

Chapter 6:

Special section on drought

Among the weather-related natural hazards, drought is probably the most complex and severe due to its intrinsic nature and wide-ranging and cascading impacts. It affects agricultural production, public water supply, energy production, transportation, tourism, human health, biodiversity, natural ecosystems, etc. Droughts are recurrent; they can last from a few weeks to several years, and can affect large areas and populations. The related impacts develop slowly, are often indirect and can linger for long times after the end of the drought. While the impacts result in severe economic losses, environmental damage and human suffering, they are generally less visible than the impacts of other natural hazards (e.g. floods and storms) that cause immediate and structural damages, which are clearly linked to the hazard and quantifiable in economic terms.²³¹ Therefore, the drought risk is often underestimated and remains a “hidden” hazard.²³² Proactive drought risk management is still not a reality in most parts of the world.

Drought-related fatalities mainly occur in poor countries. However, in wealthy countries, people suffer from indirect effects such as heat stress or dust, leading to a variety of health impacts.²³³ Examples are persistent unemployment, migration and social instability related to failures in public water supply, food insecurity and potential conflict.

Drought is likely to become more frequent and severe in the twenty-first century in many regions of the world.²³⁴ A better understanding of the physical processes leading to drought, its propagation, the societal and environmental vulnerability to drought and its impacts are more important than ever. The key challenge is to move to the widespread adoption of proactive risk management strategies.²³⁵ This includes the analysis of past trends and future projections of drought, as well as analysis of the societal and environmental exposure and vulnerability. All determine drought risk, which can be managed by developing policies and management plans that are adapted to the local context.²³⁶

Droughts are a recurring feature and are defined with respect to the long-term average climate of a given region. They should be distinguished from aridity, a seasonally or fully dry climate (e.g. desert) and from water scarcity, a situation where the climatologically available water resources are insufficient to satisfy long-term average water requirements. A megadrought is a very lengthy and pervasive drought, lasting much longer than normal, usually a decade or more.

231 (UNISDR 2011a)

232 (UNISDR 2011a)

233 (van Lanen et al. 2017); (UNESCO 2016)

234 (Spinoni et al. 2018); (IPCC 2014)

235 (Wilhite 2014); (Wilhite, Sivakumar and Pulwarty 2014)

236 (Wilhite 2014); (Global Water Partnership Central and Eastern Europe 2015)

Box 6.1. Drought types

Depending on the effect in the hydrological cycle and the impact on society and environment, different drought types can commonly be distinguished:

1. *Meteorological drought* is a period of months to years with a deficit in precipitation or climatological water balance (i.e. precipitation minus potential evapotranspiration) in a given region. The deficit is defined with respect to the long-term climatology. These droughts are often accompanied by above-normal temperatures and precede and cause other types of droughts. Meteorological drought is caused by persistent anomalies in large-scale atmospheric circulation patterns, which are often triggered by anomalous

tropical sea-surface temperatures or other remote conditions.

2. *Soil moisture (agricultural) drought* is a period with reduced soil moisture that results from below-average precipitation. This impinges on crop production, causes land degradation and affects ecosystem function in general.

3. *Hydrological drought* occurs when river stream flow and water storage in aquifers, lakes or reservoirs fall below long-term mean levels. Hydrological drought develops slowly because it involves stored water that is depleted but not replenished. Time series of these variables are used to analyse the occurrence, duration and severity of hydrological droughts.

While a lack of precipitation often triggers drought, other factors, including more-intense but less-frequent precipitation, soil moisture conditions, poor water management and soil erosion, can also cause or enhance these droughts. Overgrazing, for example, led to elevated erosion and dust-storms that amplified the “Dust Bowl” drought of the 1930s over the Great Plains in North America.²³⁷ Droughts threaten human security because they undermine livelihoods, compromise culture and individual identity, and increase migration. As they can also undermine the ability of States to provide the conditions necessary for human security. Droughts may influence some or all the factors at the same time. Situations of acute insecurity, such as famine and sociopolitical instability, usually emerge from the interaction of multiple factors. The conflict in the Syrian Arab Republic is a clear example of how drought could accelerate instability.^{238,239} For many populations that are already socially marginalized, resource dependent and have limited capital assets, human security will be progressively undermined. In such cases, sequences of smaller magnitude droughts can have disproportionate impacts.

6.1

Drought indicators

Different drought types require different indicators for their characterization. The World Meteorological Organization (WMO) and the Global Water Partnership (GWP) published an overview on widely used drought indicators.²⁴⁰ The standardized precipitation index (SPI) and the standardized precipitation-evapotranspiration index (SPEI),^{241,242} for example, are well known for meteorological drought analysis. Indicators related to soil moisture such as the drought severity index²⁴³ or the Palmer drought severity index²⁴⁴ aim to characterize drought impact in terms of plant water stress. Hydrological indicators such as flow percentiles are used to quantify the volume of water deficit in rivers and reservoirs.²⁴⁵ Finally, indicators based on remote sensing, such as the normalized-difference vegetation index or the fraction of absorbed photosynthetically active radiation, are used to monitor drought effects on vegetation.

Combined indicators that blend several physical indicators into a single indicator have recently been developed. The European Drought Observatory, for instance, uses the combined drought indicator²⁴⁶ to monitor drought impacts on agricultural and natural ecosystems.

To obtain an overview of the potential impacts of droughts, a core set of variables is needed to represent different aspects related to the water deficit. Frequency, intensity and duration are some of the key drought variables. Severity describes the accumulated deficit over the entire duration of an event, while intensity describes the average degree of the precipitation, soil moisture or water storage deficit during a drought. Both may determine the degree of associated impact.

For instance, the duration and area affected are linked to the propagation in time and space of the water deficit. Longer and more widespread events might trigger cascading effects, the magnitude of which is directly related to the water deficit. The timing of the onset, cessation and end of a drought are particularly relevant information during the growing season. The impacts of a drought may be felt after the drought has ended.

An emerging consideration in drought analysis is the occurrence of subseasonal (less than three months) drought events that can intensify or extend longer-term drought or background aridity. These “flash droughts” refer to relatively short periods of warm surface temperature and anomalously low soil moisture. Based on the physical mechanisms associated with flash droughts, these events are classified into two categories: heat-wave and precipitation deficits.²⁴⁷

Understanding the mechanisms behind low-frequency climate features like the El Niño Southern Oscillation is key to seasonal prediction of drought events. Though it is still incipient, reliable seasonal prediction with a reliable monitoring network and an appropriate risk assessment will allow for the development of EWSs.²⁴⁸

6.2

Climate change and future droughts

Improvements in knowledge have reinforced the findings of the Fourth Assessment Report of IPCC,²⁴⁹ especially with respect to an increasing risk of rapid, abrupt and irreversible change with high levels of warming. These risks include increasing aridity, drought and extreme temperatures in many regions of the world.²⁵⁰ Despite the uncertainty in climate projections, several regions of the globe are likely to experience increased drought frequencies and/or intensities in the twenty-first century. These include countries in the Mediterranean, Southern Africa, South-Western North America and Central America.²⁵¹

A reduction in precipitation or changing precipitation patterns and greater evaporative demands related to higher temperatures are the underlying processes driving such changes. A temperature increase of 3°C is estimated to bring current 100-year droughts (severe droughts that occur once

237 (Cook, Miller and Seager 2009)

238 (Erian, Katlan and Babah 2011)

239 (Erian et al. 2014)

240 (Svoboda and Fuchs 2016)

241 (McKee, Doesken and Kleist 1993)

242 (Vicente-Serrano, Beguería and López-Moreno 2009)

243 (Cammalleri, Micale and Vogt 2015)

244 (Palmer 1965)

245 (Hisdal et al. 2004); (Cammalleri, Vogt and Salamon 2017)

246 (Sepulcre-Canto et al. 2012)

247 (Otkin et al. 2018)

248 (Dutra et al. 2015); (Naumann et al. 2014)

249 (IPCC 2007)

250 (World Bank 2012)

251 (Orlowsky and Seneviratne 2012)

every 100 years) to around 30% of the emerged lands on a 10-year basis.²⁵²

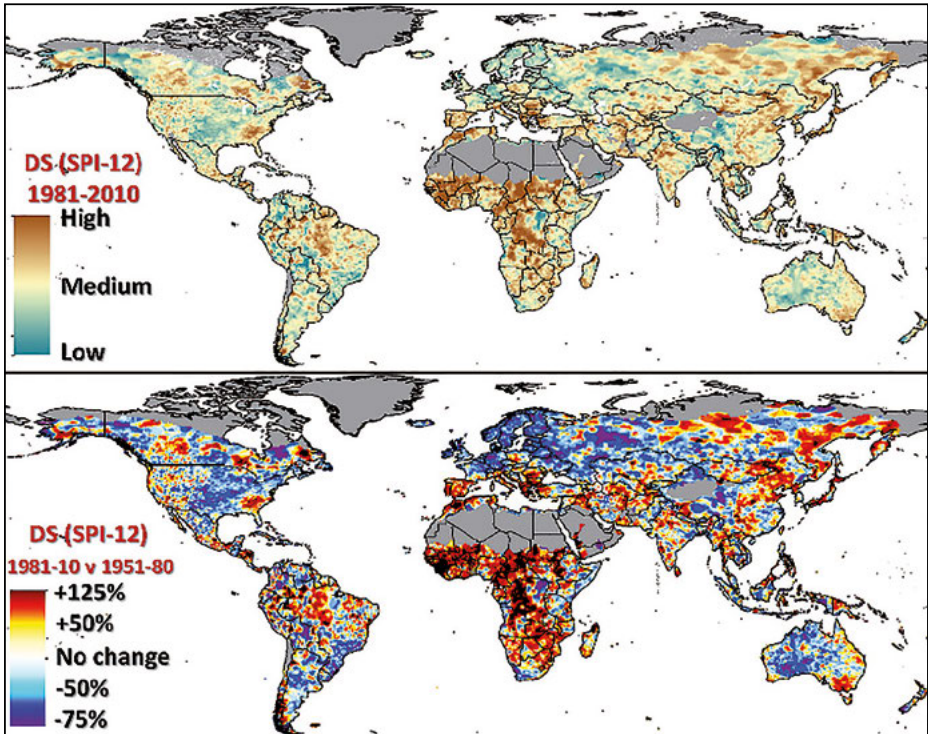
These scenarios suggest that drought risk will increase for many economic sectors and vulnerable regions unless appropriate climate change mitigation and adaptation measures are taken. Many regions in the world with high population densities and vulnerable societies that rely on local agricultural production could experience significant losses because of droughts.

Studies after the IPCC Fourth Assessment Report indicate that there is medium confidence in a projected increase in duration and intensity of droughts in some regions of the world, including Southern Europe and the Mediterranean region,

Central Europe, Central North America, Central America and Mexico, North-East Brazil and Southern Africa. Decreases in soil moisture are likely in several regions, particularly in Central and Southern Europe, and Southern Africa. For a range of scenarios, soil moisture droughts lasting four to six months double in extent and frequency, and droughts longer than 12 months become three times more common, between the mid-twentieth century and the end of the twenty-first century.²⁵³ A decrease in soil moisture can increase the risk of extreme hot days and heat-waves.²⁵⁴

Compared to the analysis of past trends, the effect of temperature becomes more evident in drought projections. Drought projections use two IPCC representative concentration pathways (RCPs).

Figure 6.1. Drought severity according to SPI-12 (left) and SPEI-12 (right). Top panels show the cumulative severity for the period 1981–2010, bottom panels show the difference between the periods 1951–1980 and 1981–2010. Grey zones represent masked cold and desert areas.



Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

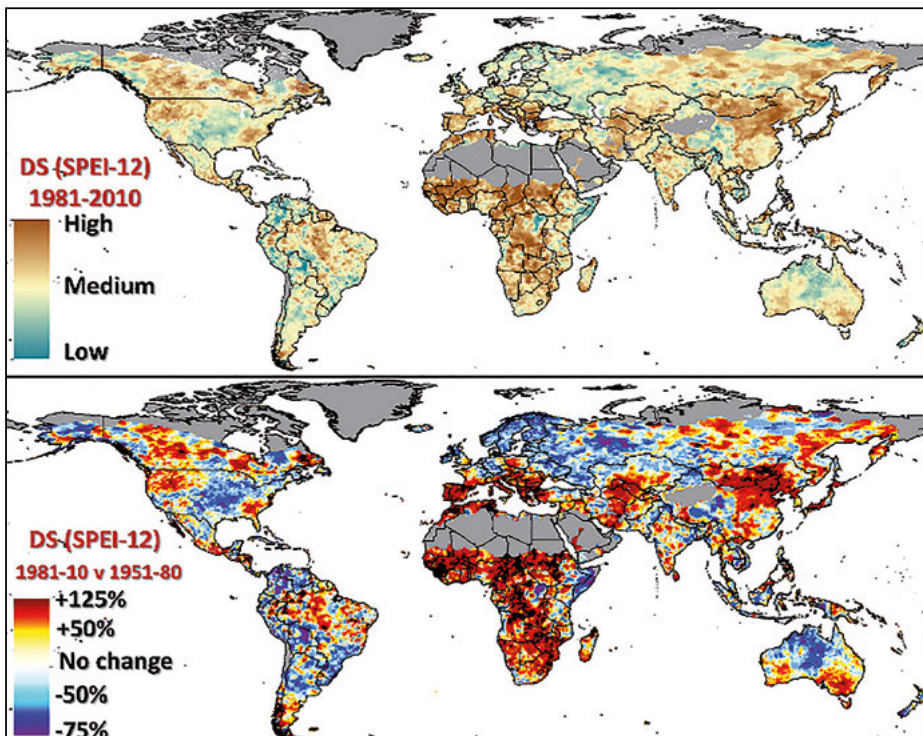
(Source: JRC 2018)

RCP4.5 projects a future scenario characterized by strong reforestation programmes, decreasing use of croplands and grasslands, stringent climate policies, CO₂ emissions increasing only slightly before soon declining. RCP8.5 projects a scenario in which CO₂ emissions rise continuously, there is an increased use of croplands and grassland, a population of 12 billion by 2100, heavy reliance on fossil fuels and no implementation of climate policies.²⁵⁵

According to model outputs using SPI, drought severity is likely to increase in some areas by the end of the twenty-first century: Argentina and Chile, the Mediterranean and large parts of Southern Africa, under both RCP 4.5 and RCP 8.5 climate scenarios. Areas in South-Eastern China and Southern Australia are likely to experience an increase in drought severity only under the more extreme climate scenario, the RCP8.5. As expected, almost

the entire globe, excluding northern North America, northern latitudes in Eurasia, and maritime South-East Asia, show a tendency towards an increase in drought severity, which is even stronger based on RCP8.5. SPEI model outputs suggests that many more regions will likely experience more-frequent and more-severe drought events.

Combining the information derived from Figures 6.1 and 6.2, most of the drought hot spots of the last decades are projected to see a further increase in DS, thus becoming the areas at highest risk of impacts, including irreversible land degradation. The regions where a continuous increase in DS is projected, according to moderate and high-emission scenarios (RCP4.5 and 8.5) are Argentina and Southern Chile, the Mediterranean region and large parts of Southern Africa. Higher temperatures are likely to exacerbate droughts in these areas.



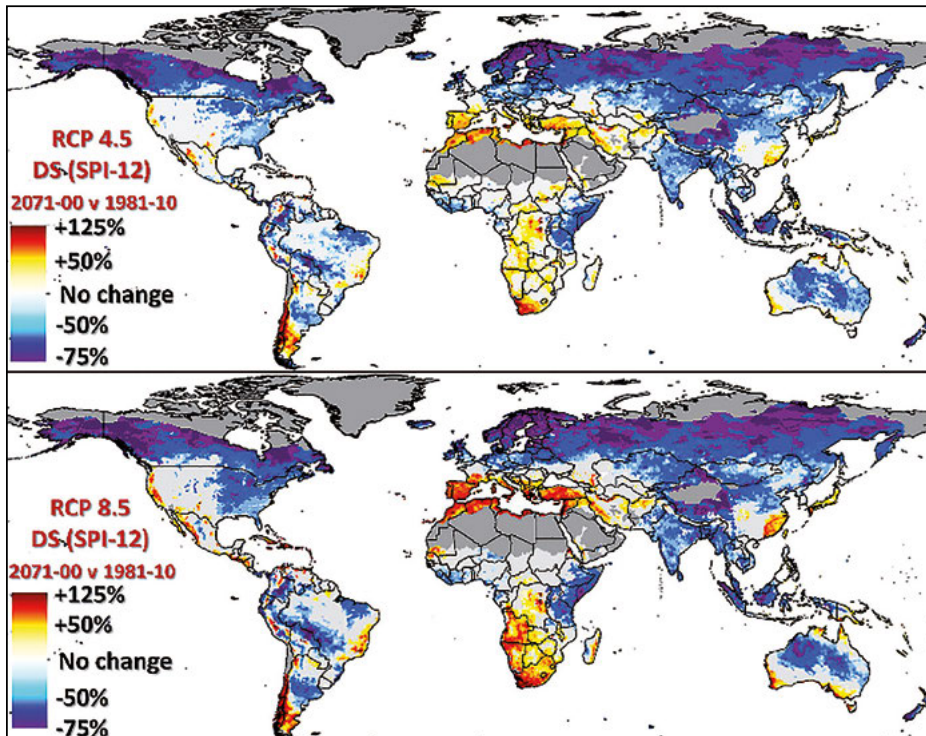
252 (Naumann et al. 2018)

253 (Sheffield and Wood 2008)

254 (Seneviratne et al. 2006)

255 (IPCC 2019)

Figure 6.2. Drought severity (DS) to SPI-12 (left) and SPEI-12 (right). All panels show the difference in percentage between 1981–2010 and 2071–2100 under RCP4.5 (top) and RCP8.5 (bottom) scenarios. Light grey zones represent areas in which less than two thirds of the simulations agree on the sign of change. Dark grey zones represent the cold and desert masked areas.



(Source: JRC 2018)

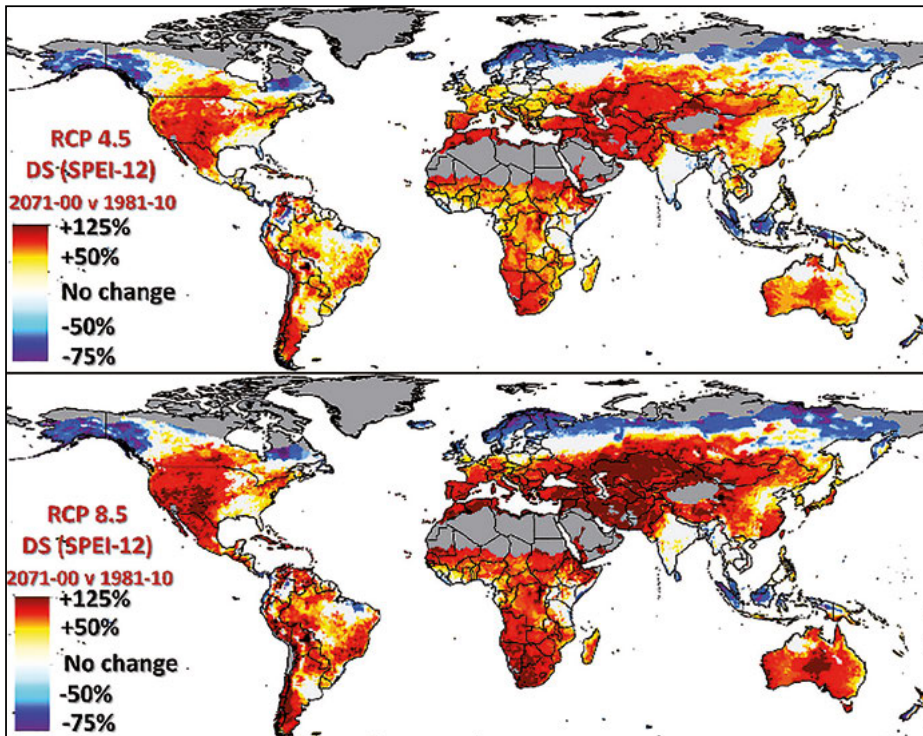
Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

6.3

Assessing global drought risk

The term “risk” and the related terms of “hazard”, “exposure” and “vulnerability” have been used and defined in different ways within the scientific community, with notable differences between the DRR and the climate change adaptation (CCA) communities.²⁵⁶ They base their analysis on two theoretical frameworks, commonly referred to as the outcome or impact approach (CCA community) and the contextual or factor approach (DRR community).²⁵⁷

The outcome or impact approach is based on the relationships between stressor and response. Here, the endpoint of the analysis is the vulnerability (the more damage a society suffers, the more vulnerable it is). This approach relies on the use of quantitative measures of historical impacts as proxies for the vulnerability estimation.²⁵⁸ However, relying on historical impacts has several limitations, mainly because impacts are



often available for short timescales only, or even unavailable, which inhibits the derivation of homogeneous global risk maps using this process. In addition, the number of affected people and the types of impact vary by region, thus hindering consistent broad-scale analyses.

The contextual or factor approach is based on intrinsic social or economic factors or dimensions that define the vulnerability. Here, the vulnerability is the starting point, allowing understanding why the

exposed population or assets are susceptible to the damaging effects of a drought. It is more suitable for setting targets for risk reduction. This approach generally relies on combined risk determinants that have no common unit of measurement.²⁵⁹ The resulting values are not an absolute measure of economic loss or damage to the society or the environment, but a relative statistic that provides a regional ranking of potential impacts, which can serve to prioritize actions for reinforcing disaster management and adaptation plans.

256 (Brooks 2003); (Field et al. 2012); (Wisner et al. 1994)

257 (Tánago et al. 2016)

258 (Brooks, Adger and Kelly 2005); (Peduzzi et al. 2009)

259 (OECD, JRC and EC 2008)

Both approaches represent alternative but complementary ways for drought risk estimation at different scales. As drought impacts are context specific and vary geographically, regression models (i.e. the outcome approach) are important for developing preparedness plans and mitigation activities from local to national scales, while composite indicators (i.e. the contextual approach) can identify generic leverage points for reducing impacts at the regional to global scales.

For a global assessment, a contextual approach is adopted. This defines risk as a function of the natural hazard, the exposed assets and the inherent vulnerability of the exposed social or natural system. Following this definition, the risk of incurring losses from a drought depends on the combination of DS and the probability of occurrence, the exposed assets and/or people, and their vulnerability or capacity to cope with the hazard.

End users, water managers and policymakers rely on drought risk assessments to better protect populations from shocks and to develop management plans to reduce impacts. Therefore, drought risk assessments should include information tailored to the needs of specific users. This information should answer questions about where and which entities are more likely to be affected. As exposure and vulnerability vary between economic sectors (e.g. agriculture, public water supply, energy production, inland water transport, tourism and public health) and different ecosystems, drought risk assessments need to be sector specific.

