Chapter 3

Understanding disaster risk: hazard related risk issues

SECTION III

Meteorological, climatological and biological risk

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3 Understanding disaster risk: hazard related risk issues

Section III. Meteorological, climatological and biological risk

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3.9 Climatological risk: droughts

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3.9.1 Introduction

Drought is one of the most complex and severe weather-related natural disasters and its causes and multifaceted impacts are often not well understood. Droughts can last from a season to multiple years, and even decades, and cover small watersheds to hundreds of thousands of hectares. In Europe, drought is a recurrent phenomenon, affecting extended areas and large populations annually (Vogt and Somma, 2000). Across the world, millions of people are annually exposed to droughts that seriously affect economic development and environment. While fatalities mainly occur in poor economies, even in more prosperous regions many people die as a result of indirect effects (e.g. Tallaksen and Van Lanen, 2004; WMO and GWP, 2014). In Europe, almost 80 000 excess fatalities as a result of heatwaves (see Chapter 3.8) and forest fires (see Chapter 3.10) associated with droughts were reported over the period 1998-2009 (EEA, 2011).

UNESCO notes that drought can have economic consequences that can go far beyond the immediately impacted areas, such as persistent unemployment and threats to food security, regularly leading to forced migration and social instability (WWAP, 2016). The World Economic Forum (2015) labelled the water crisis as first on the list of factors with a risk of severe impacts for the global community. As one of the reasons for this crisis, drought is likely to become more frequent and severe in the 21st century in many regions of the world, especially in already water-scarce and vulnerable areas, including parts of Europe (IPCC, 2012, 2014).

The key challenge is to move from a reactive society fighting impacts to a pro-active society that is resilient and adapted to the drought risk, for example through the adoption of pro-active risk management (WMO and GWP, 2014; Wilhite et al., 2014). This chapter demonstrates that this requires practitioners, policymakers and scientists to collaborate and use a consistent set of definitions and characteristics. Observed and projected trends in drought as a natural hazard need to be understood.

Drought is a recurrent phenomenon that affects extended areas and large populations, putting societies and the environment at risk in many regions of the world.

The hazard has to be connected to its manifold primary and secondary impacts (e.g. on public water supply, food security, energy production, waterborne transport, health, ecosystems). Current, but also future, societal exposure and context-specific vulnerability must be identified to assess drought risk. If all of these aspects are known, drought risk can be managed through a set of institutional, structural and operational measures, including monitoring and medium-range to seasonal forecasting.

3.9.2 Drought definition and characteristics

From a climatic point of view, a drought results from a shortfall in precipitation over an extended period of time, from the inadequate timing of precipitation relative to the needs of the vegetation cover, or from a negative water balance due to an increased potential evapotranspiration caused by high temperatures. This situation may be exacerbated by strong winds, atmospheric blocking patterns and antecedent conditions in soil moisture, reservoirs and aquifers, for example. Droughts can also be triggered in cold climates by temperature anomalies (Van Loon and Van Lanen, 2012; Van Loon et al., 2014). If this situation leads to an unusual and temporary deficit in water availability, it is called a drought. Droughts are to be distinguished from aridity, a permanent climatic feature, and from water scarcity, a situation in which the climatologically available water resources are insufficient to satisfy long-term average water requirements (e.g. Tallaksen and Van Lanen, 2014).

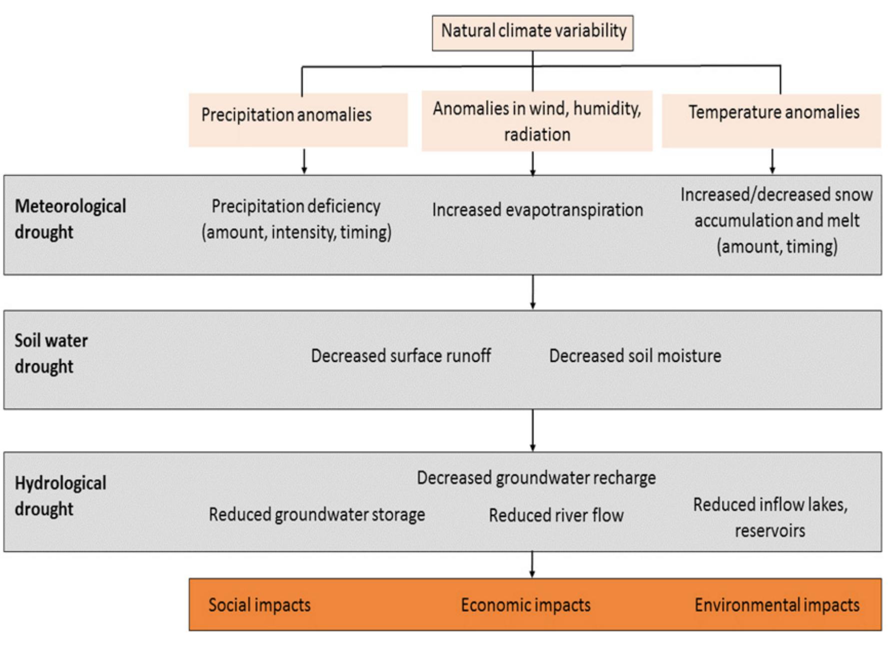
Depending on the prevailing effects on the hydrological system and the resulting impacts on society and environment, droughts can be distinguished in terms of meteorological, soil moisture and hydrological factors (groundwater, streamflow, reservoirs) (Figure 3.34 and Box 3.1). The definition of a drought, therefore, will depend on the sector analysed and the related processes and impacts. Finally, the feedbacks between the hydrological cycle and society must be considered (Van Loon et al., 2016). The impacts of drought point to a multitude of drivers that turn lower than average precipitation, limited soil moisture and low water levels into disaster events for vulnerable communities and economies (UNISDR, 2011).

Droughts can be characterised in terms of their onset, duration, severity (accumulated deficit over the entire event) and intensity (total deficit divided by duration).

Standardised indices are used to analyse droughts in different domains of the water cycle (e.g. precipitation, climatic water balance, soil moisture, river flow, groundwater). Among the meteorological indicators, the Standardized Precipitation Index (SPI, McKee et al., 1993) and the Standardized Precipitation-Evapotranspiration Index (SPEI, Vicente-Serrano et al., 2010) are the most well-known. The SPI is a probabilistic measure of the severity of a dry event (WMO, 2012). It can be calculated for different rainfall accumulation periods (e.g. 1-48 months) and statistically linked to impacts in different economic and environmental sectors. The SPEI has similar characteristics but includes potential evapotranspiration. Recent studies have shown that including the potential evapotranspiration can provide useful drought early warning indicators (McEvoy et al., 2016), al-

FIGURE 3.34

Drought Types: Generating Processes and Impacts
Source: adapted from NDMC and Van Loon (2015)



though some weaknesses occur when the potential evapotranspiration is calculated with temperature-based approaches (e.g. Thornthwaite) in dry, hot regions. Use of SPI and SPEI in cold regions has some limitations, because these indices do not distinguish between rain and snow, which affects the water availability over the year (snow accumulation and melt). Soil moisture-related indicators such as the Soil Moisture-based Drought Severity Index (Cammalleri et al., 2016) or the Palmer Drought Severity Index (Palmer, 1965) aim to characterise the impact on plant water stress; although no specific plant characteristics are included. Hydrological indicators are often based on threshold approaches to quantify the volume of water deficit in rivers and reservoirs (Yevjevich, 1967; Hisdal et al., 2004; Van Loon and Van Lanen, 2012). Finally, combined indicators blend several physical indicators into an indicator of hazard (e.g. US Drought Monitor (Svoboda et al., 2002); Combined Drought Indicator (Sepulcre Canto et al., 2012)).

Drought differs from aridity and water scarcity, and different drought types and associated indices have to be analysed to quantify the multiple drought impacts.

The World Meteorological Organization and Global Water Partnership (2016) have recently published the Handbook of Drought Indicators and Indices, providing structured information on commonly used drought indicators for identifying the spatial extent, onset, duration and severity of drought events. This information supports drought practitioners in selecting appropriate indicators for drought monitoring and early warning as an integral part of risk- based drought management policies and preparedness plans.

3.9.3 Past trends and future projections

Historic trends and future projections of meteorological droughts in Eu-

BOX 3.1

Drought types

Drought types:
Depending on the effect in the hydrological cycle and the impacts on the society and environment, different drought types are commonly distinguished:

Meteorological Drought:
A deficit in precipitation or climatological water balance (i.e. precipitation minus potential evapotranspiration) over a given region and defined period of time with respect to the long-term climatology. It is characterised based on measured and estimated climate variables (e.g. precipitation, temperature, evapotranspiration).

Soil Moisture or Agricultural Drought:
Characterised by reduced soil moisture resulting in a deficit in water supply for agricultural crops and natural vegetation and impacts on crop yield and biomass production. A higher risk for forest fires, due to the accumulation of dry biomass, is another important impact.

Hydrological Drought:
Characterised by reduced streamflows, lake levels, and groundwater reservoirs. Time-series of these variables are used to analyse the occurrence, duration and severity of hydrological droughts that have, for example, impacts on public water supply, energy production and inland water transport.

rope have been investigated by Spinoni et al. (2015a,b, 2016a, 2017) using a combination of indicators based on precipitation and temperature from the E-OBS dataset (Haylock et al., 2008). The analysis considers droughts at seasonal and annual timescales and covers the period 1951-2015 (trend analysis) and 2041-2100 (future projections), the latter of which is based on the EURO-CORDEX multimodel ensemble (Jacob et al., 2014) and moderate (RCP4.5) and extreme (RCP8.5) climate scenarios.

Drought frequency increased in southern and western Europe, but decreased in other parts of Europe. However, an increased frequency is projected, particularly in summer, for most of Europe.

Figure 3.35 demonstrates that in the past six and a half decades northern and eastern Europe experienced a decrease in drought frequency and, less prominently, in drought severity (not shown), while southern and western Europe experienced an increase in drought frequency and severity, particularly over the Mediterranean region (see Hoerling et al., 2012; Gudmundsson and Seneviratne, 2015; Stagge et al., 2016). The noted increase in drought frequency and severity is more widespread when analysing the SPEI, which includes the effect of increasing air temperature on potential evapotranspiration (Spinoni et al., 2015b; Touma et al., 2015; Stagge et al., 2016).

With respect to seasonal droughts, the decrease of drought frequency over northern Europe is more evident in winter, while the increase over southern Europe is more evident in summer.

