Chapter 1

Characterising and measuring droughts and floods

This chapter provides an overview of the meteorological, hydrological and socio-economic dimensions of drought and flood risks. It describes the approaches to characterise and assess these risks, and to measure their costs to agriculture and other sectors. It serves as a background for the economic and policy analysis developed in subsequent chapters.

1.1. The meteorological, hydrological and socio-economic dimensions of drought and flood events

One can consider three dimensions to characterise drought and flood events: meteorological, hydrological, and socio-economic, with each having a distinct set of indicators (for more details, see Box 1.1). Although distinct, these dimensions are nevertheless related (Figure 1.1). The most common indicators used are meteorological and hydrological indicators, as economic, social and environmental impacts are more difficult to assess and can vary a lot across affected people and regions. However, measuring impacts is important to assess the costs and benefits of mitigation strategies against flood and drought risks.[1]

At the source of droughts and floods, there is always a weather event or set of combined weather events. The meteorological dimension of droughts and floods basically focuses on, respectively, the deficit or excess of precipitation compared to reference values. Precipitation, either in excess or in deficit, is the main factor, but other variables such as temperature, humidity, air and soil, and wind also play a role. For example, in the case of the summer melting of glaciers that feed rivers downstream, temperature is a major factor driving river flows and potential flooding risk. Basic indicators of the meteorological dimension include, for example, percentage of normal precipitation, which is calculated as a ratio between current precipitation and a past historical average for a given period of time, but also with more complex indicators such as the Standard Precipitation Index.[2] Other characteristics are important to characterise meteorological floods and droughts, notably their time of occurrence, duration and spatial characteristics (location and spatial extent). Most often, floods relate to sudden events resulting from windstorms or heavy rain while droughts are considered as cumulative events over an extended period of time, from a few weeks to several months or even years. Drought characteristics vary a great deal across continents, countries, and regions, as illustrated by Figure 1.2 which presents the number and duration of major drought events between 1950 and 2000 at the continent level, with implications for the appropriate management of these risks.

Box 1.1. Defining droughts and floods

There are a large number of definitions of droughts and floods, from more abstract to more concrete, from more descriptive to more operational. Droughts and floods are indeed an object of study in a variety of disciplines such as meteorology, hydrology, agronomy, economics, sociology, psychology, and political science among others. In practice, water managers and policy makers need to rely on working definitions to plan their programmes and pilot their interventions in the course of action. Economists aim at measuring the costs of droughts and floods, which requires a different approach and eventually different indicators. Sociologists focus on topics such as the collective response to extreme events, such as crisis management. Definitions may therefore vary depending on objectives, local conditions and socio-economic contexts. There is no "one size fits all" definition of either droughts or floods.

Notwithstanding these complexities, droughts can be broadly defined as a temporary decrease of water availability in a given water system, caused by prolonged deviations from average levels precipitation. Drought essentially "differs from other natural disasters in the slowness of onset and its usual lengthy duration", which makes it difficult to determine the onset and duration of a drought event (European Commission, 2007; Wilhite, 2007). Drought is a normal and recurrent feature of climate, although it can evolve under certain circumstances into a disaster, depending mainly on the vulnerability of the affected society and its capacity to manage the impacts, and on the severity and duration of the event (Kampragou et al., 2011).

From a general point of view, floods can be defined as "rises, usually brief, in the water level of a stream or water body to a peak from which the water level recedes at a slower rate" (WMO and UNESCO, 2012). The main types of flood risk that affect agriculture are river floods, flash floods, and coastal floods. River flooding occurs when the river capacity system is insufficient to contain the flow of water in the river. Flash floods "arise from intense, localised rainfall, and can happen practically anywhere" (World Bank, 2010). Coastal zones are "subject to flooding as a result of storm surge-increased sea levels driven by tropical storms or by strong windstorms arising from intense offshore low-pressure systems" (World Bank, 2010).The impact of flooding on agriculture varies with crops' tolerance or land use activity, and the characteristics of the flood event (frequency, duration, depth and seasonality) (Morris et al., 2010).