6.4

Assessing the risk for agriculture and other primary sectors

This section presents an example of a global drought risk assessment with emphasis on agricultural and primary sector impacts, which are relevant at the global scale. The assessment is based on the conceptual approach proposed by UNDP.^{260,261} It includes the assessment of the hazard, the exposure and the societal vulnerability, which are then combined to arrive at an assessment of the risk for significant impacts due to droughts. The individual steps are explained in the following subsections.

6.4.1

Assessing the hazard

Precipitation can be used as a proxy indicator of the water available to the coupled human–environment system.²⁶² The frequency and intensity of precipitation deficits, therefore, can represent the drought hazard for a given area. However, increasing temperatures and evaporative demand is now better understood to affect available water supplies.

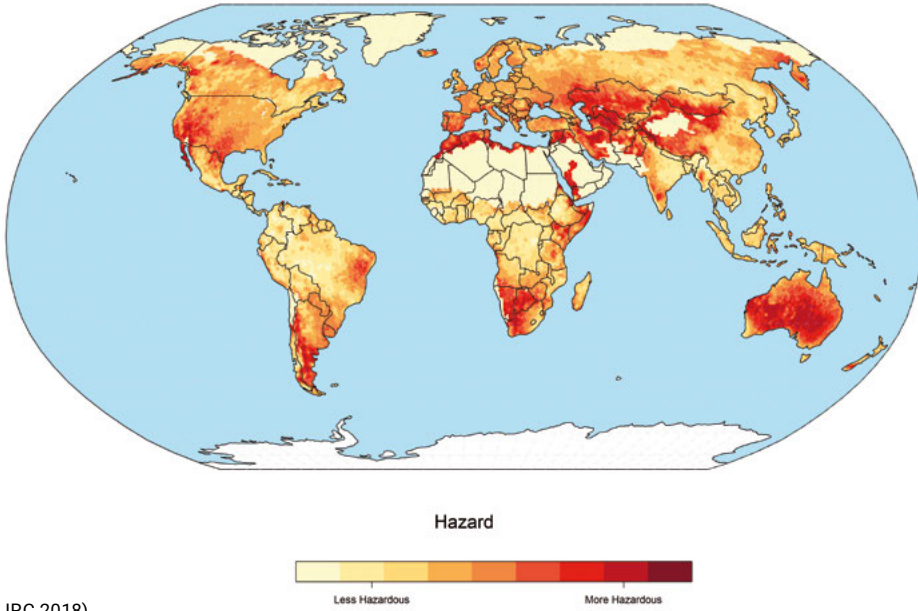
²⁶⁰ (UNDP 2004)

²⁶¹ (Carrão, Naumann and Barbosa 2016)

²⁶² (Svoboda et al. 2002)

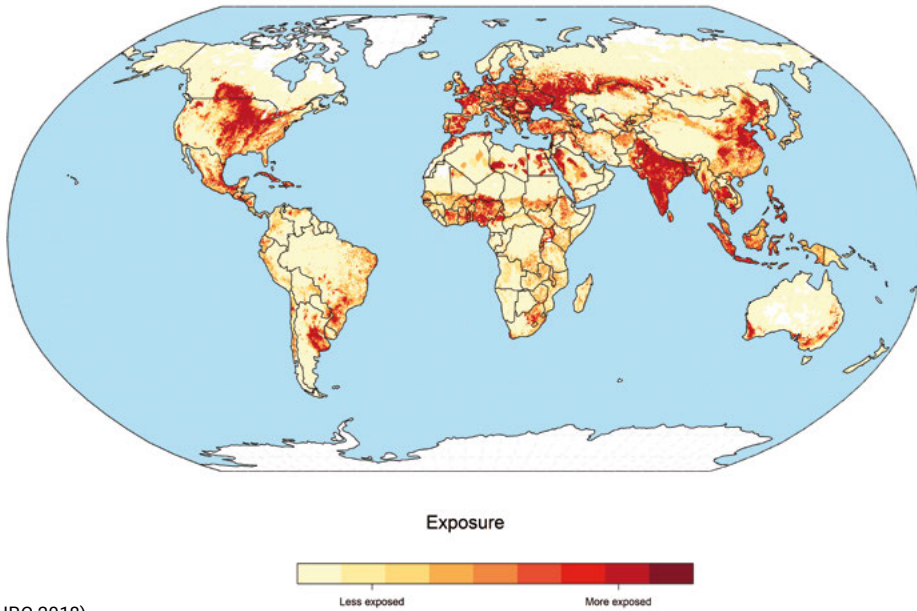
Figure 6.3. Global drought hazard according to the weighted anomaly of standardized precipitation (WASP) index: (a) hazard, (b) exposure and (c) vulnerability

(a)



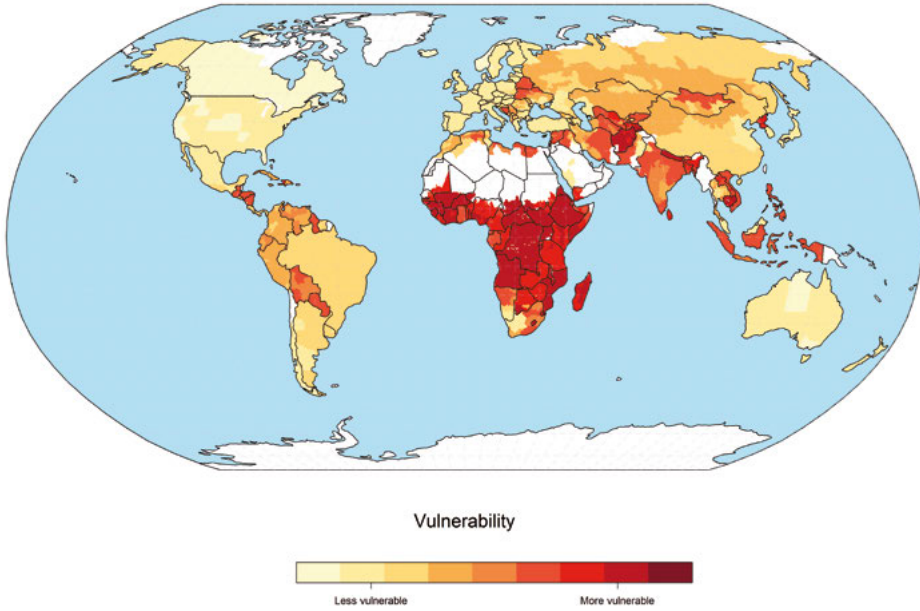
(Source: JRC 2018)

(b)



(Source: JRC 2018)

(c)



(Source: JRC 2018)

Disclaimer: The boundaries and names shown and the designations used on these maps do not imply official endorsement or acceptance by the United Nations.

In the present assessment, drought hazard was estimated as the probability of exceedance of the median of global severe precipitation deficits for a historical reference period (1901–2010) (Figure 6.3(a)). The severity of the precipitation deficit is computed by means of the WASP index.²⁶³ The WASP index was selected because it: is standardized in time and space; allows confining the influence of large standardized anomalies that result from small precipitation amounts occurring near the beginning or end of dry seasons; and emphasizes anomalies during the rainy season when crops are more sensitive to water fluctuations.

6.4.2

Assessing the exposure

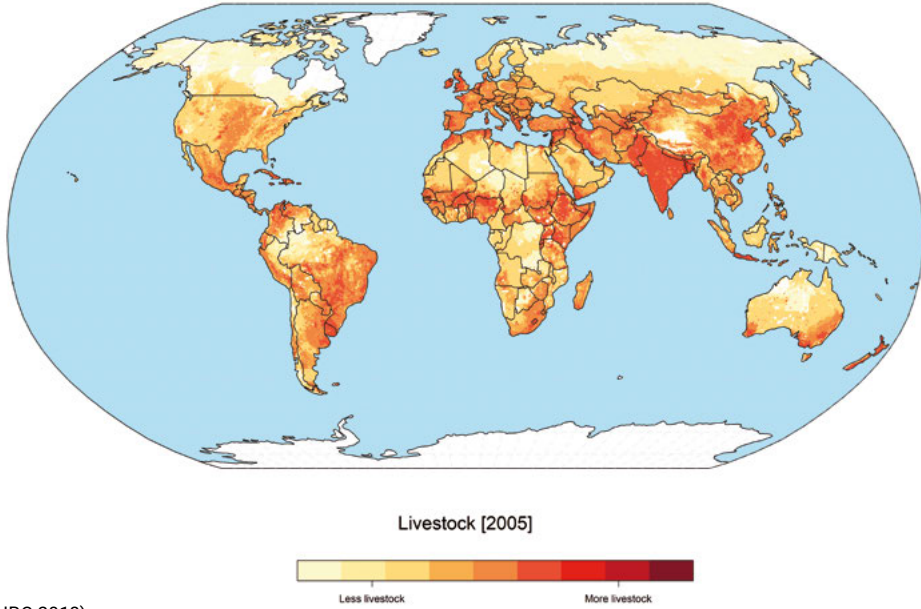
Meaningful information about the exposure is related to the entities, assets, infrastructures, agricultural land and people located in a drought-prone

area. The model of drought exposure as applied for this GAR is computed and validated based on spatially explicit geographic layers. This approach to drought exposure is comprehensive and considers the spatial distribution of several physical elements (proxy indicators) characterizing agriculture and primary sector activities,²⁶⁴ namely: crop areas (agricultural drought), livestock (agricultural drought), industrial/domestic water stress (hydrological drought) and human population (socioeconomic drought).

This approach proposes a non-compensatory model to combine the different proxy indicators of drought exposure. Using this methodology, superiority in one indicator cannot be offset by an inferiority in another indicator. Thus, a region is highly exposed to drought if at least one type of asset is abundant there. For example, a region that is completely covered by rain-fed crops is fully exposed to drought, independent of the presence of other elements at risk.

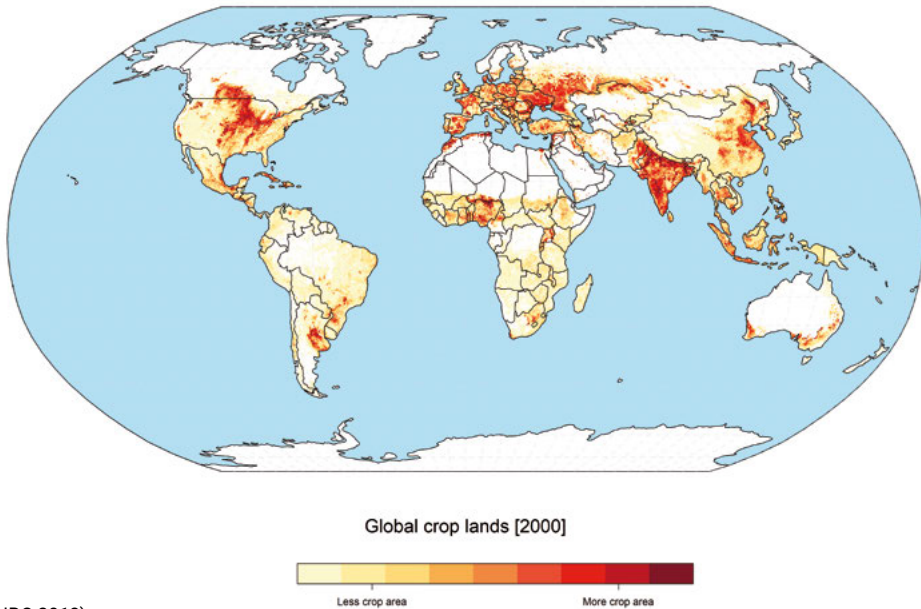
Figure 6.4. (a) Global distribution of livestock in number per grid cell, (b) global agricultural lands, in per cent croplands per grid cell, (c) Global human settlement population estimates for 2015. Distribution and density of population, in number of people per grid cell, and (d) baseline water stress: total annual water withdrawals (municipal, industrial and agricultural), as a percentage of the total annual available flow.