Figure 3.36 shows that the described past drought tendencies are likely to persist in future decades for the winter months, while in the other seasons – especially summer – the whole of Europe (excluding parts of Iceland and Scandinavia) is projected to experience an increase in drought frequency, in particular during the last decades of the 21st century. At annual scale, and according to both climate scenarios, the drying tendencies over southern and western Europe are projected to become even stronger, with the Mediterranean region being particularly strongly affected (Spinoni et al., 2017; Stagge et al., 2015b). The effects of the projected temperature increase on meteorological droughts are likely to outbalance the effects of the projected precipitation increase over northern Europe and partly over eastern Europe, resulting in more frequent droughts for both scenarios in these territories by the end of the 21st century. The combination of these effects is likely to result in more severe droughts over northern Europe according to the extreme scenario (RCP8.5), while according to moderate scenario (RCP4.5), severity is not likely to increase in this region. The projections are considered to be robust with good agreement between the suite of GCM and RCM models.

At the global scale, past changes in drought frequency and severity are still under debate. Sheffield and Wood (2008) and Sheffield et al. (2012) analysed past global and regional trends using a soil moisture-based drought index for the period 1950-2008. Their results indicate that on a global level only small changes in drought occurrence and extent can be detected over the past 60 years. However, on a regional level, significant drying trends can be seen for parts of the Mediterranean and North, West and Central Africa, as well as for parts of East and Northeast Asia, while in the northern hemisphere and in parts of South America and Australia wetting trends are prevailing. These results are largely confirmed by Spinoni et al. (2014) who analysed meteorological drought frequency, duration and severity over the period 1951-2010. Orlowsky and Seneviratne (2013) investigated future meteorological and soil moisture drought around the world using a multimodel set of CMIP5 simulations. Their results hint towards more frequent soil moisture droughts by the end of the 21st century, especially in South Africa and Central America/Mexico and the Mediterranean. While highlighting the aggravating effect of global warming on droughts, Trenberth et al. (2014) underline the importance of reliable precipitation datasets and the data used to determine the evapotranspiration component in order to avoid conflicting results.

Streamflow drought originates from a temporary deficiency in precipitation and/or from temperature anomalies over a large area that can be further aggravated by other climatic factors, like strong winds or low relative humidity (Tallaksen and Van Lanen, 2004). Long-term precipitation reduction may further aggravate streamflow droughts through the depletion of groundwater and the subsequent decrease in baseflow. In addition, anthropogenic drivers, such as intensive water use and poor water management, can exacerbate low-flow conditions in watersheds, leading to a consequent increase in vulnerability to streamflow drought (Vörösmarty et al., 2000; Döll et al., 2009; Wada et al., 2013).

Trends in historic annual river flow in Europe confirm the patterns in meteorological drought with drying trends in southern and eastern regions of Europe, and generally wetting trends elsewhere (Stahl et al., 2010, 2012). They found positive trends (wetter) in the winter months in most catchments. A marked shift towards drying trends was observed in April, gradu-

FIGURE 3.35

Drought frequency trends between 1951 and 2015, expressed as the number of events per decade: left to right, winter, summer, annual. In dotted areas trends are significant at the 95 % level
Source: adapted from Spinoni et al., 2017

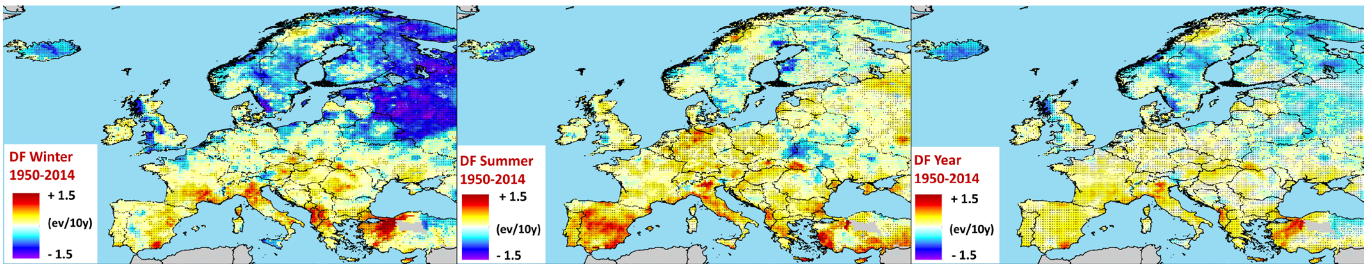
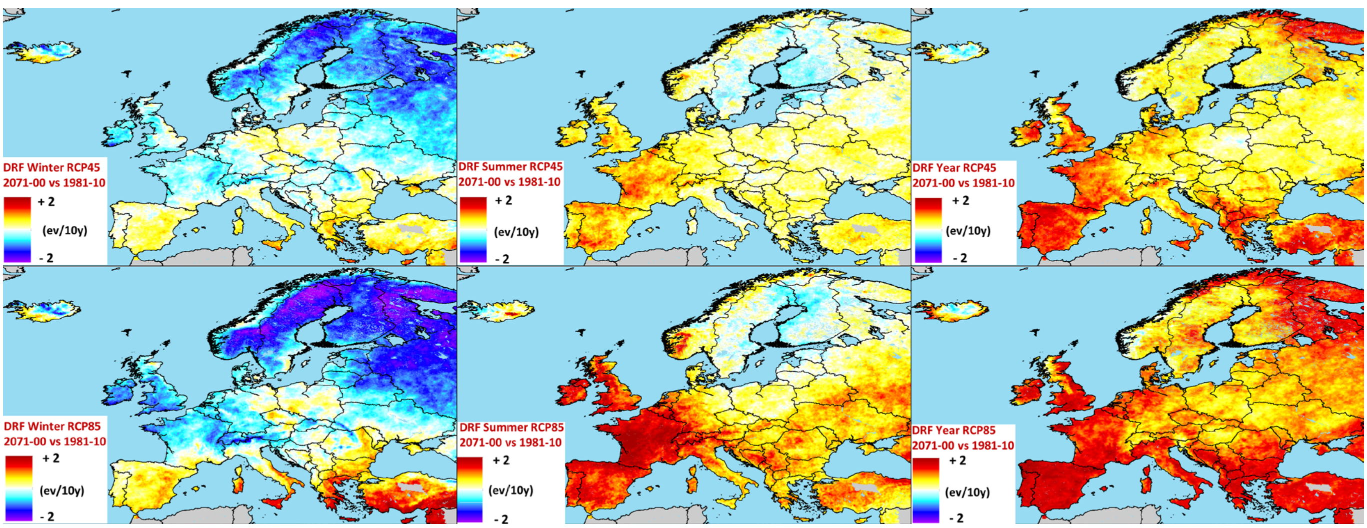


FIGURE 3.36

Drought frequency differences between the far future (2071-2100) and the recent past (1981-2010), expressed as the number of events per decade: left to right, winter, summer, annual; upper row scenario RCP4.5, bottom row RCP8.5
Source: adapted from Spinoni et al. 2017

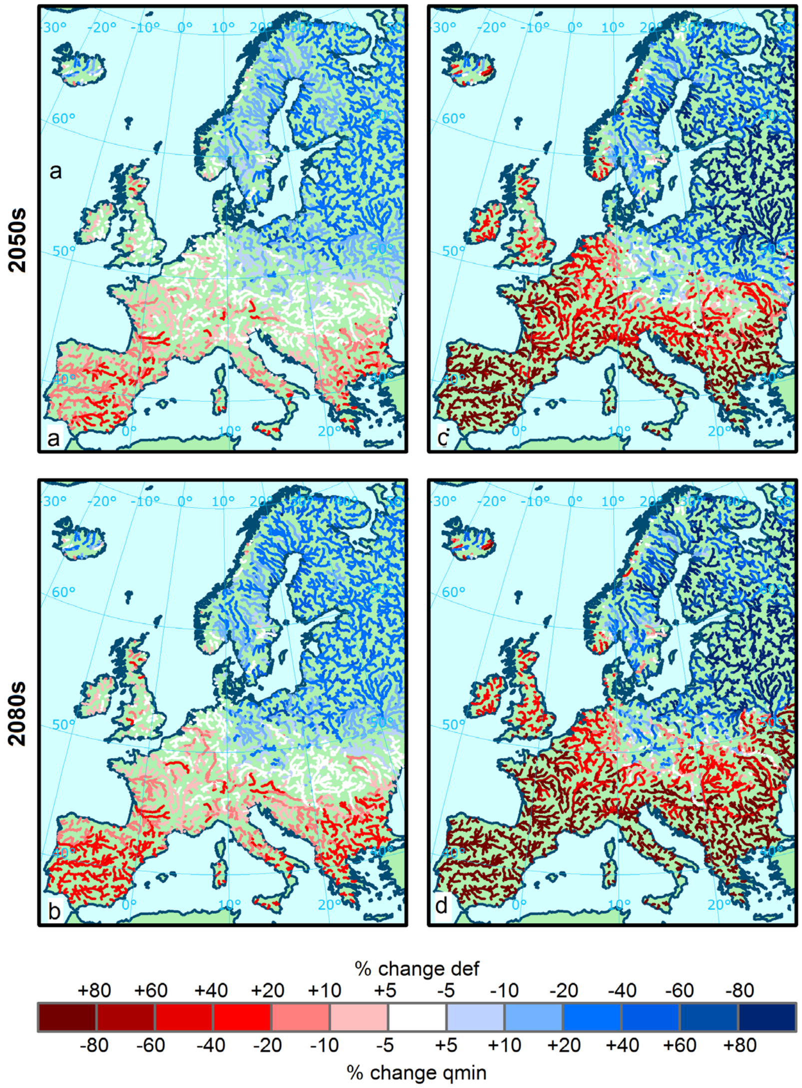


ally spreading across Europe to reach a maximum extent in August. Low flows have decreased in most regions where the lowest mean monthly flow occurs in summer, but vary for catchments that have flow minima in winter. Hannaford et al. (2013) show that trends are sensitive to the selected period (sign may change) owing to decadal climate variability.

Global changes in climate and socioeconomic patterns are expected to affect the development in space and time of river low flows (IPCC, 2012). Many river basins in Europe are likely to be more affected by severe water stress. Projected changes presented in different studies depend on the chosen drought indices (e.g. minimum flow, streamflow deficit), climate scenarios, temporal and spatial resolution of the climate signal and the hydrological representation. However, some coherent patterns emerge. Research studies based on multimodel ensemble climate and hydrological projections show consistent drought intensification both in terms of magnitude and frequency in south-western Europe. The main drivers are reduced precipitation and increased potential evapotranspiration. River low flows in these regions are expected to increase in severity by up to 40 % (Feyen and Dankers, 2009; Forzieri et al., 2014; Roudier et al., 2015) and current 100-year events could occur every 2 to 10 years (Lehner et al., 2006). The 20-year event of the river deficit volume is expected to increase by over 50 % both in the Mediterranean and European mid-latitudes by the end of the century (Figure 3.37). In contrast, northern regions of Europe will probably experience less severe hydrological droughts as a result of expected increased precipitation, which will outweigh the effects of higher evapotranspiration. In north-eastern Scandinavia and northern Russia, deficit volumes are expected to become more than 50 % lower. The projected changes are less clear in a transition zone (Forzieri et al., 2014; Roudier et al., 2015) because of the high climate uncertainty in changes in precipitation patterns.