Figure 1.1. Characteristics and impact of droughts and floods

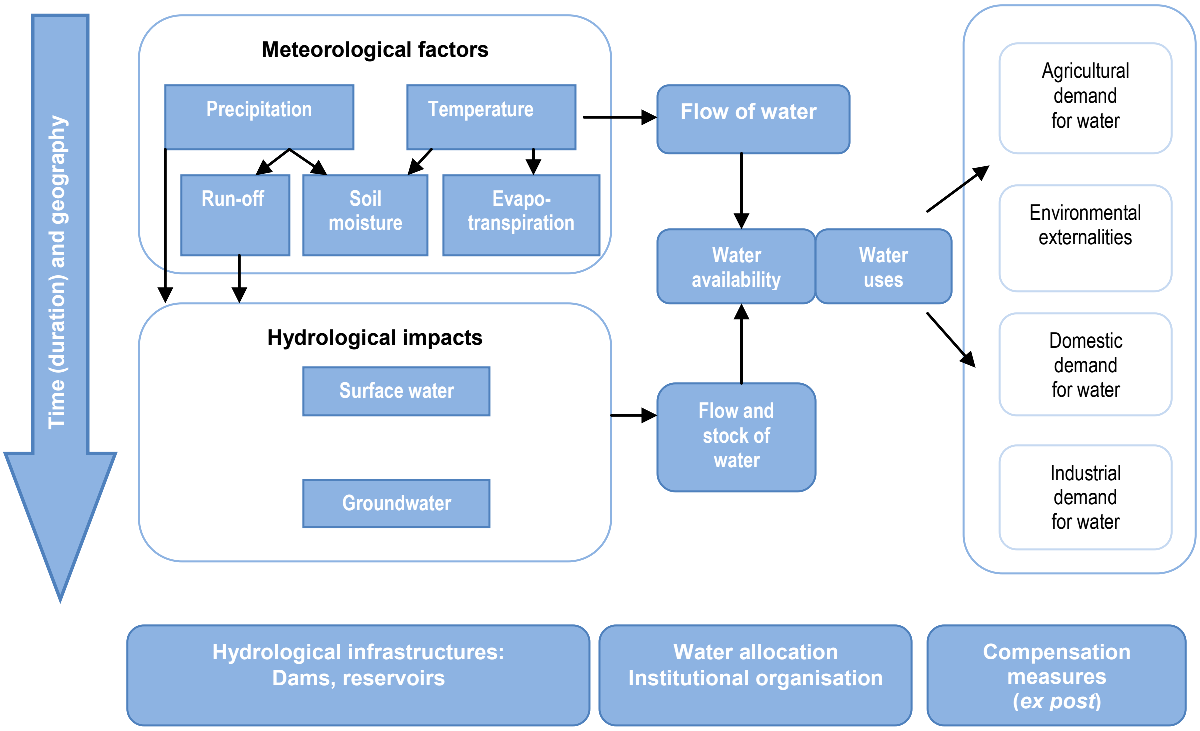
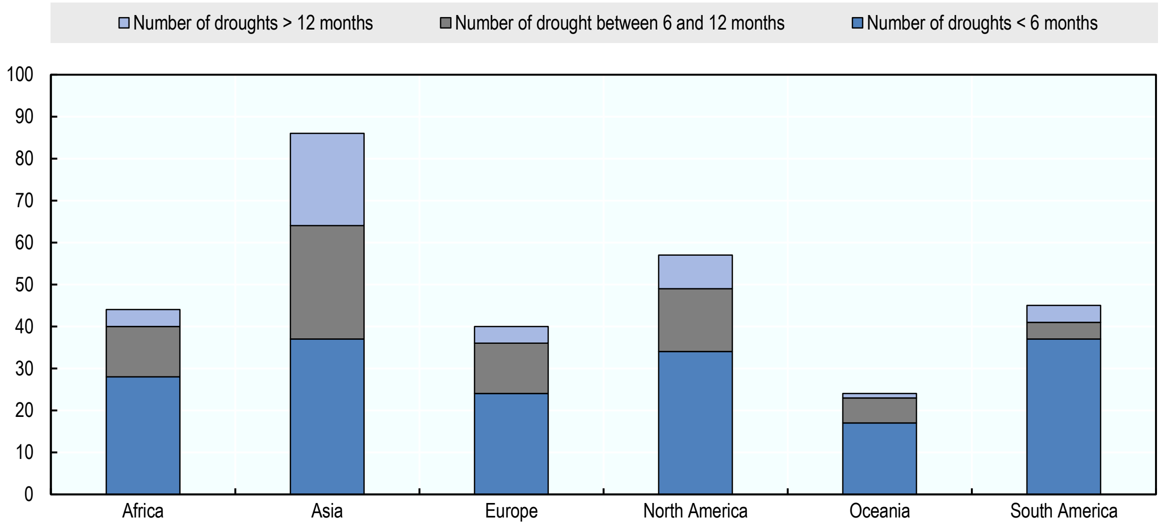


Figure 1.2. Number and duration of droughts in the different continents



Source: Based on Sheffield, J. et al. (2009).