(a)



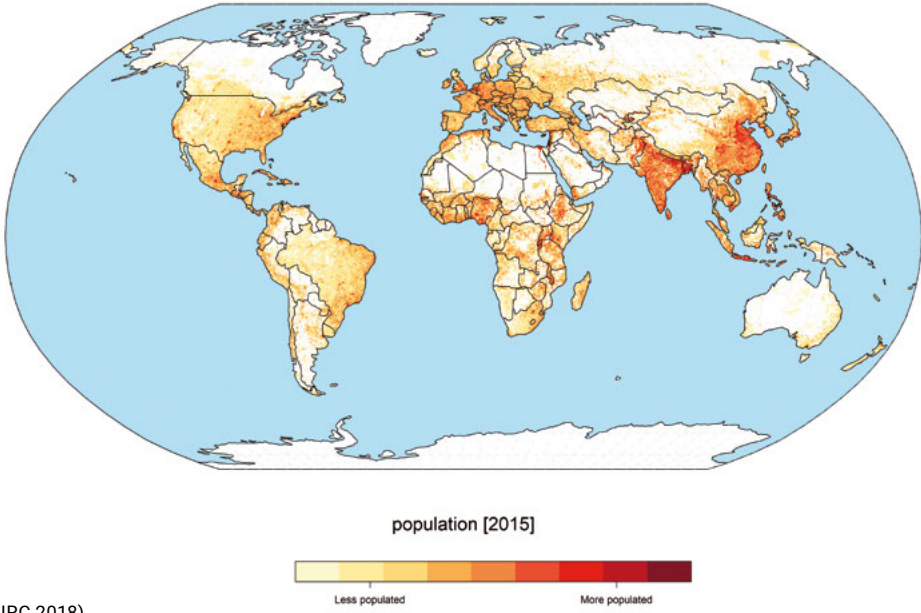
(Source: JRC 2018)

(b)



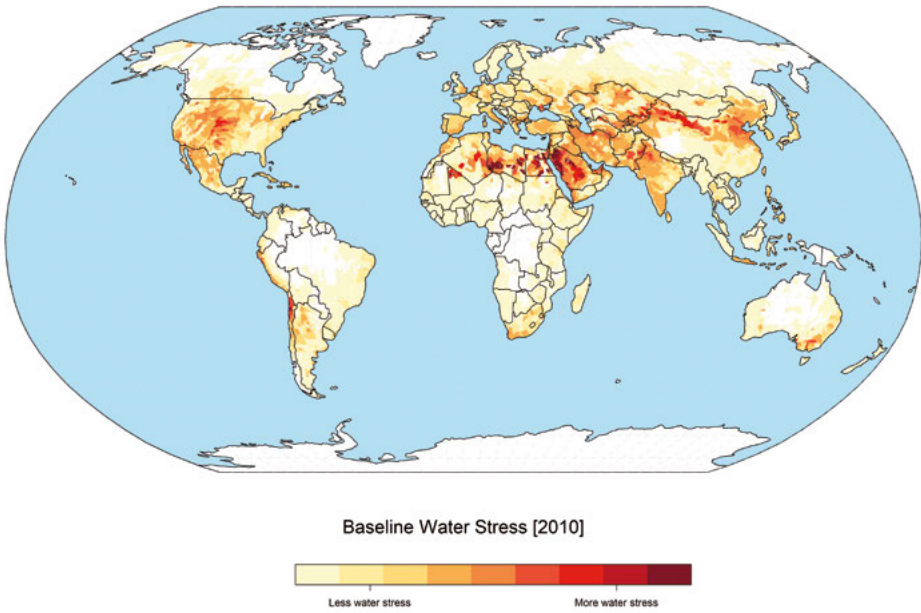
(Source: JRC 2018)

(c)



(Source: JRC 2018)

(d)



(Source: JRC 2018)

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6.4.3

Assessing the vulnerability

Vulnerability assessments are a key component of any drought risk estimation as they support the design of mid- and long-term preparedness actions to target sectors or more sensitive populations. Particularly, interventions to reduce drought impact should be oriented towards mitigating the vulnerability of human and natural systems.

In the present framework, vulnerability to drought is represented by a multidimensional model composed of social, economic and infrastructural factors. Social vulnerability is linked to the level of well-being of individuals, communities and society. Economic vulnerability is highly dependent upon the economic status of individuals, communities and nations. Infrastructural vulnerability is comprised of the basic infrastructures needed to support the production of goods and sustainability of livelihoods. This definition of vulnerability is in line with the framework proposed by UNDRR,²⁶⁵ where vulnerability is defined as a reflection of the state of the individual and collective social, economic and infrastructural factors of a specific region. Such factors may be viewed as the foundation on which local plans for reducing vulnerability and facilitating adaptation are built.²⁶⁶

According to this theoretical framework, each factor is characterized by generic proxies that reflect the level of quality of different constituents of a society and its economy. This follows the concept that individuals and populations require a range of independent factors or capacities to achieve positive resilience to impacts and that no single factor is sufficient to describe the varied livelihood outcomes that societies need to cope with such disasters.

As represented in Figure 6.3(c), the most vulnerable regions to drought are in Central America, North-West South America, Central and South Asia, South-Western North America and almost the entire

African continent, except for some areas in Southern Africa. These results match the outcomes of other authors,²⁶⁷ which classified nearly all nations situated in sub-Saharan Africa among the most vulnerable to climate disasters.

6.4.4

Assessing the drought risk

Figure 6.3 presents the three components of drought risk as well as their combination, which results in the global drought risk map. The three components of risk were aggregated following a multivariate and non-parametric linear programming algorithm (Data Envelopment Analysis).²⁶⁸ The values for each component are not an absolute measure, but a relative statistic that provides a regional ranking of potential impacts (hot spots) with which to prioritize actions to reinforce adaptation plans and mitigation activities. Figure 6.5 shows that drought risk is generally higher for highly exposed regions – mainly heavily populated areas and regions extensively exploited for agriculture – such as South-Central Asia, the southeast South American plains, Southern and Central Europe and the midwestern United States of America.

²⁶⁵ (UNISDR 2004)

²⁶⁶ (Naumann et al. 2014)

²⁶⁷ (Brooks, Adger and Kelly 2005)

²⁶⁸ (Carrão, Naumann and Barbosa 2016)

6.5

Considerations for other sectors

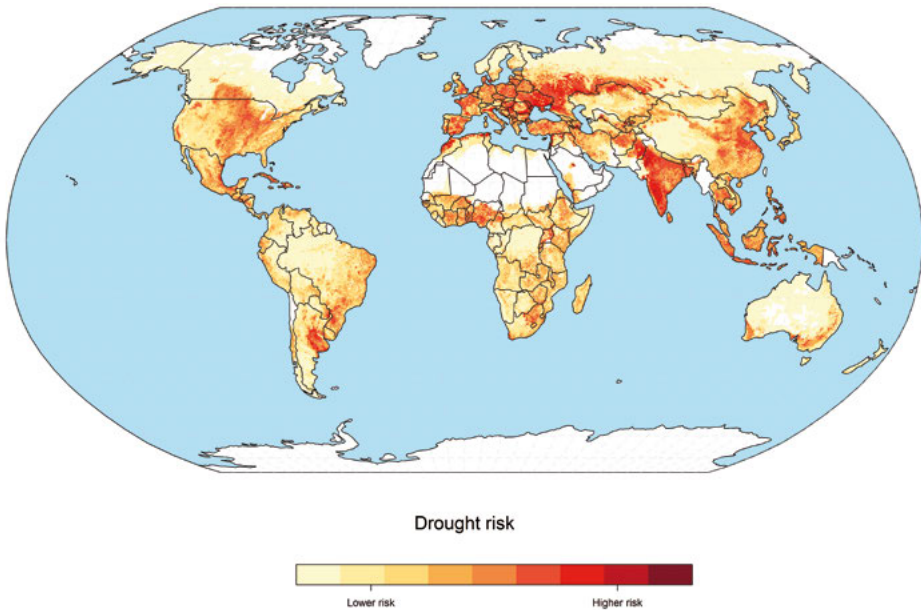
The assessment presented above is targeted to the agricultural sector and other primary activities. However, the methodology can be implemented and re-calibrated for analysing the risk in other sectors, such as energy production (hydropower generation, and cooling of thermal and nuclear plants), navigation and transportation (waterways), public water supply or recreation, which should be part of any comprehensive drought risk management plan.

6.5.1

Uncertainty

Several factors of uncertainty must be considered in such analysis, as the metrics involved are partially subjective and conditioned by the data availability at a global scale. Agricultural drought can be quantified by several different indicators, each one able to provide a valid estimate of the different components of drought risk. As an example, Figure 6.6 depicts the drought hazard map according to the soil moisture-based yearly drought severity index (YDSI). This indicator quantifies the simultaneous occurrence of soil water deficit and extremely rare dry conditions,²⁶⁹ and could replace or be combined with the WASP index used above.

Figure 6.5. Drought risk based on the risk components shown in Figure 6.3



(Source: JRC 2018)

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

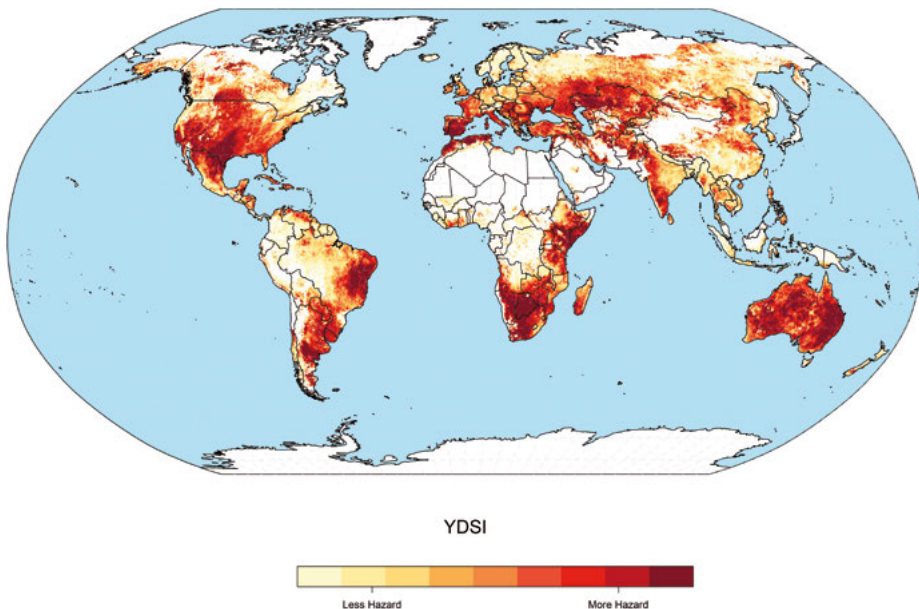
Though it is possible to observe analogues in the patterns between the drought hazard map in Figure 6.3a and the one in Figure 6.5, different conclusions

at local scale can be obtained by using one indicator or the other.