FIGURE 3.37

Future projections of river flow in Europe. Percent change in 20 year events of minimum flow (qmin, left) and deficit volumes (def, right) in the 2050s and 2080s relative to the control period (1961-1990)
Source: adapted from Forzieri et al. (2014)



The spatial drought patterns in Europe are confirmed by global studies on future hydrological drought by Prudhomme et al. (2014) and Wanders and Van Lanen (2015). The Caribbean and South and Central America are other hotspots where river flow is projected to be substantially affected, which is in line with the projected soil moisture decrease (Orlowsky and Seneviratne, 2013).

Future water consumption for domestic use, tourism, energy, manufacturing, agriculture and livestock sectors (Kämäri et al., 2011) will aggravate streamflow drought conditions by 10-30 % in southern, western and central Europe. Some regions (e.g. Eastern Europe) that are subject to little or small positive impacts of climate change could manifest a reversion of this trend by intensive water use, showing more severe drought situations (Forzieri et al., 2014). Wanders et al. (2015) illustrate in a global analysis that future drought impacts are very much dependent on the extent to which society will adapt to the gradually changing hydrological regime.

Droughts are likely to experience a much faster increase in severity and frequency of extreme events than other climate-related hazards, such as river floods, windstorms, wildfires and cold waves (Forzieri et al., 2016); thus, future impacts are expected to represent a major threat for society and the environment.

3.9.4 Drought impact

3.9.4.1 Drought impacts on society and environment

Drought impacts affect almost all parts of the environment and society. Unlike other natural hazards such as floods, earthquakes or hurricanes that result in immediately visible, mostly structural, damage, droughts develop slowly. Frequently, drought conditions remain unnoticed until water shortages become severe and adverse impacts on environment and society become evident. Drought impacts may be influenced by adaptive buffers (e.g. water storage, purchase of livestock feed) or can continue long after precipitation has returned to 'normal' (e.g. owing to groundwater or reservoir deficits). The slowly developing nature and long duration of drought, together with a large variety of impacts beyond commonly noticed agricultural losses, typically makes the task of quantifying drought impacts difficult (Wilhite, 2005b).

Quantification is, however, an important task, because, of all weather extremes, droughts have one of the largest impacts on society. Economic damage from drought events can be catastrophic, with a single drought event capable of causing billions of euros of damage (EC, 2007; EEA, 2011).

The impacts of droughts can be classified as direct or indirect (Tallaksen and Van Lanen, 2004; Meyer et al., 2013, Spinoni et al., 2016b). Examples of direct impacts are limited public water supplies, crop loss, damage to buildings due to terrain subsidence and reduced energy production. Indirect impacts relate to the secondary consequences on natural and economic resources. They may affect ecosystems and biodiversity, human health, commercial shipping and forestry. In extreme cases, drought may result in temporary or permanent unemployment or even business interruption and lead to malnutrition and disease in more vulnerable countries (Hiller and Dempsey, 2012). Figure 3.38 schematically illustrates possible direct and indirect social, economic and environmental impacts. Because of their very nature (i.e. the dependence of livelihoods and economic sectors on water), most drought impacts are indirect. These indirect effects can propagate quickly through the economic system, affecting regions far from the origin of the drought (Wilhite, 2002).

Drought impacts society and the environment (e.g. public water supply, agriculture, energy production, infrastructure, shipping, forestry, ecosystems and human health). Impact quantification is a prerequisite for drought management and policymaking.

Since droughts affect socioeconomic systems directly or indirectly, their damage may be tangible (market related) or intangible (non-market related). The latter are particularly difficult to quantify as they include, for example, ecosystem degradation or the costs of mitigation and long-term adaptation measures. Impacts of droughts usually cascade. For instance, a lack of water causing crop losses will subsequently prevent farmers from investing in new machinery, resulting in losses to the farm equipment dealer and producers in the business chain. As a consequence, governments may have to provide aid to the different sectors. As droughts often affect large areas, sometimes over several years, these cascading impacts can affect large parts of society. If drought is severe and widespread, impacts may spread further in the community, as well as to other sectors and regions.

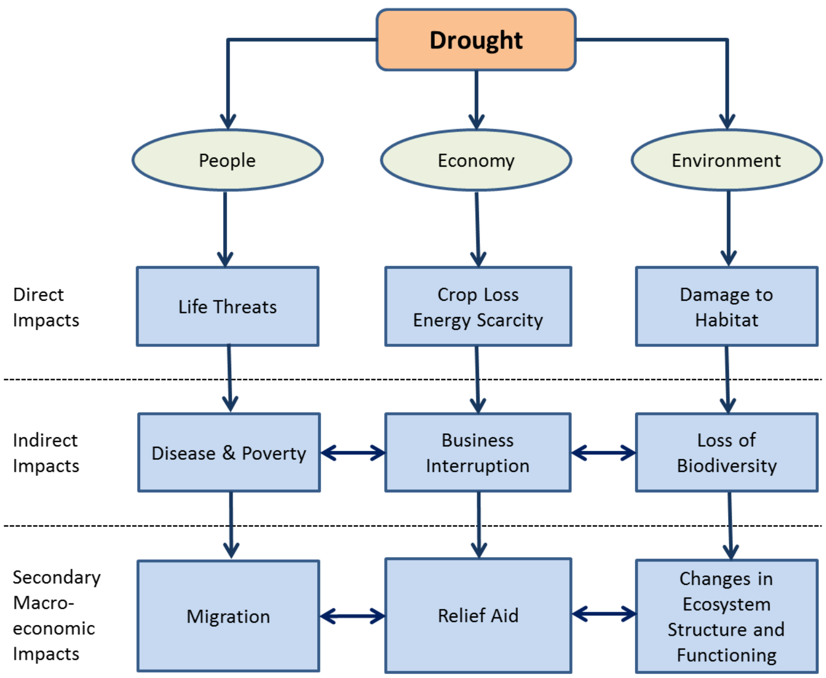
To foster risk management and adaptation strategies, drought impacts and the resulting damage and economic losses must be functionally linked with the monitored drought severity. Gudmundsson et al. (2014), Bachmair et al. (2015), Blauhut et al. (2015 and 2016), Naumann et al. (2015) and Stagge et al. (2015a), among others, have tested modelling approaches that link drought indicators such as SPI, SPEI, soil moisture, streamflow, groundwater and vegetation-related indicators to reported impacts. All studies conclude that a more quantitative monitoring of impacts and more research towards the quantification of the complex damage caused by drought is needed to improve such estimates. A survey by Bachmair et al. (2016) shows that many providers of EWSs do monitor impacts, but this is not yet done systematically or quantitatively. The variable strength of the relationship between drought severity and recorded damage can often be explained by the sector-specific drought vulnerability and the adaptive capacity of the region affected.

The overall expected damage, estimated by HELIX (2016) and based on the combination of the observed impacts and estimated changes in the recurrence time of severe droughts, are projected to increase in the near future. In some regions such as southern Europe, Southeast Asia, eastern North America and south-east South America, damage could increase from twofold in the near future to tenfold in the far future compared with today (Figure 3.39).

These scenarios suggest that drought risk may increase for many economic sectors and vulnerable regions unless appropriate mitigation and adaptation measures are implemented. Since many regions with high population densities and, often, vulnerable societies relying on local agricultural production show large expected losses in Figure 3.39, they remain a high priority to target better impact monitoring and quantification as a basis for drought management and adaptation.

FIGURE 3.38

Schematic presentation of examples of drought impacts and their interrelations
Source: adapted from Jenkins (2011)



3.9.4.2 Health impacts

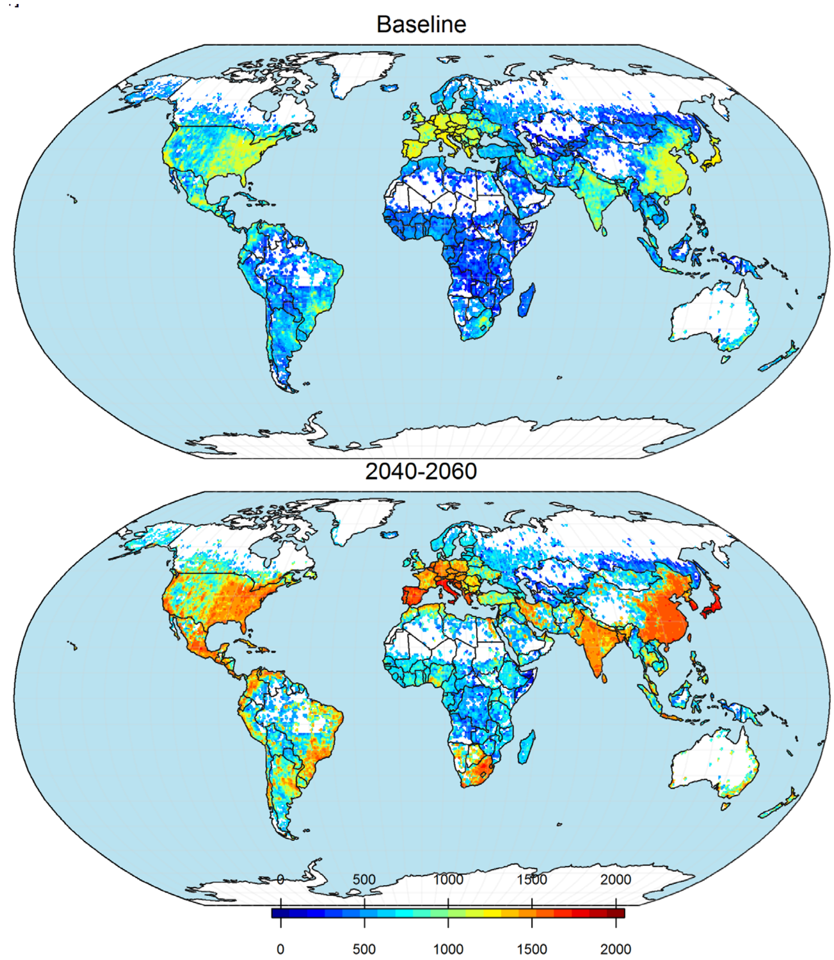
Between 1900 and 2015 drought affected 2.3 billion people worldwide and led to an estimated 11.7 million deaths (EM-DAT, 2009). Drought-associated impacts on people are often linked to health (WHO, n.d.). Health effects can be direct (increased morbidity and mortality) or indirect (economic disruption, infrastructure damage, forced migration). Health impacts include (1) malnutrition, (2) water-, vector- and air-borne diseases, and (3) mental aspects (WHO, 2012). Population vulnerability may be enhanced by socioeconomic factors, such as poverty, that force people to live on lands with poor soil fertility or in ecosystems at risk of drought.