The hydrological dimension of floods and droughts refers to the state of water resources in the different compartment of the water system. Basically, excess or deficit rainfall is transmitted to the different components: soils, surface water and groundwater. This transmission may have some time dependency and inertia; for instance, affecting soils first, then surface water, and lastly groundwater. The overall water availability for water users depends on the status of the stock and water flow in the different compartments of the water system. Measuring the state of hydrological systems can be done through the use of indicators: soil moisture, river flows, and levels of groundwater, lakes and dams. The state of water resources is not solely driven by meteorological conditions; rather it is the joint outcome of weather conditions and anthropic use of water: e.g. management of river banks, reservoirs, dams, land cover, and drainage which influence how deficit or excess rainfall is transmitted to hydrological compartments. Water systems are not just ecosystems, but socio-ecosystems.

These considerations lead to an important distinction. While floods are usually defined from a hydrological perspective, there is a net distinction between droughts, a meteorological notion, and water shortages, which relate to a short-run deficit between aggregate water use and aggregate water availability in a given water system. This means that not all droughts translate into water shortage events since it depends on the exposure and vulnerability of affected societies. Finally, water shortages should be distinguished from water scarcity, which corresponds to an aggregate deficit between water use and availability, and in the longer-term, to a structural perspective.

The economic, social and environmental dimensions of droughts and floods relates to the economic, social and environmental impacts of these extreme events. Economic impacts of droughts include direct damages faced by sectors that heavily rely on water for their production process such as agriculture, hydroelectricity, water intensive manufacturing and households. Floods most often affect the productive assets of households and different industries, with potential longer lasting negative impacts on production capacities. Droughts and floods may also have social implications, notably when they affect poorer and more vulnerable categories of the population. Finally, the environmental impact of droughts and floods can also affect the associated ecosystem services and thus social welfare. Examples of this include an increase in the erosion transfer of sediments and nutrients, which results in a decrease of water quality; the non-respect of minimum water flows during drought events can increase concentrations of pollutants as there is less dilution in water and be potentially damaging to aquatic life.

1.2. Assessing and characterising drought and flood risks

Formally, risks are typically characterised by probability distributions. Estimating the probability distribution of droughts and floods requires clearly defining the nature of the risk and the associated indicator that is being used to measure it. In this area, it is more common to focus on meteorological and hydrological indicators, as economic, social and environmental impacts are more difficult to assess and can vary widely across affected people, regions, and time.

There are a number of challenges in assessing the probability distribution of droughts and floods risk, including the following:

- Each drought or flood is to a certain extent unique in terms of spatial characteristics, intensity, impacts, etc. Thus estimating a risk distribution requires some standardisation of definitions which may be challenging in practice.
- Non-stationarity of exposure and vulnerability. Climate change, but also risk exposure, is non stationary: farmers change their cropping patterns over time; the composition of land cover is evolving between urban areas, agriculture, forests and other areas. This makes it difficult to

build a stable relation between a given meteorological event and its associated impact on human systems.

- For "catastrophic risks" or "extreme events", there are specific methodological challenges to risk assessment which makes it difficult to have reliable risk estimates, compared to more common or frequent weather events (Box 1.2).

Box 1.2. Assessing the probability of extreme weather events: A statistical challenge

Assessing the probability of extreme events is a statistical challenge. It is possible to use descriptive statistics, however the observed period of rainfall disasters might not include all possible extreme values because some critical droughts and floods events are so rare that they are not observed in the data sample. Extreme Value Theory (EVT) is one way to address this issue by providing estimations of the occurrence of values beyond the observed extremes (Reiss and Thomas, 2007). The principle of EVT is to calibrate a probability distribution on the flow of water (precipitation, discharge of water on river) and extrapolates the distribution function beyond the observed extremes. The extrapolation results can be used to analyse the probability of occurrence of events like droughts and floods that could not otherwise be observed. This approach has, however, limitations (Annex 1.A1).