In the case of other sectors and related drought types, such as hydrological drought, the divergence can be more dramatic when adopting a more suitable indicator. Indicators related to stream flow and river discharge rather than soil moisture and precipitation better capture the drought hazard for energy production and navigation. An example of such an indicator is the one reported in Figure 6.7, where the

hazard is represented by the number of hydrological drought events observed in a fixed time window (1980–2013) according to the low-flow index.²⁷⁰ This indicator detects unbroken sequences of river discharge below a daily low-flow threshold. The number of events is just one of the possible metrics to be used to quantify the “average” hazard of a region to drought.

Figure 6.6. Drought hazard according to YDSI, 1980-2013



(Source: JRC 2018)

Disclaimer: The boundaries and names shown and the designations used on these maps do not imply official endorsement or acceptance by the United Nations.

The foregoing exemplifies how the maps reported in Figures 6.3(a), 6.6 and 6.7 are just a few of the possible depictions of drought hazard. This highlights the complexity in providing a definitive measure of drought hazard. Similar arguments can be made for drought vulnerability and exposure, whose characterization is even more fundamentally

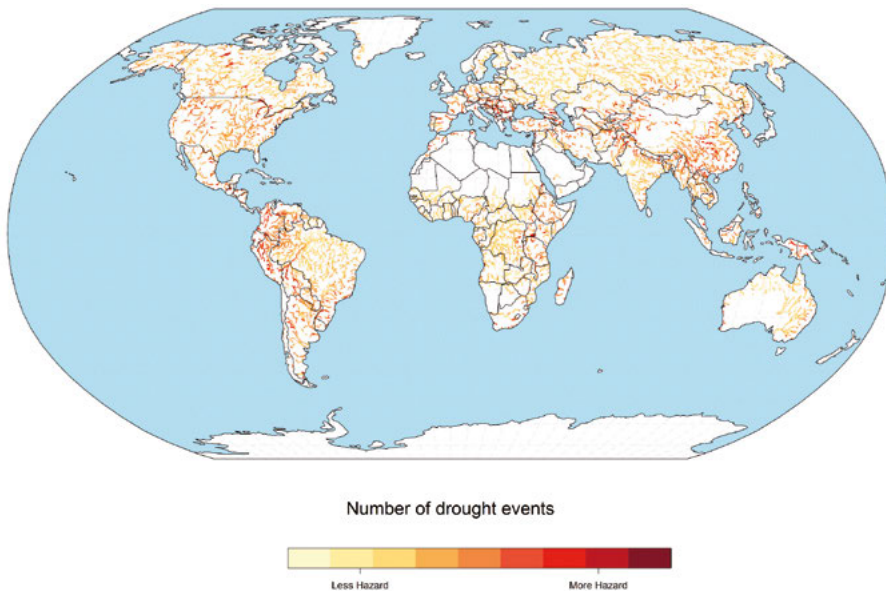
related to the factors considered relevant for the analysis. Factors relevant for assessing agricultural exposure and vulnerability may be irrelevant for energy production and vice versa, for example.

Even within a specific economic sector, the options for representation and quantification of risk and

its components are multifaceted. As an example, power plants may depend on water directly (hydro-power) and indirectly (cooling systems of generators). In both cases, insufficient water implies a reduction or a halt in energy production. Power plants typically use surface water,²⁷¹ therefore, they are affected by hydrological droughts and consequent low stream flows.

This translates into the likelihood of reduced water intake at the installation. An indicator such as the low-flow index of Figure 6.7 may provide a good indicator for the drought hazard for energy production. While the use of meteorological drought indices such as SPI has been tested for limited geographic scales,²⁷² a general correlation with hydrological droughts could not be established at the global scale.

Figure 6.7. Drought hazard according to the number of events detected by the low-flow index



(Source: JRC 2018)

Disclaimer: The boundaries and names shown and the designations used on these maps do not imply official endorsement or acceptance by the United Nations.

With regard to exposure, as electricity can be transported long distances from the source and across national boundaries, identifying people and assets potentially affected by reductions in power output is a challenging task. However, installed power capacity is a proxy for exposure (Figure 6.8): the higher the capacity, the higher the exposure, as presumably more electricity users are relying on it. This assumes that, even if power plants are not operated at full power, when energy demand is high, their full capacity is critical, especially when this occurs during warmer and drier periods.²⁷³ An advantage of

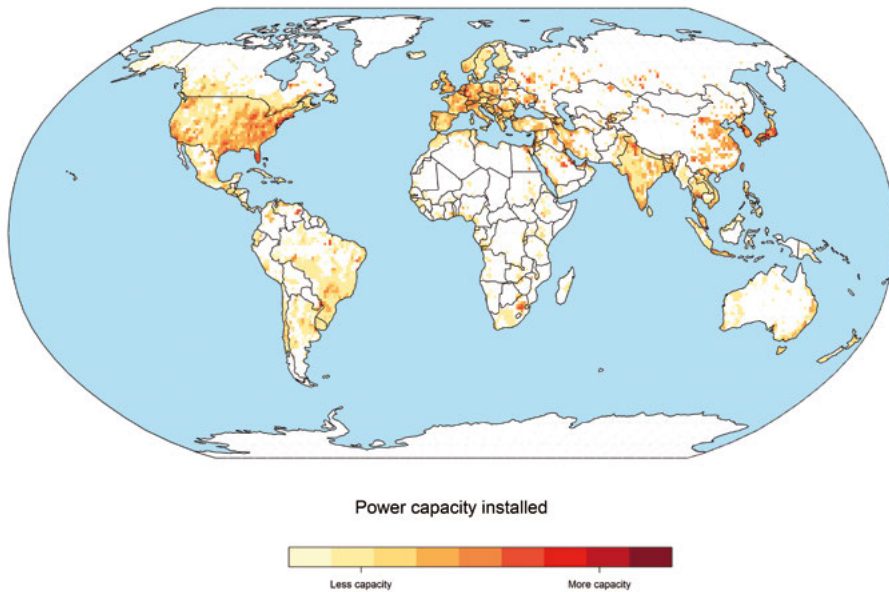
using power capacity is that thorough data is available for individual installations at the global level.²⁷⁴

Actual energy demand in a given time interval may provide a more accurate estimate of exposure. Such specific information is available only for a limited number of power plants, while the only consistent data is found at the national scale, such as yearly electricity consumption per capita. This data can be downscaled through population data (Figure 6.9), but with some caveats. First, the per capita consumption refers to the whole consumption, regardless

of the use. For instance, industrial sites in sparsely populated areas will strongly influence the per capita consumption in the related mapping unit. Second, it assumes that electricity consumption and generation

are located close together; therefore, a drought occurring at an important but remote power plant will not be accurately represented. Third, demand is equated to consumption (i.e. all demand is met).

Figure 6.8. Map of installed power capacity whose facilities depend on water directly or indirectly (cooling)



(Source: JRC 2018)

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Finally, vulnerability to droughts refers to the means available to mitigate the lack of water. Conceptually, this may have several definitions depending on the context. At the power plant level, it essentially relates to the amount of water required to produce a unit of energy.

From a broader perspective, country statistics on the energy sector can provide a wide range of indicators that are helpful to understand and model overall vulnerability to droughts. Examples

are the ratio between energy sources dependent and non-dependent on fresh water, the diversification of fuel types (which usually entails different capacity factors), the percentage of electricity imports against total use, the amount of freshwater resources per capita, the ratio of water use for energy production against the total, the electricity prices evolution, etc. Each of these descriptors may be combined to show specific aspects of vulnerability at the country scale.

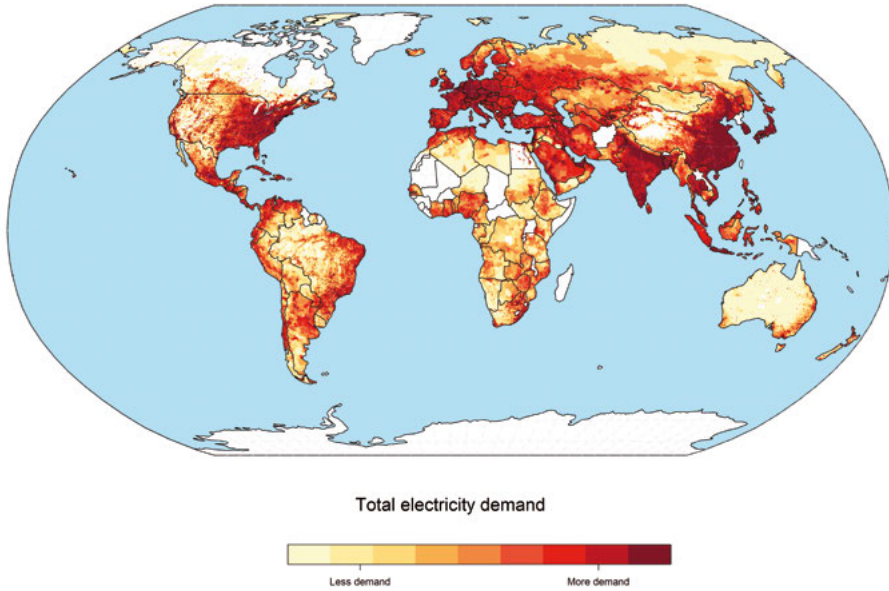
271 (Bauer 2014)

272 (Barker 2016); (Bayissa et al. 2018)

273 (van Vliet et al. 2016)

274 (Global Energy Observatory et al. 2018); (S and P Global Platts 2015)

Figure 6.9. Map of total electricity demand by population, as the yearly national electricity consumption per capita times population in 2015; note that all non-domestic uses are included



(Source: JRC 2018)

Disclaimer: The boundaries and names shown and the designations used on these maps do not imply official endorsement or acceptance by the United Nations.

Ideally, with specific information on power plant features, it would be possible to represent and upscale vulnerability from the individual power plant to the global scale. Data on the power sector is dispersed, uneven and sometimes inaccessible, but harmonized data sources are constantly evolving and improving.²⁷⁵ As an example of dynamic risk assessment at the power plant level, Figure 6.10 shows the situation in Europe during the abnormally hot and dry summer of 2003, when

several power plants had to reduce their output because they could not divert enough cooling water either physically or legally from the rivers.²⁷⁶ The map highlights the rivers most affected by low flows across Europe during the end of August 2003, by means of the low-flow index,²⁷⁷ and the nuclear power plants downstream at risk of power reductions. Several of those depicted had to reduce operations due to low water intakes or high-water temperature.

Box 6.2. European drought, 2003

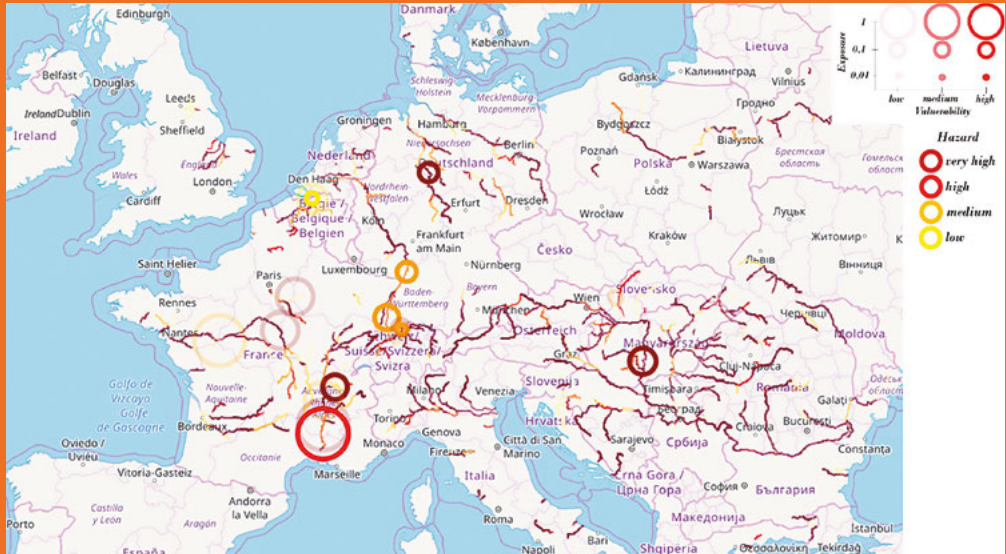
At the end of August 2003, due to the ongoing drought, several power plants in Europe were exposed to low-flow conditions. The three dimensions of risk for power generation can be represented as in Figure 6.10. The circle size is proportional to the gross

power capacity of the station, as a proxy for exposure (circles from smaller to bigger correspond to about 500 to 4,000 MW); the hazard is represented by the low-flow anomalies over the rivers affected (yellow, orange and red streams) and the river intake (circle

colour); the transparency level of circles highlights the level of vulnerability associated with the cooling system, with the more

intense colours related to the more vulnerable (i.e. a higher amount of water required per unity of energy output).