Malnutrition

The World Health Organization (WHO) ranked malnutrition as the largest global health problem associated with climate change and drought (Campbell-Lendrum et al., 2003; IPCC, 2012). Exposure to drought has been associated with morbidity and mortality owing to the deterioration of people's nutritional state (Stanke et al., 2013; Friel et al., 2014; Sena et al., 2014). Water shortages may result in reduced food production (crop failure and livestock loss), leading to malnutrition and health risks, such as low birth weight (WHO, 2012). Vulnerable groups, such as pregnant women, children aged < 5 years and people living in shelters are mostly affected (Black et al., 2008; Gitau et al., 2005; Singh et al., 2006a, b; WHO, 1985).

FIGURE 3.39

Expected annual losses due to drought [in thousand USD] for the present (baseline) and the period 2040-60 according to seven different climate models and RCP8.5 (high-end scenario).
Country losses are disaggregated according to gridded GDP values.
Source: HELIX project (Naumann et al., 2017)



Water-borne diseases

Shortage of water, lack of clean water and inadequate sanitation are typical during a drought. A number of water-borne infectious diseases have been linked to drought (Effler et al., 2001; Brandley et al., 1996). A direct link between drought and the transmission of the pathogens is, however, difficult to observe owing to other concurrent environmental factors and human vulnerability. Drought-induced stress in livestock and livestock use of human water resources may lead to high concentrations of pathogens and increase the risk of human exposure and infection, particularly after heavy rain following a drought. Poor hygiene and poor water quality for human consumption may result in the transmission of diarrheal diseases (WHO, 1985; Sena et al., 2014; Burr et al., 1978; Smoyer-Tomic et al., 2004).

Vector-borne diseases

Pathogens and vectors are sensitive to climatic and other environmental conditions, which is reflected in the characteristic geographic distribution and seasonal variation of vector-borne infectious diseases (Kilpatrick et al., 2012). While increased precipitation may increase mosquito densities owing to new aquatic habitats, mosquito densities may also increase dramatically following a drought (habitat rewetting) because of the reduced number of competitors and aquatic predators (Chase et al., 2003). Drought may boost the density of birds and mosquitoes around any water sources remaining and thus may accelerate the transmission of pathogens such as West Nile virus (WNV) within these populations, thereby increasing the risk of WNV outbreaks in humans (Shaman et al., 2005; Wang et al., 2010). Mosquitoes, which can efficiently transmit pathogens such as the dengue and chikungunya viruses, may adapt to drought in urban environments and exploit artificial aquatic habitats (e.g. water containers), thus elevating the risk of infection in humans (Brown et al., 2014).

Airborne diseases

Drought-related processes can result in atmospheric dust loadings and associated dispersion of microorganisms at various scales, which may have significant implications for human health. The WHO (2015) has identified drought and dust wind activity in sub-Saharan Africa as a risk factor for regional outbreaks of meningococcal meningitis. Dust storms and winds facilitate the transport of microorganisms favouring meningitis seasonality, which can have serious consequences for public health (Griffin, 2007, WHO, 2015; Agier et al., 2012). The mechanisms by which dust and climate may influence meningitis occurrence, along with outbreak location and severity are, however, not fully clear.

An association between respiratory and cardiovascular diseases could be shown in several regions, but little attention has been paid to West Africa, where desert winds and storms may cause more diseases, such as meningococcal meningitis (De Longueville et al., 2013, Garcia-Pando et al., 2014).

Mental health

Studies on the association between drought and mental health point to fears and anxieties among the rural population in particular, although suicidal thoughts have been recorded as more critical symptoms. (Polain et al., 2011; Carnie et al., 2011; Hanigan et al., 2012).

In summary, disease incidence is often more pronounced in drought-prone regions and affects more vulnerable population groups, such as children and the elderly, or people with difficult living conditions, which may be caused by poverty, for example. Enhancing drought resilience in regions with high population vulnerability and low adaptation capacity should, therefore, be reflected in relief aid programmes.

3.9.5 Analysing drought risk

Risk analysis is a major technique for measuring global progress in the implementation of the Sendai Framework for Disaster Risk Reduction (Aitsi-Selmi et al., 2015). Analysing risk is crucial to identify relief, coping and management responses that will reduce drought damage to society. The objective of risk analysis is to determine the underlying causes of drought damages resulting from the combination of drought hazard, drought exposure and drought vulnerability (Table 3.6).

3.9.5.1 Analysing hazard, exposure and vulnerability

Measuring drought hazard includes estimating the location, duration, intensity and frequency of water deficits over land. Traditionally, drought hazard has been characterised by meteorological indicators, but a simple precipitation shortage often does not translate into immediate concerns and impacts on the ground. Indeed, owing to the multiple-timescale nature of drought, its impacts can continue long after precipitation conditions have returned to ‘normal’ (see Chapter 3.9.4). Therefore, recent scientific developments have focused on combining meteorological indicators with indicators that take into account hydrological processes (e.g. soil moisture, groundwater and river flow), which reflect more closely the impacts felt on the ground.

Interactions between drought hazard, exposure and vulnerability underlie any comprehensive drought risk analysis, which is crucial for drought management and reducing drought impacts.

A review of existing drought hazard indicators by Bachmair et al. (2016)

reveals the unsolved challenges of (1) designing and implementing indicators able to represent drought propagation across the whole hydrological cycle at different spatial and temporal scales, and (2) the systematic collection of impact data to enable validation and a better understanding of the variety of drought impacts on the ground.

To assess the impacts of drought hazard, the first step is to inventory and analyse the environment that can be damaged (Di Mauro, 2014). In the disaster risk-reduction community, exposure refers to the different types of physical entities that are on the ground and that can be adversely affected by a hazardous event, including built-up assets, infrastructures, agricultural land and the location and density of people (UNODRR, 2015). Since drought develops slowly and results in a great variety of impacts in most parts of the world, even in wet and humid regions, drought exposure is often measured for distinct water use sectors as a function of the location, timing, duration and amount of a water deficit (Dracup and Lee, 1980; Wilhite and Glantz, 1985). Proxy indicators of drought exposure include, for example, the distribution of crop and livestock farming, industrial and household water withdrawals, and the human population.

TABLE 3.6

Components of drought risk analysis.

	Characterisation	Relevant data	Examples of studies
Hazard	Magnitude of a hydrometeorological deficit	Meteorological, hydrological and/or biophysical indicators	Sepulcre-Canto et al. (2012); Vicente-Serrano et al. (2010); Svoboda et al. (2002); Kogan (1995); McKee et al.(1993); Palmer (1965).
Exposure	Amount of elements subject to drought hazard	Amount and location of human populations, activities and/or ecosystems	Winsemius et al. (2015); Christenson et al. (2014).
Vulnerability	Susceptibility of exposed elements to damaging effects of drought hazard	Composite indicators that include environmental, social, economic and/or infrastructural components	Gonzélez-Ténago et al. (2016), Neumann et al. (2014); Brooks et al. (2005); Cutter et al. (2003).
Overall risk	Likelihood of impact	Measured in a probabilistic scale linked to intervention policies	Blauhut et al. (2016); Carrão et al. (2016); Kim et al. (2015); Eriyagama et al. (200g); Peduzz et al. (200g).

Since the location, severity and frequency of droughts are difficult to forecast (see Section 3.9.6.2), and since exposure expands as a result of economic and population growth, interventions to reduce drought impacts need to focus on mitigating the vulnerability of human and natural systems. This requires an understanding of who is vulnerable, to which impacts and the reasons for this vulnerability (Gbetibouo and Ringler, 2009). While tools such as drought management plans are key to deliver a structured and coordinated response when drought hits, drought vulnerability assessments (DVAs) can be used to support the design of mid- and long-term drought preparedness actions to increase structural resilience. As such, they provide a crucial link between drought management and water resources planning, where those actions have to be designed and agreed upon in an integrated way. A broad variety of factors have been used to determine vulnerability to drought (Table 3.7).

Some factors are specific to drought (e.g. the existence of drought management plans or the level of diversification of water sources), while others (e.g. poverty or the quality of social networks) are likely to influence vulnerability to an array of hazards in diverse sociopolitical and geographical contexts (Brooks et al., 2005; Cardona et al., 2012). A recent review of 46 assessments of drought vulnerability (González-Tánago et al., 2016) highlighted that data availability still represents a major constraint in building sound and policy-relevant vulnerability assessments. In particular, it is key to invest in the systematic, high-resolution collection of data on drought impacts, water uses, non-conventional water sources and the quantitative and qualitative status of water resources. Moreover, the review revealed the need for greater transparency in the design of drought vulnerability assessments and for increased efforts in the validation of the results.

3.9.5.2 Estimating drought risk

Definitions of risk are commonly probabilistic in nature, referring to the potential impacts or the likelihood of harmful consequences (i.e. environmental, economic, social and/or infrastructural) from a particular hazard to an exposed element in a future time period (Blaikie et al., 1994; Cardona et al., 2012; Carrão et al., 2016). Therefore, the estimation of drought risk requires the development of a model that combines drought hazard with relevant indices or metrics of drought exposure and vulnerability (Government Office for Science, 2012).