Such methodology leads to an estimation of the frequency of an event of a given *size*. Usually these frequencies are expressed as return periods of extremes (or average waiting times between the occurrences of extremes of a fixed size). For example, a return period of a 100–year flood is defined as a flood that can occur on average once every 100 years. Although very long periods return values can be calculated from the fitted distribution, the confidence that can be placed in the results is reduced for very long return periods. Additionally, there are potentially large biases due to uncertainty in a climate change context.

In sum, in spite of specific statistical tools on the estimation of extremes, the management of extreme weather events such as droughts and floods must deal with considerable residual uncertainty. Non-stationary climate due to global warming adds another layer of uncertainty to this global picture. A change in the overall distribution of precipitation modifies the value of average precipitation. A shift in the precipitation distribution can greatly increase the likelihood of extreme values above the critical threshold on the left tail of the distribution. This means that the effect of a shift to the left implies less precipitation on average and more situations with extreme deficit* of precipitation.

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* "Deficit" means a level below a physical threshold, while the word "shortage" will be used to refer to a level below demand.

Another important issue associated with the definition and characterisation of droughts and floods is that of the "extreme", "catastrophic" or "disastrous" nature of these risks, especially as this may have implications in terms of policy responses to their management. While these three terms seem to be closely related, they are in fact very different. IPCC (2012) defines an "extreme weather event" as "the occurrence of a weather variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values and variables". This is essentially a statistical perspective, for which the range of extreme values in the probability distribution is respectively represented by the extreme right and left tails.

Such a statistical approach also means that extreme weather events are relative, based on a benchmark of what are considered as average or "normal" weather conditions. It often means that extreme weather events are characterised by low probabilities; however this ultimately depends on the overall shape of the probability distribution function. In some countries, extreme weather events can occur frequently, every five or even three years depending on the region considered. In these cases, it is inappropriate to speak about "extreme" weather events in that sense. Examples include severe droughts in Australia and Spain, which are considered as common weather conditions.[3]

While extreme weather events can be defined in an objective way, the notions of catastrophes and disasters are more subjective and convey very different meanings. Firstly, compared to the notion of extreme weather events, notions of "catastrophes" and "disasters" place more emphasis on the economic, social and environmental impact of climate events rather than their probability and meteorological features. Disasters are often measured in terms of human losses and monetary costs, or loss of biodiversity. The two concepts can coincide: extreme weather events are typically more likely to cause catastrophic economic, social and environmental damages, but this is not necessarily the case. The extent of the damage depends on the exposure and vulnerability of the affected system, which can vary across regions and depend on policy responses to manage droughts and floods. It can be also the case that poor management of moderate drought or flood events may result in catastrophic damages.

Secondly, the terms "catastrophes" or "disasters" have a strong subjective and emotional content, and are used in varying contexts. The term catastrophe or disaster can be applied equally well to a plane crash, an epidemic or to a poor harvest due to drought. Going a step further, one could say that the use of the word catastrophe is more of a prescriptive than descriptive nature. This can be illustrated in practice by the fact that in a number of countries, declaring an area in a state of natural disaster involves triggering exceptional specific responses, beyond the set of usual risk management tools. Calling an event a catastrophe is thus an act that defines the boundaries of risk management.

1.3. Assessing the costs of droughts and floods to agriculture and other sectors

Economic impacts caused by drought affect agriculture through losses in crop yields and livestock production, but also through increased insect infestations, plant diseases and wind erosion (European Commission, 2007). Droughts are rarely considered as a catastrophic event for the agricultural sector in OECD countries at the macroeconomic scale, although they can significantly affect the agriculture sector. Flooding is a significant hazard worldwide, with an estimated USD 700 billion of damages in the period 1985-2008 (Morris et al., 2010). Agriculture, however, by occupying a large proportion of the landscape, can be at once affected by flood risk, but also play a positive role in the overall mitigation of flood risks in water systems as a provider of floodplain areas, or through the influence of upstream agronomic practices reducing flood risk downstream (Morris et al., 2010).

