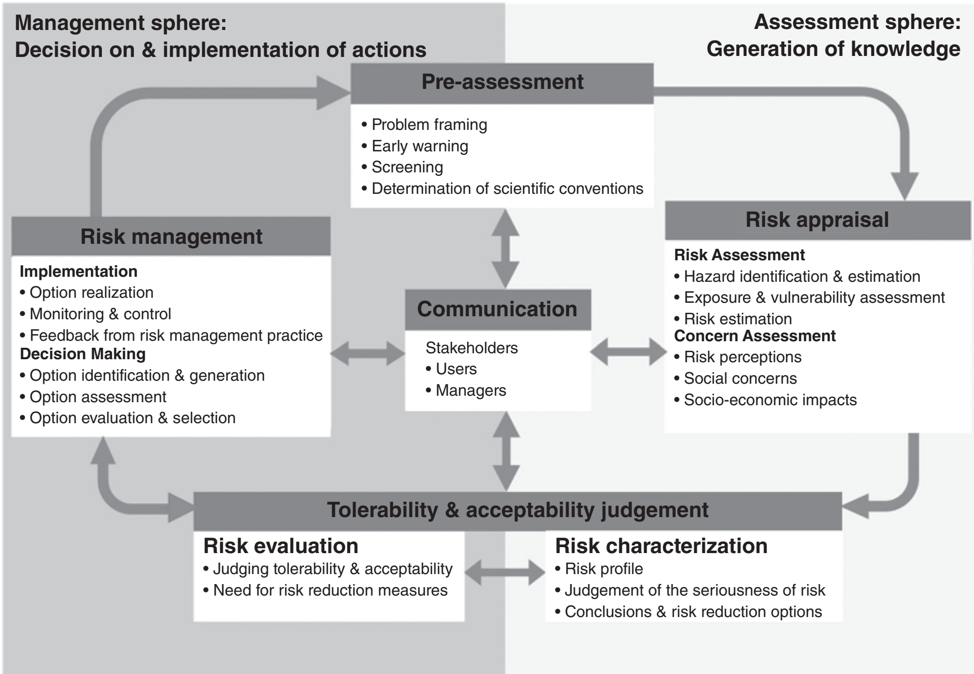

Figure 1.4 Framework for risk governance adapted from the International Risk Governance Council (IRGC, 2006).

the analysis of risk governance, for which the International Risk Governance Council (IRGC) has developed a framework of analysis. This framework (Figure 1.4) comprises five stages (IRGC 2006):

1. *Risk pre-assessment*. In this phase, the early warning and framing of the risk is conducted in order to provide a structured definition of the problem.
2. *Risk appraisal*. This stage combines a scientific risk assessment (of the hazard and its probability) with a systematic concern assessment (of public concerns and perceptions). It provides a concern assessment at different levels of society.
3. *Characterization and evaluation*. The representation of risk and its appropriation make it possible to assess its tolerability which supports the evaluation needs to reduce risks. This necessitates defining solutions to decrease risks and render them acceptable, tolerable (requiring mitigation), or intolerable (unacceptable).
4. *Risk management*. All the actions and remedies initiated to avoid, reduce, transfer, or retain risks are part of risk management.
5. *Risk communication*. In this phase, the authors consider all the solutions used by stakeholders and civil society to understand the risks and participate in the risk governance process.

Frameworks of both environmental and risk governance focus on actors' roles in the multilevel governance structure and their involvement in creating knowledge and implementing actions, from local to larger spatial scales. This explains why analysing the management of hydrometeorological extreme events addresses the following issues:

1. What is the available information on hydrometeorological extreme events?
2. How do actors represent hydrometeorological extreme events by considering all stakeholder categories?
3. What are the strategies and instruments implemented? What measures are taken before and after the events? Which instruments are favoured? Why?
4. What does this governance change in the effective management of past, present, and future uncertain hydrometeorological extreme events?

Based on the adaptive governance framework and risk governance framework, by combining theoretical approaches with national and local case studies, this book aims to point out success stories of multilevel governance decision-making processes for managing hydrometeorological extreme events, as well as present lessons learnt from difficult implementation processes. In doing so, this book presents a variety of points of view: legal, socio-political or more practical, without however attempting to model this wide range of diversified situations and points of view in a global model. Finally, it will issue some recommendations stemming from the cross analysis of the cases presented.

Notes

1. https://www.munichre.com/en/reinsurance/business/non-life/natcatservice/index.html. According to this service, hydrometeorological extreme events are part of meteorological events (tropical storms, extratropical storms, local windstorms) for coastal and windstorms; hydrological events (Flooding: river floods, flash floods and storm surges, wet mass movements) for floods and storm surges; climatological events (extreme temperature: both heatwaves, freezes and extreme winter conditions, droughts, wildfires) for droughts. This book does not concern geophysical events (earthquakes, tsunamis, volcanic activity, dry mass movements).
2. http://www.preventionweb.net/drr-framework/sendai-framework-monitor/indicators
3. https://www.eea.europa.eu/data-and-maps/data/european-past-floods
4. https://www.efas.eu
5. http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A52012DC0672
6. Directive 2000/60/EC, OJ L 327, 22.12.2000, p.1.
7. http://ec.europa.eu/environment/iczm/demopgm.htm
8. http://www.europeanwindstorms.org/expl
9. The papers presented in the book stem from the following European research projects (amongst others):
   Climb: www.climb-fp7.eu
   Starflood: http://www.starflood.eu
   Capflo: http://capflo.net
   DROP: http://www.nweurope.eu/about-the-programme/our-impact/challenge-5/the-drop-project

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