An entry point for both understanding and addressing drought risk is to use quantitative measures of historical impacts as proxies for its estimation (Brooks et al., 2005). In particular, historical data relating to socioeconomic losses might be used as a retrospective measurement of drought risk to forecast the impacts arising from the interaction of hazard, exposure and vulnerability. For example, Peduzzi et al. (2009) carried out a global assessment of drought risk by fitting the number of human casualties to the determinants of drought risk by means of a generalised linear regression. More recently, Blauhut et al. (2015, 2016) tested the capability of logistic regression to predict the likelihood of drought impacts (LDI) in Europe for different sectors of activity from a set of drought risk determinants. Regression analyses are generally desirable from a risk assessment viewpoint because they may be validated from observed historical data. However, relying on historical impacts has some limitations when estimating current and future drought risk (Government Office for Science, 2012). Foremost, the number of affected people and the types of impacts vary by region, thus hampering consistent broad-scale analyses. For example, drought in developing countries can contribute to malnutrition, famine and loss of human lives, whereas in developed countries it primarily results in economic losses. Second, these analyses do not account for shifts through time in the distri-

TABLE 3.7

Examples of factors included in selected drought vulnerability assessments
Source: modified from González-Tánago et al. (2016)

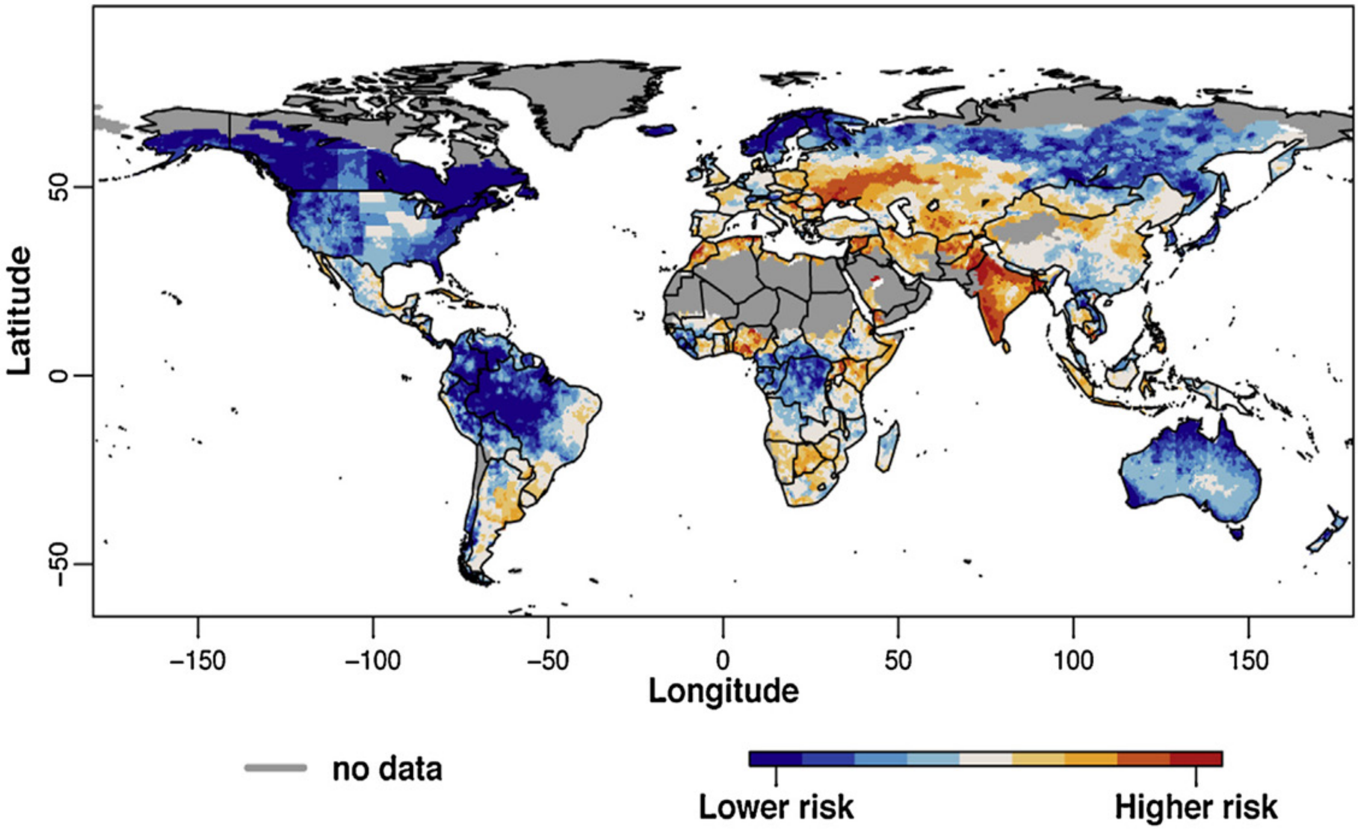
	Sub-dimension	DVAs #	DVAs %	Most frequent factors (#of DVAs)
Biophysical dimension	Drought characteristics	17	41%	SPI (3), NDVI (4)
	Climatic components: rainfail, evapotranspiration, temperature	20	49%	Average annual precipitation (9)
	Soil characteristics and topographic factors	20	49%	Soil water-holding capacity (10)
	Water resources: runoff storage capacity. Surface and groundwater	19	46%	Status groundwater (12) and surface water (10)
	Water uses	11	27%	Agricultural water use (9)
	Land use	17	41%	Agricultural land uses (9)
Socioeconomic dimension	Socio-cultural (demography, education, health, gender, drought awarness, etc.)	29	71%	Population (24) and education (16)
	Economic and financial resources	28	68%	Economic resources (20), agricultural income (17), employment (9)
	Institutional, Policy and Governance (social networks, taxes, governmental programs, participation, etc.)	14	34%	Government presence or programs (9)
	Technical, technological and infrastructural (irrigation, tillage, improved seeds, fertilisers, access to services, etc.)	28	68%	Irrigation (23)
	Others (“Others”)	4	10%	Impacts

bution of exposure or vulnerability to loss, thus biasing the predictions (Güneralp et al., 2015). Finally, impacts may be available only for short timescales and unavailable in some countries (Below et al., 2007), while the available records often do not include the most extreme cases to tune the regression models (Government Office for Science, 2012).

More recently, composite indicators have been proposed to estimate drought risk, for example by Naumann et al. (2014), Kim et al. (2015) and Carrão et al. (2016). Composite indicators are mathematical combinations of risk determinants that have no common unit of measurement (OECD/JRC, 2008). For example, Carrão et al. (2016) used a multivariate and non-parametric linear programming algorithm, that is, a DEA, to aggregate proxy indicators of hazard, exposure and vulnerability into a composite statistic of global drought risk (Figure 3.40). Its values are not an absolute measure of economic losses or damage to human health or the environment, but a relative statistic that provides a regional ranking of potential impacts with which to prioritise actions to reinforce adaptation plans and mitigation activities. Figure 3.40 illustrates that drought risk is generally higher for populated areas and regions extensively exploited for agriculture, such as South-Central Asia, south-east South America, Central Europe and the Midwestern United States. This indicator, while useful for risk assessments in the agricultural sector, may not be adequate for analysinf the risk in other sectors, such as energy production (hydropower, cooling of nuclear plants), navigation

FIGURE 3.40

Global map of drought risk.
Source: Carrão et al. (2016)



and transportation (waterways), or recreation, which should be part of any comprehensive drought risk management plan.

Composite indicators and impact models represent alternative but complementary ways of approaching drought risk estimation at different scales and coordination levels. Since drought impacts are context specific and vary geographically, regression models are most important for local to national management when preparedness plans and mitigation activities are put in practice, while composite indicators can identify generic leverage points in reducing impacts from drought at the regional to global scales.

3.9.6 Managing drought risk

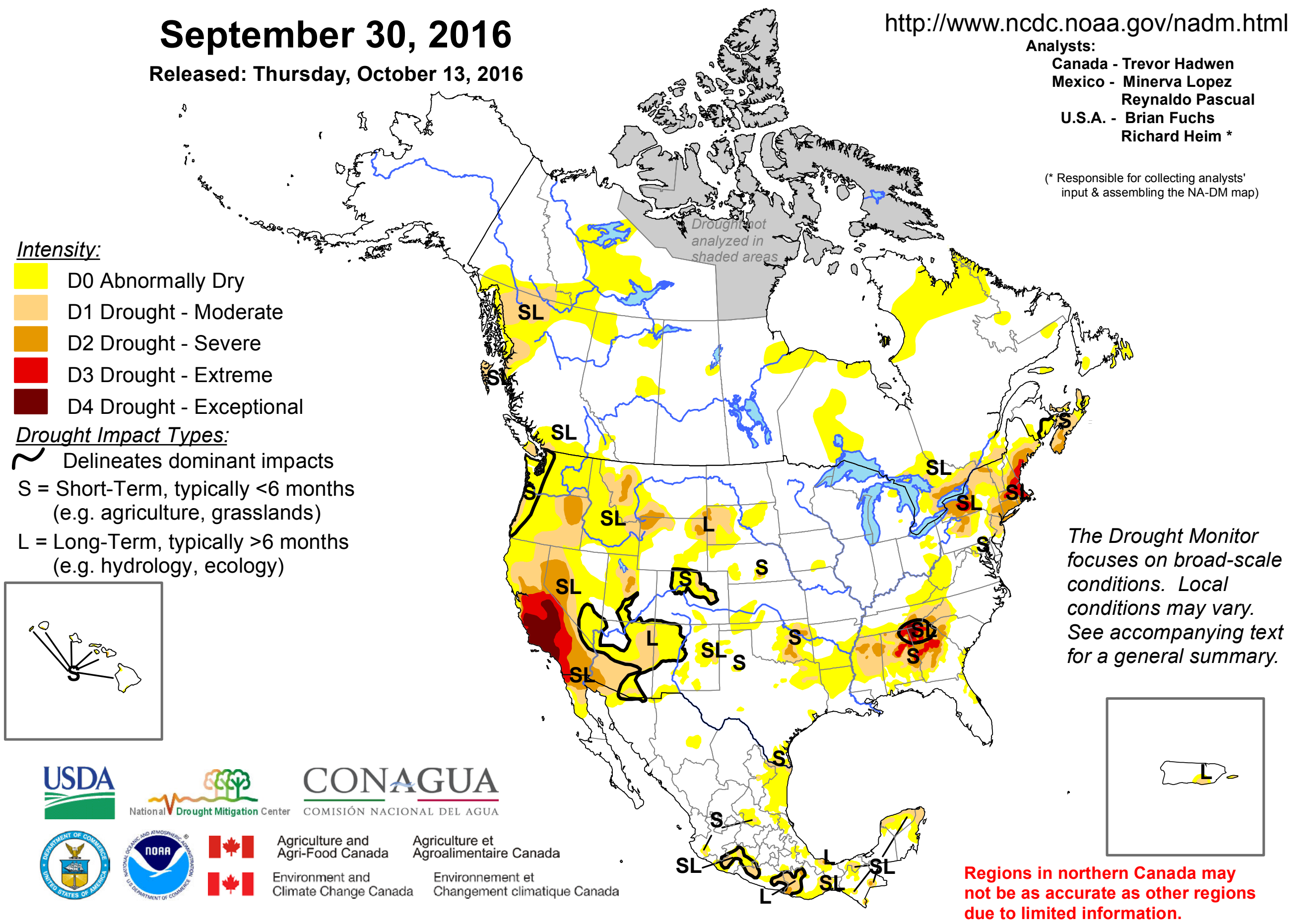
3.9.6.1

Drought monitoring

Drought monitoring and forecasting systems are an essential component of integrated drought management. They provide the necessary and timely information for stakeholders to analyse drought hazards for use within their decision-making processes (WMO, 2006; Ba iley, 2013, Wood et al., 2015). In recent decades, such systems have been developed at different scales from the local or community

FIGURE 3.41

The North American Drought Monitor
Source: NOAA (2017)



scale up to the global level, illustrating the broad variety and complexity of users addressed by these systems. Since droughts affect extended regions that frequently cross national borders, it is important to maintain harmonised systems at different scales that provide comparable information and allow for an integrated monitoring of the evolving events. This is even more important with aquifers and river basins that are frequently transboundary and with globally interconnected economies, resulting in primary and secondary impacts that are felt across many countries and even globally.