Figure 6.10. Major European rivers feeding hydroelectric power generation facilities, 2003



(Source: JRC 2018)

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

6.5.2

Scale considerations

Besides the highlighted differences in hazard, exposure and vulnerability among sectors, risk assessment is also dependent on the scale of analysis. This is due to the generally increasing detail of input data when moving to smaller spatial domains. As such, the presented methodology allows rescaling the analysis over different spatial domains and therefore obtaining adequate (useful) results at different scales of analysis. These can range from

the farm level to the continent and the global levels as demonstrated above, thus allowing analysis of the spatial distribution of the drought risk within a given area of interest (e.g. farm, country, region, continent or global levels).

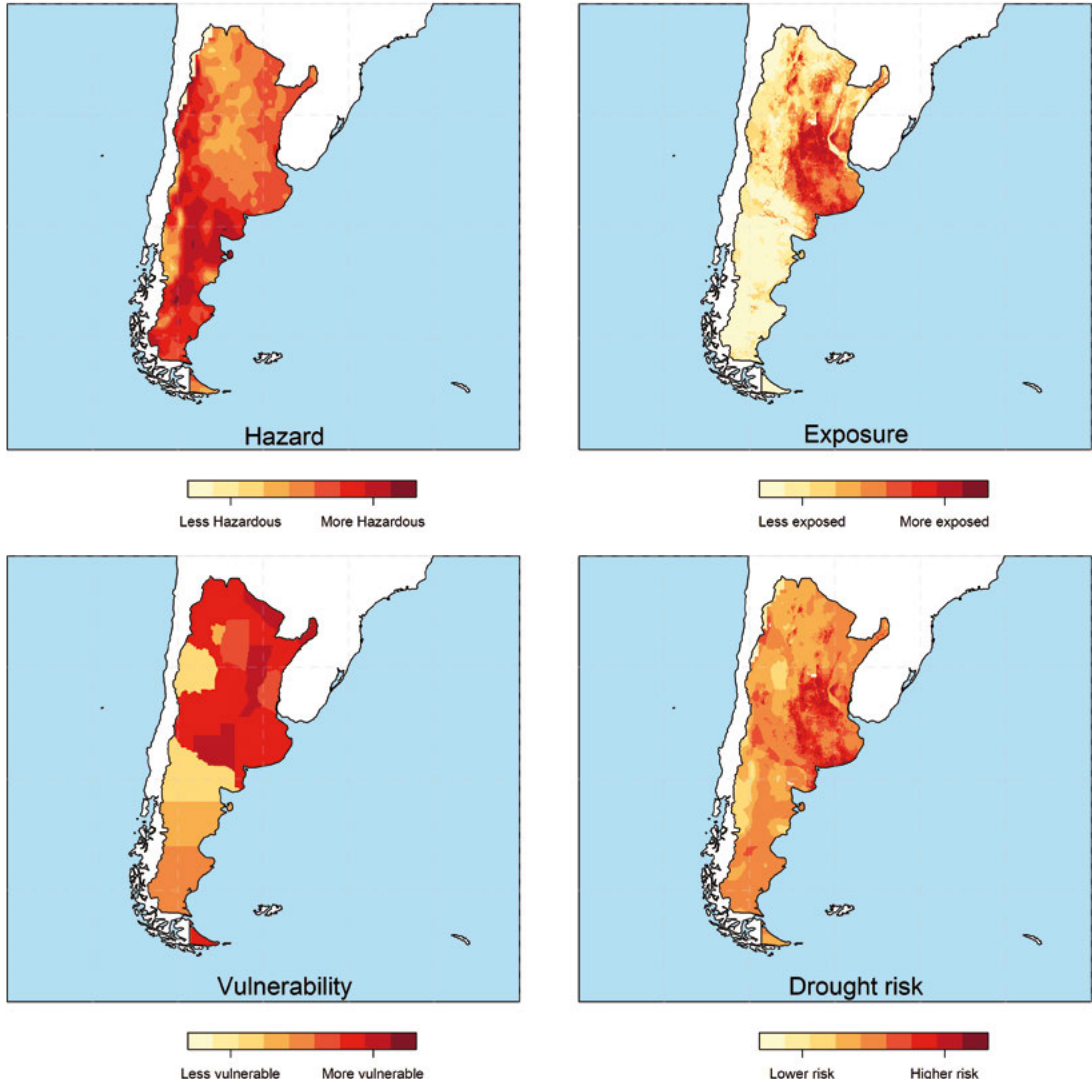
As this framework is data driven, more socioeconomic data at local levels is required to obtain reliable estimates. Wherever this information is available, it allows tailoring the analysis and setting adaptation strategies fitted to local requirements and specific sectors that might be adversely affected by droughts.

275 (Global Energy Observatory et al. 2018); (S and P Global Platts 2015)

276 (Fink et al. 2004)

277 (Cammalleri, Vogt and Salamon 2017)

Figure 6.11. Drought hazard, exposure, vulnerability and overall drought risk for Argentina in 2018



(Source: JRC 2018)

Disclaimer: The boundaries and names shown and the designations used on these maps do not imply official endorsement or acceptance by the United Nations.

Figure 6.11 shows the same analysis as shown in Figures 6.3 and 6.5 for the global level, based on the same data re-scaled for the domain of Argentina. The country analysis shows that vulnerability in Argentina is higher in the northern part of the country due to weaker infrastructure and other drivers.

Combining the vulnerability with the hazard and the exposure shows that the drought risk is lower for remote regions, and higher for populated areas and regions extensively exploited for crop production and livestock farming, such as the Buenos Aires, Córdoba and Santa Fe provinces. Regions characterized by a lower or almost null exposure experience a lower drought risk. As the remaining regions

are still subject to severe drought events, their risk increases as a function of the total exposed entities (mainly croplands) and their local coping capacity.

6.6

Drought impact

Drought conditions frequently 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, land and ecological conditions) or can continue long after precipitation has returned to normal (e.g. owing to groundwater, soil moisture or reservoir deficits). The slowly developing nature and long duration of drought, together with a large variety of impacts beyond direct and visible agricultural losses, typically make the task of quantifying drought impact difficult.²⁷⁸

Impact of droughts can be classified as direct or indirect.²⁷⁹ Examples of direct impacts include limited public water supplies, crop loss and damage to buildings due to terrain subsidence and reduced energy production. Because of the dependence of livelihoods and economic sectors on water, most drought impacts are indirect. These indirect effects can propagate quickly through the economic system, including trade, affecting regions far from where the drought originates. Indirect impacts 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. Drought-related damage may further

be classified as tangible (market related) or intangible (non-market related). The latter is particularly difficult to quantify, including, for example, ecosystem degradation or the costs of long-term adaptation measures.

In the few disaster databases that are publicly available, drought disasters are particularly poorly estimated or are underreported.²⁸⁰ The general lack of tangible damages combined with a prolonged duration make it extremely difficult to retrieve correct or attributable loss estimates. Given these data gaps, droughts are estimated at less than 7% of total losses from natural hazards since 1960.²⁸¹ However, it should be noted that there is a significant gap between the reported and real drought impacts, which hinders their systematic quantification.

Developed and larger economies like Australia, Brazil, China or the United States of America suffer from economic and environmental consequences of droughts. Less developed countries face more direct or indirect impacts on the population. Economic damage from single drought events can be catastrophic, with a single event capable of causing billions of dollars of damage. In term of losses, the most severe events can affect the economy of an entire region or country. For instance, according to NatCatSERVICE data, the severe drought in California in 2006 caused losses of \$4.4 billion, and during the 2013–2015 drought in midwestern United States of America, the reported losses were \$3.6 billion. Estimates of impacts are however thought to be much higher than these numbers as they primarily reflect direct agricultural damage. The 2013–2015 drought that affected central eastern Brazil (mainly São Paulo, Minas Gerais and Rio de Janeiro) was linked to reported losses of about \$5 billion. The 2010–2011 drought in the Horn of Africa is estimated to have caused up to a quarter of a million deaths, and to have left over 13 million people dependent on humanitarian aid.

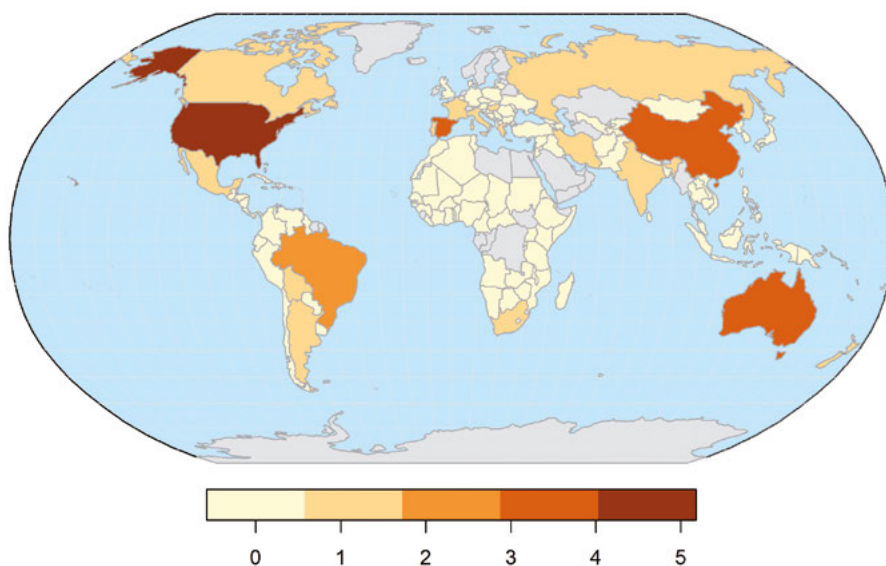
²⁷⁸ (Wilhite 2005)

²⁷⁹ (UNISDR 2011a); (Tallaksen and van Lanen 2004); (Meyer et al. 2013); (Spinoni et al. 2016)

²⁸⁰ (Svoboda et al. 2002)

²⁸¹ (Gall, Borden and Cutter 2009)

Figure 6.12. Expected annual damage due to droughts in billion \$, 2015



(Source: JRC with data from NatCatSERVICE, Emergency Events Database (EM-DAT) and DesInventar 2018)

Disclaimer: The boundaries and names shown and the designations used on these maps do not imply official endorsement or acceptance by the United Nations.