Economic costs of droughts and floods in agriculture can be direct or indirect, instantaneous or induced (Brémond et al., 2013; Table 1.1). Direct and short-run costs typically include crop and livestock production losses. Direct but induced (longer term) impacts include losses of productive assets such as machinery and buildings, and declines in land value, which can reduce productivity in the longer run and may require significant resources for recovery. Indirect impacts can also be born outside the agriculture sector by related sectors or through agricultural markets. For example, a severe drought in a large commodity exporting country may cause a substantial drop in global agricultural production, leading to a rise in commodity prices at the world level. When insurance markets or compensation mechanisms are in place, the cost of droughts and floods can also be borne at a broader level by insurance policyholders or taxpayers depending on the risk sharing characteristics of these mechanisms.

Typically, direct and tangible costs, i.e. reduction in crop yield, are easier to quantify than are indirect, non-tangible costs such as loss in biodiversity or soil erosion and its associated impact on soil productivity (Meyer et al., 2012; Meyer et al., 2013). In some cases, direct tangible costs of droughts and floods may indeed just represent the "tip of the iceberg" as compared to the "real" (but unobserved) full cost of these weather events. Such heterogeneity in cost assessment is susceptible not only to lead to underestimation of the costs of droughts and floods, but also to be a source of bias in favour of sectors for which the cost estimates are more feasible. Caution is therefore necessary when it comes to comparing the costs of droughts and floods between countries and across time.

Another challenge is that the agriculture sector faces a variety of risks that can affect production and income: weather risks, pests and diseases, price risks (on both input and output sides), institutional risks (due to changes in regulations or policy environment). The relative importance and combination of these risks can vary a great deal across countries and farming systems, which can explain different kinds and degrees of policy responses to address them (OECD, 2011). The impact of droughts and floods on farmers' income should be considered thus holistically. Risks can be positively correlated; for example, drought or flood conditions may increase the risk of pests and diseases in some cases, and thereby aggravate crop losses. However, one can observe in some countries a negative correlation between yield and price risks which can, to a certain extent, offset each other in the formation of farmers 'incomes (OECD, 2011). In certain cases, such income can increase if the price swing more than compensates yield losses, and risk is transferred through prices in the value-chain of agricultural commodities.

Without a systematic and harmonised method to assess the costs of droughts and floods in agriculture, one has to rely on case-by-case evaluations. For example, the 1976 drought in France reduced farmers' income by 9% compared to more typical years; the 2005 drought lead to a 22% decrease in farmers' income compared to 2004 (Amigues et al., 2006). Drought is quantitatively the most important risk in France, representing on average 57% of indemnities paid by the French National Guarantee Fund for Agricultural Disaster Risks (Babusiaux, 2000). For some of the most important droughts of the last 40 years, price increases have in a few cases slightly offset yield losses, but external drivers of commodity prices seemed to have been more important drivers than the production failure itself.

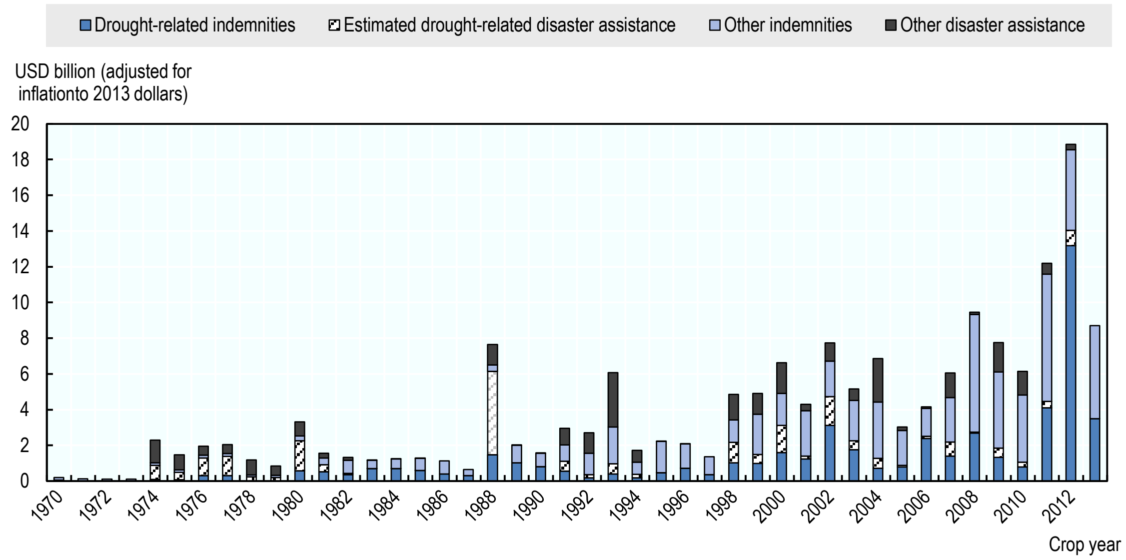
Table 1.1. Cost of floods and droughts to agriculture sector