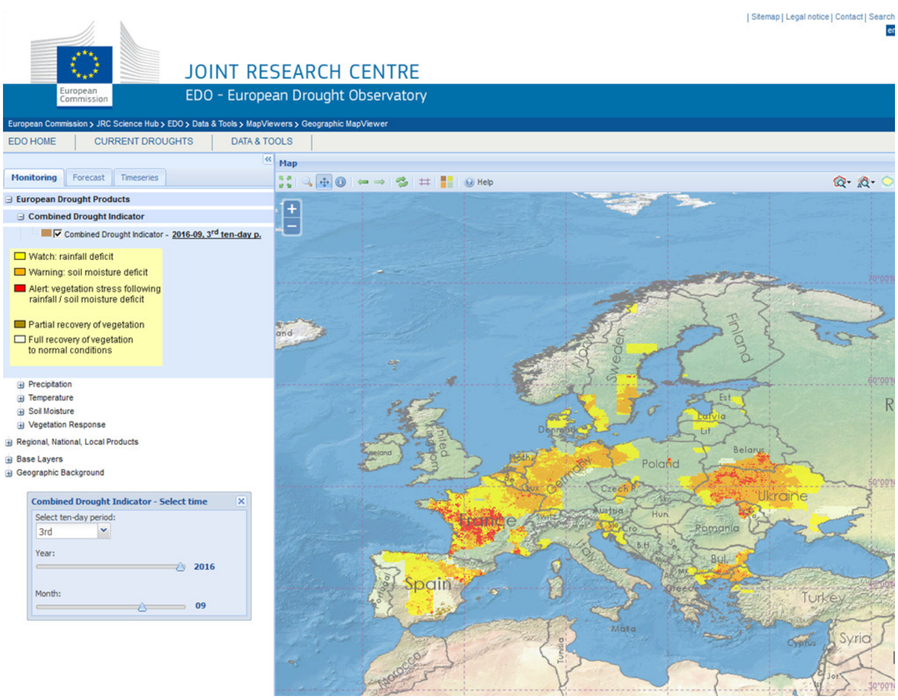
Available information typically includes meteorological, hydrological and remote sensing-based indicators, allowing for an assessment of the extent and severity of drought events across continents. More specific indicators for water management often become available at the regional to local levels. While the first type of information is targeted at policy and high-end decision-makers in the water management sector and at the general public (i.e. awareness raising indicators), the latter is targeted at water managers and stakeholders at the river basin or sub-basin level (i.e. management indicators).

A well-known example of continental systems is the North American Drought Monitor (NADM), which provides monthly information based on a suite of hydro-meteorological indicators, integrated with expert knowledge into a drought map showing five drought intensity levels, ranging from abnormally dry to exceptional drought. A suite of forecasting products and a seasonal outlook complement the picture. It is based on the concept of the weekly updated US Drought Monitor (USDM, Svoboda et al., 2002) and the US National Drought Information System (NIDIS, Pulwarty and Verdin, 2013), combined with information and expert knowledge from Canada and Mexico (Figure 3.41). Information is provided in the form of maps and analyst reports.

Harmonised monitoring and forecasting of a suite of drought indices is crucial in drought management and information interchange across borders. It contributes to a move from reactive to proactive risk management.

FIGURE 3.42

The European Drought Observatory (EDO). Example of the Combined Drought Indicator (CDI) for the period 21 to 30 September 2016. Source: EDO (2015)



In Europe, the European Drought Observatory (EDO) provides maps of 10-day and monthly updates on the hydro-meteorological situation and the occurrence and evolution of drought events, including a 7-day forecast of soil moisture. In addition, a Combined Drought Indicator for agriculture and ecosystem drought analyses the drought propagation from a rainfall deficit through reduced soil moisture to impacts on the photosynthetic activity of the vegetation (Figure 3.42). The goal of such combined indicators is to provide easy to understand sector-specific information for decision-makers in the form of alert levels (Sepulcre-Canto et al., 2012). Like the NADM, the EDO delivers analyst reports during exceptional events, albeit not in a regular manner. The EDO is implemented in a nested manner, allowing for information to be processed and stored at the appropriate levels (i.e. the river basin, country or continental level). To allow for comparability between levels, a set of core indicators are processed following agreed algorithms.

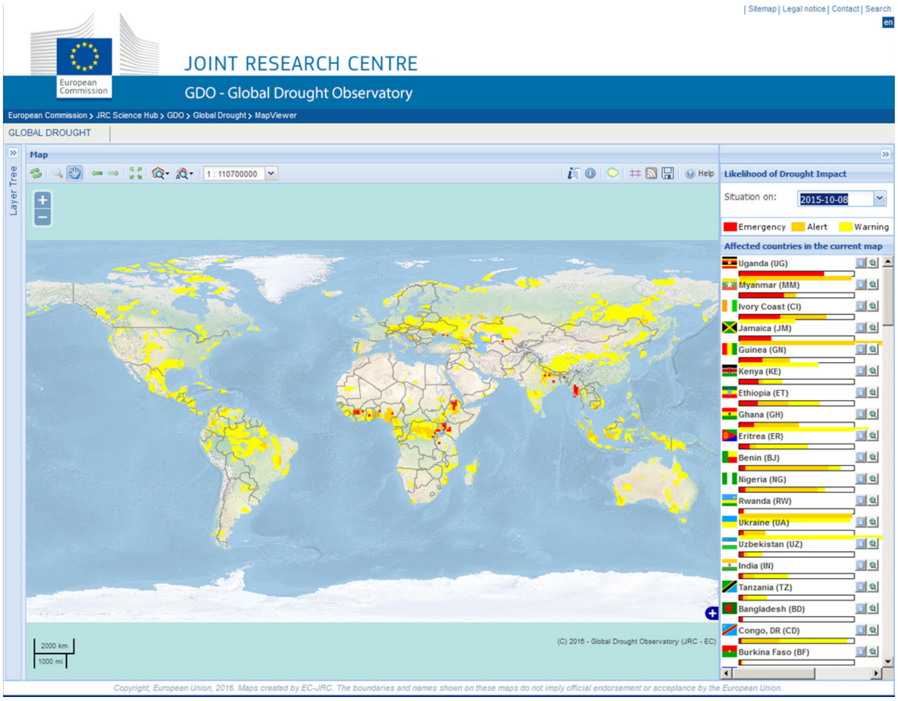
Challenges to drought monitoring and early warning are the continuous availability of indicators covering the various hydro-meteorological components and their combined analysis into usable information for the decision-making process at different levels. Important variables to monitor include precipitation, snow pack and snow water equivalent, temperature, evapotranspiration, river flow, reservoir storage, lake levels, groundwater levels, soil moisture and vegetation vigour, among others. The recently published Handbook of Drought Indicators and Indices (WMO and GWP, 2016) provides a good overview of frequently used indicators.

Cooperation between various entities ensures ownership at all levels, which is important to sustain EWSs. National Meteorological and Hydrological Services (NMHSs), as well as regional and subregional centres, are important partners in this task as they routinely monitor many of the required input variables. This, however, requires the exchange of data and interoperability between systems.

Two other major challenges exist with monitoring and forecasting systems. The first relates to linking drought severity with drought impacts in the variety of economic, social and environmental sectors. Consideration of this challenge is slowly being addressed with several studies in the United States and Europe (Chapter 3.9.5.1) and with systems such as the Global Drought Observatory (GDO), developed by the European Commission JRC for the European Union ERCC and Humanitarian Aid services aim to include sector-specific vulnerabilities for assessing the LDI. The GDO system shown in Figure 3.43 presents a map of the LDI together with a hierarchical list of all affected countries visible in the map. The second challenge relates to developing an understanding of how decision-makers will use the information being disseminated from monitoring and forecasting systems. That challenge needs to be investigated through social science-based research projects and interactions with key users of the information. An example for such interaction is implemented by the US NIDIS system (Pulwarty and Verdin, 2013).

FIGURE 3.43

The Global Drought Observatory (GDO). Example of Likelihood of Drought Impact (LDI) for the period 8 to 15 October 2015.
Source: GDO (2015)



3.9.6.2 Drought forecasting

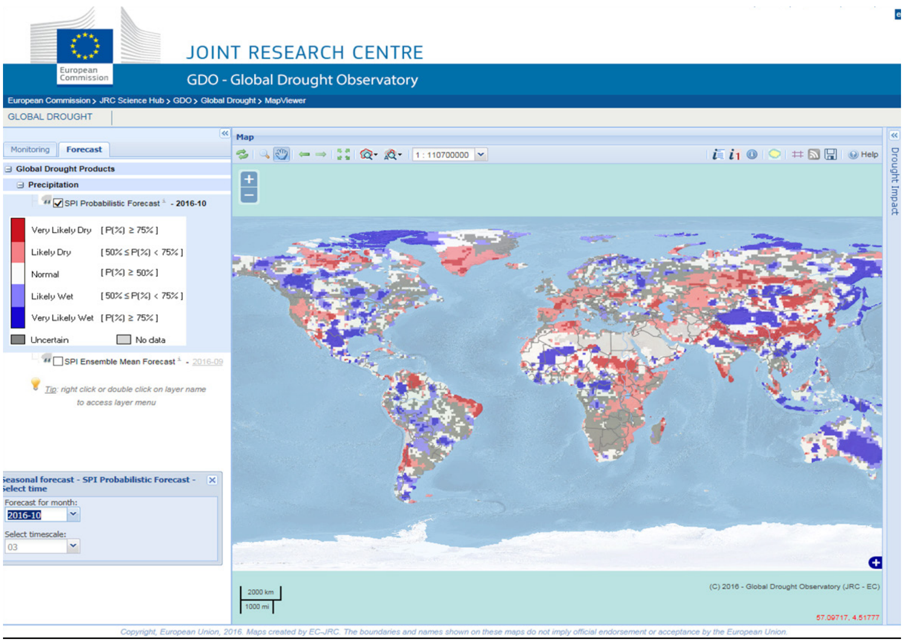
Forecasting the onset or likely evolution of an ongoing drought over the weeks and months ahead or over the season is important to trigger actions for mitigating negative impacts on human activities and environmental processes. Decision-makers and end users require adapted and robust forecast indicators that are capable of informing about the onset, possible duration, intensity and end of drought conditions (Section 3.9.6.1). The timescale of this forecast is considered a challenge as it stands between medium-range forecasting, which is strongly related to initial conditions, and the seasonal timescale, which is mainly driven by oceanic variability and large-scale climate features such as the El-Niño phenomenon (Vitart, 2014).