Approximately \$1.3 billion was spent on drought-relief measures.²⁸²

Among all economic activities, the agriculture sector has been one of the sectors most directly affected by drought. Impacts on health and water resources for non-agricultural uses are increasingly better understood. To identify trends in the economic impact of disasters on crops, livestock, fisheries and forestry, a review was conducted of 78 post-disaster needs assessments (PDNAs) undertaken in the aftermath of medium- to large-scale disasters in 48 developing countries in Africa, Asia and Latin America between 2003 and 2013.²⁸³ According to this GAR, agriculture absorbs on average about 84% of all the economic impact in these countries. Livestock is the second most affected subsector after crops, accounting for \$11 billion, or 36% of all damage and losses reported in PDNAs, where almost 86% of these losses were caused by drought events. Missing from these estimates are losses due to livelihood disruption, migration and insecurity. Environmental conditions affect

plants and their productivity during all phases of growth and development. Studies show that moisture stress in all growth stages reduced the grain yield significantly.²⁸⁴ Severe droughts are linked with significant reduction in yields of the main cereals and most other crops throughout the most drought-prone regions.²⁸⁵

The health of human populations is sensitive to shifts in weather patterns and other aspects of climate change. These effects occur directly, due to changes in temperature and precipitation and in the occurrence of heat-waves and droughts. Human health may be affected indirectly by ecological disruptions related to climate change (e.g. crop failures or shifting patterns of disease vectors) or by social responses to climate change (e.g. displacement of following prolonged drought) and the elderly face disproportional physical harm from heat stress and drought.²⁸⁶

Climate change is likely to increase the frequency and severity of meteorological and agricultural

droughts in presently dry regions by the end of the twenty-first century. Particularly vulnerable are countries located in arid and semi-arid regions where water stress will be further exacerbated due to strain from overexploitation and degradation already tangible under the present conditions.²⁸⁷ Consequently, many other economic sectors and ecosystems are likely to be adversely affected by climate change. For instance, freshwater-dependent biota will suffer directly from changes in flow conditions and also from drought-induced river temperature increases linked to discharge reductions.²⁸⁸ Decreases in soil moisture and increased risk of agricultural drought are likely in drylands, and the agricultural risk in these areas is projected to increase by the end of this century.²⁸⁹ This is likely to lead to an increased risk of food insecurity, which is particularly relevant for poorer populations. In many countries, increased fire risk, longer fire season and more-frequent large, severe fires are expected because of increasing heat-waves in combination with drought.²⁹⁰

6.7

Recognizing drought as a complex hazard

Drought is a slow-onset hazard, often referred to as a creeping phenomenon. The absence of a precise, universally accepted definition of drought adds to the confusion. Definitions must be region specific because each climate regime has distinctive climatic characteristics. Drought impacts are non-structural and are spread over larger geographic areas and temporal scales than damage that results from other natural hazards such as floods, tropical storms and earthquakes. Drought risk drivers include non-meteorological factors, and are often spatially or temporally removed from drought impacts. These characteristics of drought have hindered: development of accurate, reliable and timely forecasts; estimates of severity and impacts; and, ultimately, the formulation of drought management plans and implementation of appropriate risk reduction strategies. Similarly, local communities struggle to deal with the large temporal and spatial coverage usually associated with drought, resulting in secondary and tertiary impacts that may remain invisible to traditional risk assessments.

282 (OCHA 2011)

283 (FAO 2015b)

284 (Singh, Mishra and Imtiyaz 1991)

285 (Hlavinkaa et al. 2009)

286 (IPCC 2014); (van Lanen et al. 2017)

287 (IPCC 2014)

288 (van Vliet et al. 2016)

289 (IPCC 2014)

290 (Duguay et al. 2013)

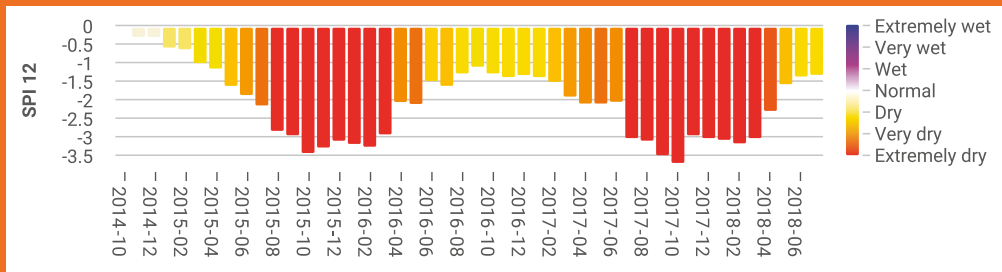
Box 6.3. Multiple droughts in South Africa

Since 2015, the South African province of Western Cape has experienced a sustained chain of very low and below-average precipitation periods, resulting in a hydrological drought that further intensified between April and September 2017. The precipitation deficit became, in early 2018, the worst drought recorded in the region in a century, and a true emergency

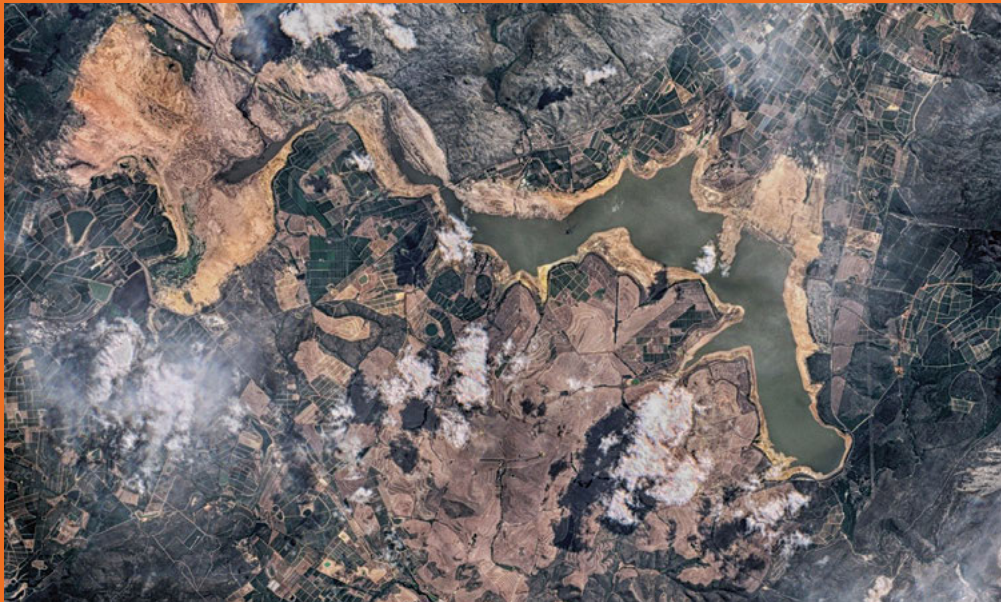
for the city of Cape Town. This is one of the biggest urban areas of the country with an exposed population of over four million people.

During this multi-annual drought, the water deficit propagated through the hydrological cycle, and most affected were the water reservoirs that supply Cape Town with drinking water.

Figure 6.13. Long-term SPI with a cumulative period of 12 months reaches extremely low values for many months, indicating a prolonged and severe hydrological drought in Cape Town, South Africa



(Source: JRC 2018)



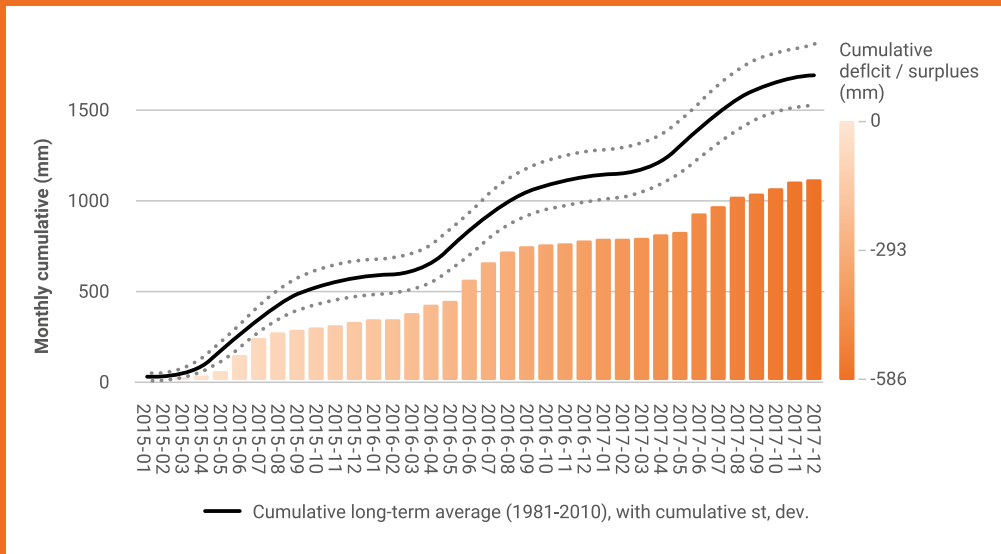
Theewaterskloof Reservoir at 12% capacity near Cape Town, South Africa, 10 February 2018

(Source: Antti Lipponen CC 2.0 2018)

Short-term meteorological indicators (e.g. SPI-3) did not detect any particularly harsh conditions at the peak of the drought, as precipitation in the previous quarter was close to normal, suggesting a mild drought at the most. However, longer rainfall accumulation

periods (e.g. SPI-12, Figure 6.13) show the serious lack of precipitation during the previous two years, with SPI values dropping to the “extreme drought” level. This entails a constant undersupply of water to reservoirs since at least early 2015.

Figure 6.14. Cumulative precipitation in Western Cape, South Africa, 2015–2017



(Source: JRC 2018)

Figure 6.14 indicates the cumulative deficit compared to the cumulated monthly long-term average (solid line), for the same timespan and location. There is a steady increment of the deficit in time, as result of the constant underperforming rainfall levels, compared to the normal.

During this event, city authorities restricted tap water allowance for any use to 50 litres per person per day. Due to the relatively dry climate of the region, several reservoirs are dedicated to water storage in Western Cape to cope with the periodical lack of precipitation. However, the situation was extraordinary, and critically low water levels put the

water supply chain in serious distress. The Theewaterskloof Reservoir, the largest in the Western Cape water supply system, holding 41% of the water storage capacity available to Cape Town went to critically low levels in early 2018 (about 11% of the 480 million m³ total capacity). In addition, due to the fast demographic growth of the city in recent years, the water infrastructure has not kept pace with demand. Thanks to water rationing and collective water-saving efforts, as well as some precipitation events, the so-called “day zero” was avoided for 2018. However, the complete recovery from this water crisis depends on the replenishment of reservoirs and the operational availability of alternative sources.



Portion of Theewaterskloof Reservoir, close to empty in 2018, showing tree stumps and sand that are usually covered by water
(Source: Zaijan 2018)

6.8

Drought risk management

While it is impossible to control the occurrence of droughts, the resulting impacts may be mitigated through appropriate surveillance and management strategies in a drought management plan.

The proactive approach is based on short- and long-term measures and includes monitoring systems for a timely warning of drought conditions, the identification of the most vulnerable part of the population and tailored measures to mitigate drought risk and improve preparedness. The proactive approach entails planning necessary measures to prevent or minimize drought impact in advance.

Drought monitoring and early warning (Pillar 1) is the foundation of effective proactive drought policies to warn about impending drought conditions. It identifies climate and water resources trends and detects the emergence or probability of occurrence and the likely severity of drought and its impact. Reliable information must be communicated in a timely manner to water and land managers, policymakers

and the public through appropriate communication channels to trigger actions described in a drought plan. That information, if used effectively, can be the basis for reducing vulnerability and improving mitigation and response capacities of people and systems at risk.