Floods		
	Instantaneous (short-run)	**Induced (medium to long-run)**
Direct	Human fatalities Damage/destruction of economic goods Emergency costs Fatalities to livestock Damage/destruction of infrastructure	Loss of value added due to damages on production factors Rehousing of households Relocation of livestock
Indirect	Increase in travel time due to damage on infrastructure Delay or cancellation of supply from the flooded area (e.g. inputs, machinery)	Loss of value added due to business interruption of assets in the flooded area Loss of value added due to damage on infrastructure (Re)financing costs, borrowing costs
Droughts		
Direct	Damage/destruction of economic goods Negative impacts to livestock production and health Reduced yield and crop acreage for agriculture due to drought related water shortage	Loss of value added due to damages on production factors, e.g. soil Relocation of livestock
Indirect	Higher cost or irrigation water pumping or water prices Cost of buying additional external feed due to reduced pasture production Increasing cost of farming operations due to inappropriate soil conditions or excessive heat	Loss of value added due to business interruption of assets Loss of value added due to damage on infrastructure (Re)financing costs, borrowing costs

Source: Based on Brémond, P., F. Grelot, and A.-L. Agenais (2013). www.nat-hazards-earth-syst-sci.net/13/2493/2013/nhess-13-2493-2013.pdf.

Figure 1.3. Crop insurance indemnities and disaster assistance payments in the United States, 1970-2013

USD billion 2013



Source: Wallander et al. (2013), www.ers.usda.gov/media/1094660/err148.pdf.

In the United States, drought is the primary risk for agricultural production, although exposure can vary a great deal across states. On average, drought risk has been estimated to represent about 40% of crop insurance indemnity payments made between 1948 and 2010 (Wallander et al., 2013). Figure 1.3 presents the crop insurance indemnities and disaster assistance payments for droughts and other weather events since 1970, illustrating the importance of this risk. The 2011-2012 droughts in United States led to unprecedented levels of compensation compared to previous years, although the increasing scale of the programme also explains their upward trend. The 2014 drought in California also had large costs for agriculture and other water users and uses. In terms of price effects, one can observe a significant negative price-yield correlation, especially in the Corn Belt, providing a partial natural hedge for farmers’ revenues (Harwood et al., 1999).

A lack of comprehensive knowledge of the costs of droughts and floods is a barrier to the improvement of policy approaches to managing these. In particular, it does not allow to undertake sound cost-efficiency or cost-benefit analysis that could provide useful guidance to citizens, stakeholders and decision-makers. The lack of data and knowledge is not the single barrier: even from a methodological perspective, cost-benefit analysis is more complex when introducing risk and uncertainty. Lack of data on costs is not only an issue for *ex ante* assessment, but also can be used as decisive arguments in the course of action. For example, in a negotiation process for water restrictions between different waters users (agriculture, industry, tourism) and uses (environmental flows), using cost figures in monetary terms is a powerful rhetorical tool during the bargaining process; however, it may ultimately lead to inefficient water allocation or favouring short-term mitigation efforts over long-run sustainability.

In view of these methodological and data limitations, some encouraging progress is being made. For example, the European project *Cost of Natural Hazards* (Meyer et al., 2012) funded by the EU *Seventh Framework Programme for Research and Technological Development* (FP7, 2007-2013) undertaken between 2010 and 2012, conducted a state-of-the-art assessment of costs of natural hazards such as droughts and floods. It also analysed their appropriate use in cost-benefit analysis of mitigation and prevention strategies, and identified the main data and methodological gaps (Meyer et al., 2012). The scope was not limited to agriculture but all sectors concerned by natural hazards. The report proposed a comprehensive set of recommendations to expand and improve the assessment of the costs of natural hazards, including specific advice on droughts and floods with a view to better integrate this information in decision-making.