The lead time and duration of drought forecasts should be adapted to the needs of the region. In Europe, where resilience is higher owing to the widespread availability of irrigation systems, needs are more related to the forecast of long-term droughts, although shorter lead times are relevant for water-borne transport. In Africa, where agriculture is mainly rainfed, a short-term deficit of precipitation constitutes a higher risk. In these regions, the forecasts of dry spells (short-term droughts of about 10 days) is also important (Winsemius et al., 2014, 2015).

Studies have demonstrated that droughts can be forecasted using stochastic or neural networks (Kim and Valdes, 2003; Mishra et al., 2007) with a reasonably good agreement and with 1- to 2-month lead times. Linking weather types to drought (Fleig et al., 2011; Kingston et al., 2013) and statistical downscaling methods using weather types can also be used (Lavaysse et al., 2017). Eshel et al. (2000), for example, used the North Atlantic SLP precursors to forecast drought over the eastern Mediterranean. Forecasts of droughts can also be produced using deterministic Numerical Weather Prediction Models. Such forecasts are highly uncertain as a result of the chaotic nature of the atmosphere, which is particularly strong on a subseasonal timescale (Vitart, 2014). In general, the published literature indicates that the skill of the precipitation fields produced by Numerical Weather Predictions over Europe is low (Richardson et al., 2013; Weisheimer and Palmer, 2014). Predictions will be better in regions where precipitation origins are related to large-scale structures, such as synoptic perturbations or oceanic anomalies (e.g. mid-latitudes), while regions with strong local drivers (e.g. West Africa) will record lower scores. However, these analyses tend to be performed from the point of view of weather forecasting and do not incorporate specific properties that are relevant for drought forecasting, such as persistence. Therefore, ensemble prediction systems have been developed that forecast multiple scenarios of future weather. These forecasts become particularly important to assess the risks associated with high-impact and rare weather events such as tropical cyclones or droughts (Hamill et al., 2012; Dutra et al., 2013, 2014). The ECMWF provides two different types of ensemble forecasts for this time range: an extended range forecast, with lead times of up to 45 days, which is issued twice a week, and a seasonal forecast, with lead times of up to 13 months, issued once a month. The extended-range forecast incorporates more recent model de-

FIGURE 3.44

GDO: Probabilistic Forecast for October 2016 based on SPI-3 from the ECMWF Ensemble system (experimental product, data courtesy ECMWF). Source: GDO (2015)

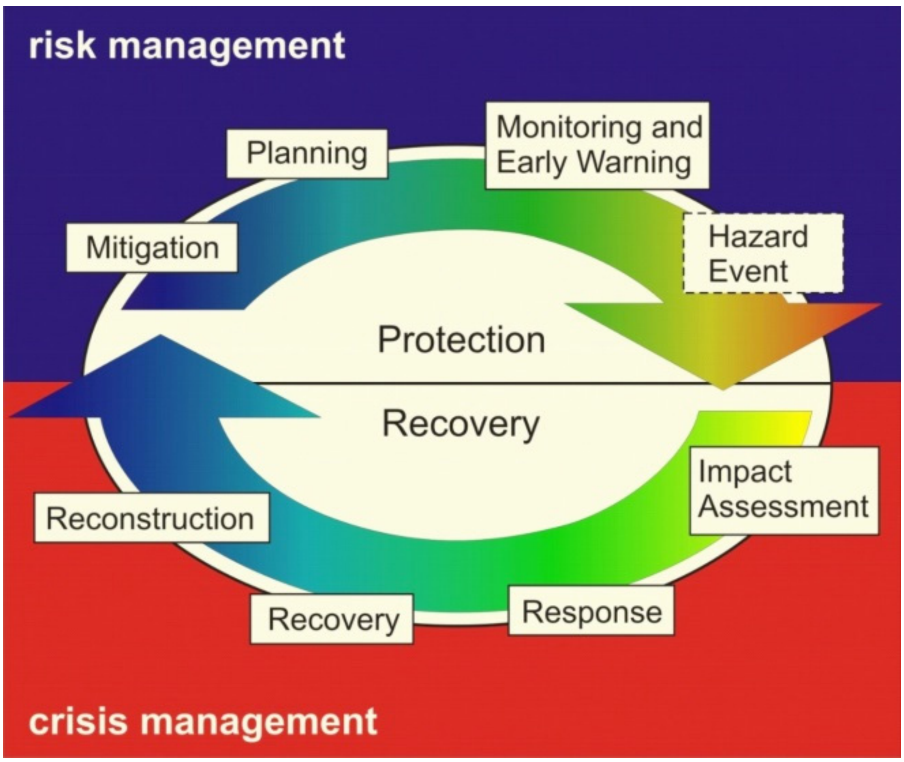


velopments and is usually of higher spatial resolution (Vitart, 2004). The seasonal forecasting system is based on an older model cycle (Molteni et al., 2011), among other significant differences. In the case of droughts, an analysis including both the numerical forecasting skill and the possibilities for binary decisions to issue drought warnings has shown that 40 % of droughts can be correctly forecasted 1 month in advance over Europe (Lavaysse et al., 2015). While the performance of these subseasonal forecasts is still behind the current medium-range weather forecasts, the ongoing efforts by academia and operational centres are encouraging. An example of monthly forecasting of the probability of drought occurrence based on the ECMWF ensemble system is shown in Figure 3.44.

Finally, the prediction skill is depends on the indicator used. Other studies, for example, analysed the prediction of drought based on soil moisture, groundwater or a multivariate index (e.g. AghaKouchak, 2014; Hao et al., 2014; Mendicino et al., 2008). Depending on the region, results can be better than using meteorological indicators, mainly due to the larger persistency (lower variability) of the variables. However, the corresponding data availability and quality, as well as the skill scores, need to be carefully assessed.

FIGURE 3.45

The Cycle of Disaster Management illustrating the importance of risk management in reducing future drought-related impacts.
Source: National Drought Mitigation Center, University of Nebraska-Lincoln.



3.9.6.3 Drought management

Most officials at all scales traditionally deal with drought impacts in a reactive fashion when a drought event takes place. This reactive approach, called crisis management, has often been uncoordinated and untimely (GSA, 2007; Wilhite and Pulwarty, 2005). In addition, crisis management places little attention on trying to reduce drought impacts caused by future drought events.

Drought risk management, however, is a paradigm that focuses on trying to reduce future impacts by improving drought monitoring and early warning, planning and mitigation strategies (Wilhite et al., 2005a). It is an approach that is inherently proactive and directed at identifying who and what is at risk, why they are at risk and how individuals respond to events.

The concept of drought risk management is illustrated in Figure 3.45, which demonstrates the Cycle of Disaster Management. Although this cycle applies to all natural hazards, which is why some of the components of the cycle (such as reconstruction) apply better to other hazards, it is also applicable for droughts. The bottom half of the cycle represents crisis management, which will always be necessary in some form to respond to the drought impacts of a current event. However, Figure 3.45 highlights that the actions of monitoring and prediction, planning and mitigation need to take place in order to reduce future drought impacts. These

actions are considered to be a part of a drought risk management approach. Drought monitoring and prediction involves the continuous assessment and anticipation of indicators of drought severity, spatial extent and related impacts. Using this information to elicit response is called 'early warning' (Hayes et al., 2012). Because decision-makers require accurate early warning information to implement effective drought policies and response and recovery programmes, drought monitoring and prediction are essential for drought risk management and illustrate an important connection between risk and crisis management (Wilhite and Buchanan-Smith, 2005).
The objective of drought planning, the second component of drought risk management, is to reduce the impacts of drought by identifying the principal activities, groups or regions most at risk and developing strategic actions and programmes that address these risks, as well as response actions that can be taken during a drought event. Drought plans provide an effective and systematic means of assessing drought conditions, developing mitigation strategies that reduce risk in advance of drought, and devising response options that minimise economic stress, environmental losses and social hardships during drought (Wilhite et al., 2005b). This overall emphasis on drought planning is fundamental to drought risk management at any decision-making level. Incorporating planning will help decision-makers to prepare for multiple hazards, including drought and climate change, and will promote sustainability and natural resources management, leading to greater economic and societal security at all levels (GSA, 2007).

The third component of drought risk management is the implementation of appropriate drought mitigation strategies, which are the specific activities taken before a drought occurs that reduce the long-term vulnerability to droughts. According to the United Nations International Strategy for Disaster Reduction (UNISDR, 2006), there are currently a limited number of tested strategies available by which to identify appropriate drought risk-reduction strategies. Furthermore, they concluded that 'it is essential to identify and demonstrate effective approaches and opportunities for drought mitigation and preparedness, including case studies to show examples of good as well as weak policies. Policymakers, scientists, media, and the public often need to see actions-at-work in order to foster buy-in to similar efforts.'

As drought monitoring systems improve in many locations (see Section 3.9.6.1), and as policymakers begin to think about trying to implement drought risk management strategies, such as planning and mitigation, an important feedback loop has emerged whereby better drought management drives the need for improved drought monitoring and, in turn, improved drought monitoring encourages more effective drought management (Hayes et al., 2012). As drought plans become more specific in space and time, the need for information at higher spatial and temporal resolutions increases.

An example of this type of coevolution in drought monitoring and risk management has occurred over the past decade in the United States, whereby improvements in the USDM (Svoboda et al., 2002) product have led to shifts in national agricultural policies, inspiring additional advancements in the spatio-temporal resolution of drought monitoring to support implementation of these policies at a local scale.

Although progress in drought risk management has been slow, there has been some success around the world (Wilhite et al., 2005a). A great example of this at the global scale occurred with the High-level Meeting on National Drought Policy (HMNDP, March 2013), which was co-organised by the WMO, the Secretariat of the United Nations Convention to Combat Desertification (UNCCD) and the Food and Agriculture Organization of the United Nations (FAO), in collaboration with a number of UN agencies, international and regional organisations.

The Policy Document of the HMNDP (UNCDD, FAO and WMO, 2013) lays out the essential elements of a National Drought Policy, namely:

- Promoting Standard Approaches to Vulnerability and Impact Assessment;
- Implementing Effective Drought Monitoring, Early Warning and Information Systems;
- Enhancing Preparedness and Mitigation Actions; and
- Implementing Emergency Response and Relief measures that reinforce National Drought Management Policy Goals.