Vulnerability and impact assessment (Pillar 2) aims to determine the historical, current and likely future impacts associated with drought and to assess the vulnerability. Drought impact and vulnerability assessment aims to improve the understanding of the natural and human processes associated with drought and the impacts that can occur. The outcome of the vulnerability and impact assessment is a depiction of who and what is at risk and why.

Figure 6.15. Three pillars of integrated drought management



(Source: UNDRR, after Pischke and Stefanski 2018)

The work related to drought mitigation, preparedness and response (Pillar 3) determines appropriate mitigation and response actions aimed at risk reduction, identification of appropriate triggers to phase in and phase out mitigation actions, particularly short-term actions, during drought onset and termination and, finally, identification of organizations to develop and implement mitigation actions. Triggers are defined as specific values of an indicator or index that initiate and/or terminate responses or management actions by decision makers based upon existing guidelines or preparedness plans.²⁹¹ Triggers should link indices or indicators to impact.

To move from a reactive to a proactive approach, local or regional conditions must be taken into consideration, including the legislative and administrative framework as well as the local drought drivers. An effective drought management plan should provide a dynamic framework for an ongoing set of actions to prepare for, and effectively respond to drought, including: periodic reviews of the achievements and priorities; readjustment of goals, means and resources; and strengthening

institutional arrangements, planning and policymaking mechanisms for drought mitigation.²⁹²

A key decision support tool for crisis mitigation is embedded within the concept of early warning information systems across timescales. Efforts in drought early warning continue in countries such as Brazil, China, Hungary, India, Nigeria, South Africa and the United States of America.²⁹³ Regional drought monitoring activities exist or are also being developed in Eastern and Southern Africa and efforts are ongoing in West Asia and North Africa. Research and experience in several watersheds show that several paradoxes in multistate water management and governance across borders can militate against the accurate assessment of socioeconomic impacts and the effective use of scientific information for meeting short-term needs in reducing longer-term vulnerabilities.

These lessons include an expanded use of incentives for improving collaboration, water-use efficiency, demand management and development of climate services to inform water-related management as new threats arise.

291 (Svoboda and Fuchs 2016)

292 (EC 2007)

293 (Pulwarty and Sivakumar 2014); (Wilhite and Pulwarty 2017)

Several cases show that changes in the management of climate-related risks (in this case, drought) may be most readily accomplished when: (a) a focusing event (climatic, legal or social) occurs, creating widespread public awareness and opportunities for action; (b) leadership and the public, the so-called “policy entrepreneurs”, are engaged; and (c) a basis for integrating research and management is established.²⁹⁴ This latter dimension emphasizes the structure for developing the capacity to apply knowledge and to evaluate the consequences of actions among partners, to ensure the reliability and credibility of the projections of changes in the system outputs and to enable acceptable revisions on management practices in light of new information. Examples of end-to-end information systems in which monitoring and forecasting, risk assessment and engagement of communities and sectors are aligned across the weather-climate continuum are exemplified by the National Integrated Drought Information System (NIDIS) and the Famine Early Warning System Network (FEWSNet), which provide coordination of diverse regional, national and local data and information for supporting planning and preparedness.²⁹⁵ Owing to FEWSNet, there have been successful cases of drought risk interventions to prevent humanitarian crises, including the severe drought in Ethiopia in 2015–2016.

However, drought remains a “hidden risk”.²⁹⁶ The microlevel actions involving households, communities and individual businesses are often underappreciated but are arguably the most important elements of drought risk mitigation. This is summarized as follows:²⁹⁷

- More secure land tenure and better access to electricity and agricultural extension were found to facilitate the adoption of drought risk mitigation practices among agricultural households in Bangladesh. Similarly, access to secure land tenure, markets and credit played a major role in helping farmers cope with droughts in Morocco.
- Improved access to credit helped farming households in Ethiopia to cope better with drought impacts since they no longer needed to divest their productive assets. Moreover, as many rural households in Ethiopia tend to channel their

savings into livestock, which may be wiped out during droughts, developing access to financial services and alternative savings mechanisms could also help to mitigate drought risk.

- Land-use change and modification of cropping patterns are frequently cited as ways to build resilience against droughts.
- Improved diversification of livelihoods by adopting off-farm activities and divesting of livestock assets.
- A strong asset base and diversified risk management options are among the key characteristics of drought-resilient households in Kenya and Uganda. These aspects were due primarily to the households having better education and greater knowledge of coping actions against various hazards. This allowed them to diversify their income sources.

Although drought insurance is an effective and proactive measure, the development of formal drought insurance mechanisms is hindered in many developing countries by obstacles such as high transaction costs, asymmetric information and adverse selection.²⁹⁸

The experience of JRC, the Integrated Drought Management Programme, NIDIS, FEWSNet and other information and risk management systems illustrates that early warning represents a proactive social process whereby networks of organizations conduct collaborative analyses and coordination.²⁹⁹ In this context, indicators help to identify when and where policy interventions are most needed, and historical and institutional analyses help to identify the processes and entry points that need to be understood if vulnerability is to be reduced. Taking local knowledge and practices into account promotes mutual trust, acceptability, common understanding, and community sense of ownership and self-confidence.³⁰⁰ As important as indicators are to such systems, it is also the governance context in which EWSs are embedded that needs further attention. A mix of centralized and decentralized activities is required, particularly for people-centred strategies at the so-called “last mile”.

EWSs are more than scientific and technical instruments for forecasting hazards and issuing alerts. They should be understood as sources of scientifically credible, authoritative and accessible knowledge. These integrate information about and from areas of risk that facilitate decision-making (formal and informal) in a way that empower vulnerable sectors and social groups to mitigate potential losses and damage from impending hazard events.

The costs of proactive drought management are usually lower than the costs of inaction, and can generate significant economic benefits. For example, one study estimated that every dollar spent by the United States Federal Emergency Management Agency (FEMA) on drought risk mitigation,^{301,302} the country would save at least \$2 on future disaster costs. Related actions to mitigate drought impacts include more secure tenure, better access to electricity, improved access to credits, land-use change and modification of cropping patterns, better use of groundwater resources and adoption of off-farm activities to diversify livelihoods.³⁰³

Drought risk management can have substantial socioeconomic co-benefits, as some of the related actions build resilience against droughts and also against additional socioeconomic and environmental shocks. Regional and local networks that provide agricultural extension, precision farming, off-farm activities and higher education, for example, which are associated with stronger resilience to drought shocks, were identified as factors that also help address land degradation, facilitate poverty reduction and improve household food security.³⁰⁴

6.9

Way forward

Assessing the risk for drought-related impacts to society and environment is a difficult task. It is complicated by the creeping nature of the phenomenon, its often-large spatial extent and temporal duration, leading to cascading impacts that may affect areas distant from the drought and it may last long after the drought has ceased. Missing standardized data on past impacts (damage and loss) is a further complication. Finally, the interlinkages with other hazards such as wildfires, heatwaves and even floods and the combined risks need to be explored. These risk assessments need to be sector specific, requiring an adequate set of environmental and socioeconomic data related to the respective sectors.

Many hot spots that show fragility in the face of climate change also exhibit soil moisture and soil quality reduction combined with reduced adaptive capacity. Scenario planning (based on past, present, and projected events) may provide better understanding of whether and how best to use probabilistic information with past data and cumulative risks across climate timescales. There is a strong need to approach climate model outputs far more critically than at present, especially for impact assessment to support adaptation at the local level. Central to all of the above is a sustained network of high-quality monitoring systems.

The major assumption behind proactive action around drought is that present or upfront actions and investments can produce significant future

294 (Pulwarty and Maia 2015); (Wilhite and Pulwarty 2017); (Gleick S2018)

295 (Pulwarty and Verdin 2013)

296 (UNISDR 2011a)

297 (Gerber and Mirzabaev 2017b)

298 (OECD 2016)

299 (Pulwarty and Verdin 2013)

300 (Dekens and International Centre for Integrated Mountain Development 2007)

301 (Multihazard Mitigation Council 2005)

302 (Logar and van den Bergh 2013)

303 (Gerber and Mirzabaev 2017a)

304 (Gerber and Mirzabaev 2017a)

benefits. No comprehensive study exists for drought. Some have outlined the advances to date in assessing benefits of action and the costs of inaction.³⁰⁵ In drought and other hazards, much more work needs to be done to realize what has been called the “triple dividend of resilience”.³⁰⁶

The benefits include:

- a. Avoiding losses when disasters strike
- b. Stimulating economic activity from reduced disaster risk
- c. Developing co-benefits, or uses, of a specific disaster risk management investment

The need to explicitly acknowledge differing social values, to strengthen institutional mechanisms for collaboration, and to collect standardized data on drought impacts as a basis for reducing vulnerability and enhancing resilience needs to be acknowledged. How drought and climate change may play into future fragility will be an area of increasing research and security interest.

6.10

Emerging issues: setting the context for the 2020 special report on drought

Despite the significant advances of the past century of drought research, in an increasingly interconnected world, several areas of concern for drought risk management are emerging:

- a. Uncertainties associated with climate change and its manifestation at all levels including cascading risks.
- b. Understanding the increasingly complex pathways through which drought affects filter (e.g. the water–energy–food nexus, socioecological buffers and thresholds).
- c. Assessing the costs of drought impacts, and the benefits of action and costs of inaction.
- d. Enhancing the role of technology, efficiency and community-based knowledge.
- e. Links to human security, globally networked risks and conflict that affect resilience.
- f. Emphasizing the role of governance, financing and decision-making in anticipating, assessing and acting on reducing and managing the impacts of complex risks.
- g. The need to explicitly acknowledge various social values and strengthening institutional mechanisms for collaboration, including data collection. How drought and climate change may play into future fragility will be an area of increasing research and security interest.

In the light of these challenges, UNDRR will publish a special report on drought risk in 2020. The foregoing discussion highlighted some of the key aspects and challenges to be discussed and further explored in this special report.

Part I

Conclusions and recommendations

Conclusions

This part has endeavoured to demonstrate the scope of current knowledge on risk management across a range of hazards. It has also outlined that measurement, quantification and proportionate responses are almost certainly inadequate to meet the challenges of the multifaceted interconnectiveness of hazard, the barely understood richness of exposure and the profound detail of vulnerability that it will take to ever do more than treat the symptoms. Risk really is systemic, and it requires a concerted and urgent effort to work in integrated, systemics and innovative ways.

Recommendations

- **Connect and collaborate:** This work is already under way and was before the Sendai Framework came into effect. But the ambition, richness and expansive spirit of cooperation required to meet systemic challenges will require levels of selfless humanism that match the scale of the challenge. In particular, integration with social science research is important.
- **Invest:** Resource challenges are always the first-cited obstacle to better risk management. EO, computing power, mitigation measures, regulatory enforcement and safety nets should be invested in, as should reducing inequality and improving participation, access and education.

- **Leverage:** The movement towards open data, collaborative science and cloud computing is in a golden age. The value of information is such that impulses towards hoarding, insularity, competition and protection could come to dominate an increasingly unequal world. This is the moment to capitalize, entrench and fortify the values of mutual support and humanity.
- **Relish uncertainty:** Past GARs have avoided including drought as fulsomely as other hazards, particularly due to intractability. It has so many drivers and so many effects, which are often indirect. This should not be a reason to avoid talking about them as damaging hazards that affect hundreds of millions of people a year and exact an untold economic toll. Risk will never be simple again. That is difficult and important to accept for risk scientists, for policymakers and for anyone faced with the task of communicating risk.

"Millions don't rally to the banner of uncertainty"
- George Packer