Finally, there are linkages between the meteorological and hydrological dimensions of floods and droughts and their impact on water users and uses, which can be measured by the effects of the water shortage or excess in terms of financial and economic losses to farmers.[4] The physical characteristics of droughts and floods, such as the time of occurrence, duration and spatial extent, have strong implications on the economy. Timing is important: droughts or floods that occur outside a critical vegetation period will have less economic impact. The spatial scale is important to evaluate agricultural impacts as some agents may be adversely affected as a result of spatial correlation. Spatial correlation risk exists when extreme weather events affect large geographical locations at the same time, causing wide-scale damage to agricultural production. The spatial extent and severity of droughts will vary seasonally and annually, whereas the spatial extent of floods is more predictable when using topographic information.

Notes

1. It is not the purpose of the present report to make an extensive review of the definitions of droughts and floods, but to focus on the elements that are meaningful for good policy approaches to manage, mitigate and cope with these risks in the short and long term.
2. The Standard Precipitation Index measures the relative rarity of a drought event in terms of cumulative rainfall at a given location, for a given period of time. It is adjusted statistically using the gamma distribution.
3. At the polar case, when drought conditions are permanent, one speaks of aridity.
4. Correlations between weather events and damages are often difficult to model, except for the most catastrophic events. Assessments of damages caused by floods of short duration, such as damages to field crops, can be undertaken immediately by a physical inspection. In the case of droughts, a set of statistical studies undertaken in the 2000s analysed the influence of climatic parameters — rainfall, temperature, soil moisture — on crop yields. They showed that a limited number of climatic variables, especially the sum of degree-days, are able to explain a significant proportion of crop yields. In addition, they identified thresholds beyond which crop yields decline drastically (Ortiz-Bobea, 2013; Roberts et al., 2013). These studies are mainly used to project the impact of climate change on crop yields, rather than for a practical estimation of crop losses for, notably, indemnification purposes.

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Annex 1.A1

Statistical theory of extreme values

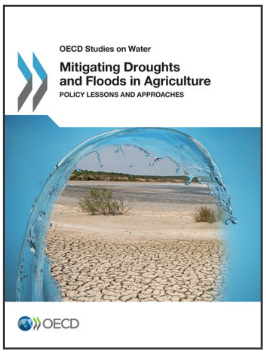
The Peak Over Threshold and Block Maxima approaches are two methodologies derived from the extreme values theory to assess probabilities of extreme events. They are different by the way they select extreme events in the data sample and by the distribution probability which is applied according to their separate methodology.

The *Block Maxima approach* requires that the maximum value observed in each time span (time span is arbitrary selected, e.g. weeks, months) be selected. This approach consists of representing the extreme values by the Generalised Extreme Value (GEV) distribution (combination of the Gumbel, Fréchet, and Weibull maximum extreme value distributions). The *Peak Over Threshold (*POT*)* method considers values greater than a defined threshold and is based on the Generalized Pareto Distribution (GPD) distribution (Reiss and Thomas, 2007).

The main drawback of the *maxima* approach is that events are selected for every single year of measurement. Peak over threshold selects extreme values for every value above a defined threshold and it has proven to be more flexible than block maxima methods. However, the choice of threshold in selecting extreme values is an important practical problem, which is based on a trade-off between bias and variance. The threshold must at once be high enough for the excess over the threshold to follow GPD and allow for a large enough sample size (Reiss and Thomas, 2007; Klein Tank, Zwiers and Zhang, 2009).

Both methodologies require the assumption of independent and identically distributed events, e.g. the sampling does not select two “nearby” maxima which relate to the same larger flood mechanism. But many environmental variables (temperatures, precipitation, wind speed) are temporally correlated and there are seasonal and long term trends. The assumption of independence can be relaxed by dealing with cluster maxima instead of all exceedances in the POT method, and one way to relax the assumption of identical distribution is to allow the parameters of the Poisson–GP model depend on covariates (e.g. annual or diurnal cycles).

The extrapolation or forecasting of extreme values techniques relies on imposing a probability distribution law and then inverting this distribution to calculate frequency (Reiss and Thomas, 2007).



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