These elements are considered to be the key pillars of a National Drought Management Policy. These pillars have been used in many different initiatives including the Integrated Drought

Management Programme (IDMP) and the Windhoek Declaration of the African Drought Conference (UNCCD, 2016). One of the successes of HMNDP is that it has drawn the attention of the international organisations and national governments to focus on proactive policies.

The strong call for a framework in the form of a policy that combines different approaches that have been considered key in moving from a crisis management approach to a risk management approach has led to the launch of the IDMP by the WMO and GWP at the HMNDP in March 2013. The objective of the IDMP is to support stakeholders at all levels by providing policy and management guidance and by sharing scientific information, knowledge and best practice for an integrated approach to drought management.

The strength of the IDMP is to leverage activities of its various partners to determine the status and needs of countries and to move forward collectively to address these needs. The IDMP also uses the network of NMHSs and related institutions affiliated with the WMO, the United Nations specialised agency for weather, climate and water, and the Regional and Country Water Partnerships of the GWP as the multistakeholder platform to bring together actors from government, civil society, the private sector and academia working on water resources management, agriculture and energy.

Based on one of the tools that has been instrumental in the development of drought preparedness plans in the United States, the 'National Drought Management Policy Guidelines — A template for action' (WMO and GWP, 2014) were developed from existing material to focus on a national policy context and to draw on experiences from different countries. The purpose of these guidelines is to provide countries with a template that they can use and modify for their own purposes. Countries should not blindly use the 10-step process. The guidelines should be modified and adapted to local needs and experiences. For example, the Central and Eastern European countries have distinguished seven steps.

3.9.7 Conclusions and key messages

The key challenge in reducing drought risk is to move from the prevailing reactive approach, fighting the highly diverse drought impacts, to a pro-active society that is resilient and adapted to the risk of drought (i.e. through the adoption and implementation of pro-active risk management). This requires practitioners, policymakers and scientists to use a consistent set of drought definitions and characteristics. Observed and projected trends in drought hazard need to be understood and considered in the management plans. The hazard has to be connected to manifold impacts (e.g. on water supply, food security, energy production, transport, health, and ecosystems). Current, as well as future, societal exposure and context-specific vulnerability should be identified to eventually assess the evolving drought risk. Through knowledge of all these aspects, drought risk can be managed through a set of institutional, structural and operational measures, including monitoring and seasonal forecasting. There is, moreover, an ongoing need to consider the institutional aspects of 'capacity' and 'coordination' at national and local levels, particularly where the required sustained collaborative framework among research, monitoring and decision-making/management is lacking (Pulwarty and Sivakumar, 2014). Central to the above is the development, support and training of a cadre of professionals and policy entrepreneurs who view the role of linking drought science, policy and risk management practices as a core goal over the long term.

Recommendations have been set according to the three pillars of DRMKC. Links to the various mentioned activities and projects are provided at the end of the chapter (see Web Resources for Chapter 3.9).

Partnership

In Europe, several drought science partnerships exist: (1) the European Drought Centre (EDC), (2) the European Drought Observatory (EDO), and (3) the Drought Monitor for South Eastern Europe (DMCSEE). On the global level, the WMO/GWP Integrated Drought Management Programme (IDMP) fosters collaboration on drought management in the broad sense. The EDC shares expertise from scientists, water managers and stakeholders, and contains the European Drought Impact Report Inventory (EDII). The EDO and DMCSEE monitor current drought conditions. The EDO also includes a forecast of drought conditions and up-to-date information on drought in the media. The EDO also performs analyses of past trends and of future projections under different scenarios for the 21st century. The IDMP coordinates regional initiatives around the globe (e.g. in Central and Eastern Europe, West Africa, Central America and South Asia), covering a wide range of drought aspects. Professional networks dealing with drought in Europe and beyond are, for example, the UNESCO EURO FRIEND-Water Low Flow and Drought network and the IAHS Panta Rhei Working Group on Drought in the Anthropocene. Further development of and collaboration between these partnerships is important to advance our understanding of drought and to improve our capacity to cope with this important threat to our societies.

Knowledge

Recent EU drought research projects (i.e. DROUGHT-R&SPI, DEWFORA, PESETA) and regional cooperation programmes such as EUROCLIMA, as well as several national initiatives (e.g. Jucar Basin, Spain, Box 3.2), have advanced the knowledge base with better access to information, guidelines and services on: (1) drought monitoring, prediction and early warning, (2) drought impacts and links with the hazard, (3) drought risk assessment, risk reduction and drought response, and (4) policy and planning for drought preparedness and mitigation across sectors. Chapter 3.9.2 to 3.9.6 illustrate progress made in these fields over the last decade. It is likely that the frequency, severity and scale of droughts will increase in multiple regions in Europe and elsewhere, affecting (Chapter 3.9.3) many economic sectors (e.g. agriculture, water-borne transport, energy), the environment (e.g. aquatic ecosystems, biodiversity) and human well-being (health). It is therefore important to improve societal preparedness for the related risks and to adapt to the future challenges resulting from droughts.

Innovation

The European Drought Impact Report Inventory - EDII (Stahl et al., 2016), has created a good base on which to learn more about the multifaceted impacts of drought, but needs to be continuously updated and expanded to cover the whole of Europe. Similar inventories need to be established for other parts of the world. This allows the establishment of improved links between impacts and drought hazard on the one hand, and a better assessment of drought risks and how to manage these across sectors on the other hand. Furthermore, context-specific drought vulnerability profiles for the river basins across Europe that also consider projections need to be elaborated. Scientific innovation is required on seamless drought prediction to address multi-monthly and seasonal forecasting, as well as drought projections for the intermediate and far future. Drought management should be put in a multihazard setting, which requires land and water management that integrates policies and measures for the different hazards (droughts, floods, wildfires and heat waves). A follow-up of the past EU working group on Water Scarcity and Drought is required to effectively disseminate progress on drought, including guidelines and good practices among EU Member States and beyond.

BOX 3.2

Jucar Basin Case Study

Proactive and participatory drought planning and management in a semi-arid water-scarce system

The Jucar Basin District (JBD) (42 989 km2) is located near Valencia in eastern Spain. Most of the area can be classified as semi-arid, and precipitation is highly variable in space and time.

Multiyear droughts are common, as illustrated by the Standardized Inflow Index for the naturalised flow into the Tous Reservoir (lower JBD) (Figure 3.46). The most significant water use is attributable to (1) irrigated agriculture (400 000 ha, 80 % of water demand), (2) urban areas (4.3 million inhabitants) and (3) industry (including hydroelectricity production and nuclear plant cooling). The water exploitation index (water demand / natural renewable resources) is approximately 86 %. Water scarcity is acute, resulting in high environmental stress and water quality deterioration. Water allocation has caused political and social conflicts between users and areas. Droughts have exacerbated these problems and are projected to become even more frequent and severe as a result of climate change.

In the JBD, water has been intensively exploited over centuries and adaptation to drought has been a common feature. Institutional and legal developments (e.g. irrigation district associations and water tribunals) were fostered centuries ago and are still working. However, while many measures (e.g. building infrastructures) were taken to decrease vulnerability, drought response remained mainly reactive. In 1936, the participative JB Public-Private Partnership (JBPPP) was founded, and nowadays it includes many stakeholders (e.g. national, regional and local administrations, water users and environmental non-governmental organisations (NGOs)).

The JBPPP does the basin administration, enforces decisions and recovers costs of infrastructures building, operation and maintenance. It provides a very good framework for governance, as well as a good forum for conflict resolution, which is fundamental in drought management. Within the JBPPP, there has been an improvement in knowledge of water resources management since the 1980s through the use of models and collaborations with scientists. Initially the focus was on individual basin components, but in the 1990s an integrative decision support systems (DSS) at the basin scale was designed for basin planning, with an emphasis on water allocation and drought vulnerability assessment (Andreu et al., 1996). To ensure that approved plans provided acceptable levels of drought vulnerability, indicators and criteria about acceptable and unacceptable values were agreed in a participative process since 2004.

In parallel, from the year 2000, the JBPPP adopted a clearly proactive approach by developing a Special Drought Management Plan (SDP) (Estrela and Vargas, 2012). A Composite Drought Operative Index (CDOI) (Ortega et al., 2015) was introduced to monitor drought states (normal, pre-alert, alert and emergency). CDOI maps are published regularly (Figure 3.46) and serve as early warning to trigger predefined anticipation and mitigation measures attached to each drought state. The final DSS, which has been regularly updated, was accepted by all parties as a reliable tool for planning scenarios (Andreu et al., 2009). It includes a probabilistic approach (Andreu and Solera, 2006) to obtain more specific risk assessments (e.g. probabilities of deficits and reservoir states at short and medium timescales, the impact of anticipation and mitigation measures) (Andreu el al., 2013). Anticipation and mitigation measures include: (1) more efficient water use, (2) water saving, (3) conjunctive use of surface and groundwater, (4) financial compensation for giving up water use, (5) water rights purchase for environmental protection, (6) irrigation sluice water recirculation, (7) reuse of waste water, (8) enhanced control of water use, water quality and the ecological status of water bodies, and (9) revision of actions and post analysis. In the alert and emergency state, the JBPPP Participatory Permanent Drought Commission (PDC) has special powers, for example to override water rights and priorities, to further improve governance aspects, thereby facilitating consensus for equitable decisions.

The JBPPP PDC demonstrated its relevance during the severe 2004-8 drought (Andreu et al., 2013). The governance body had 28 sessions with successful results, as recognised by its own stakeholders (Urquijo et al., 2016). It provided transparency and credibility to the decision and policymaking processes. Drought management and planning in the JBD is internationally recognised as exemplary (e.g. Schwabe et al., 2013; Kampragou et al., 2015; Wolters et al., 2015).

Nevertheless, improvements can still be made, for instance through: (1) refinement of monitoring of indicators and real-time data gathering, (2) the consolidation of measures, (3) further enhancement of institutional and legal aspects, (4) demand and supply management, and (5) the use of additional economic instruments (e.g. insurance for irrigated agriculture). Finally, major challenges have been maintaining the personal commitment of individuals in all sectors (knowledge brokering, policymaking, NGOs, stakeholders in general) and incorporating the comprehensive interaction in the regular functioning and procedures of the institutions and other bodies involved.

FIGURE 3.46

The Jucar Basin (south-east Spain). Standardised Inflow Index for the JBD (left), and CDOI maps corresponding to March 2006, January 2007 and March 2009 (right, from left to right).
Source: self-elaboration from public domain information.