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Floods and Droughts

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CONTENTS

Executive Summary

The largest number of flooding events during the last decades in the RIOCC region took place in Brazil, Mexico, Colombia and Peru (between 1985 and 2015), together with increases in the maximum daily flows in the La Plata and Amazon basins. In recent years, many Ibero-American regions also suffered frequent and extensive droughts, including the Iberian Peninsula, the Amazon region, north-central Mexico, and central Chile and Argentina.

Despite considerable uncertainties about future changes with respect to the incidence of droughts and floods, adaptation processes must be developed based on the best available scientific knowledge. Under warmer climate conditions, the available climate scenarios for the foreseeable future indicate that changes in the different components of the water cycle will continue to affect the RIOCC region unevenly. Increases in peak flows are projected for Colombia, Venezuela, Ecuador, the coastal region of Peru, the Plata basin, Central America and the Iberian Peninsula (except the Mediterranean coast) and increases in the incidence of droughts in the Amazon, northeast Brazil, the Mediterranean region, Central America and Mexico.

With regard to population exposure, between 1980 and 2000 the five Latin American countries with the largest populations exposed to drought were Guatemala, Chile, Ecuador, Mexico and Nicaragua. In the case of floods, the most exposed countries were Guatemala, El Salvador, Honduras, and Colombia.

Population growth, accelerated urbanization of informal human settlements, lack of well-planned and quality infrastructure, high rates of social inequality, poverty, agriculturally dependent economies and inadequate environmental practices are all socio-economic factors that foster vulnerability and result in water deficit and excess events having an even greater impact. Vulnerability to droughts and floods differs greatly among different RIOCC countries due to contrasts in the abovementioned factors; however, it is essential that efforts to reduce them are guided through collective action by the Ibero-American community.

Several multi-scale climate change adaptation measures with regard to droughts and floods are already being implemented in Latin America. These include improving the quality of forecasts, early warning systems and climate information services, plans for reducing vulnerability and increasing the resilience of the population, strategic infrastructure and production systems, and the conservation and sustainable use of ecosystems and their environmental services. Yet there are still institutional, regulatory, administrative, economic and social obstacles that can delay the implementation of some of these measures. Consequently, to accelerate the adaptation process, countries will need to improve their planning and response capacities, as well as their disaster management and insurance schemes.

10.1. Introduction

10.1.1. Conceptual framework of this Chapter

Global warming observed over several decades has been linked to changes in the hydrological cycle on a large scale: increased water vapor content in the atmosphere; changes in precipitation characteristics, intensity and extremes; decreased snow cover and widespread ice melting; and changes in soil moisture and runoff along with changes in intensity, duration, frequency and spatial extent of extreme events such as droughts and floods (Hartmann et al., 2013). These changes constitute the so-called intensification or acceleration of the hydrological cycle (Held and Soden, 2000; Arnell et al., 2001; Huntington, 2006). Under warmer weather conditions, projections suggest that changes in the different components of the water cycle will continue, although with uncertainties about the occurrence of droughts and floods. These uncertainties derive, on the one hand, from a limited understanding of the mechanisms that produce them and, on the other, from natural climate variability. The fact that floods and droughts depend on precipitation surpluses and deficits, respectively, means that the uncertainties of climate models are also relevant (Hawkins and Sutton, 2011; Fatichi et al., 2016; Zhou and Dai, 2017).

This chapter outlines a number of issues related to adaptation to droughts and floods. They are supported by examples in different RIOCC countries based on the conceptual framework shown in **Figure 10.1**, which contextualizes the need for adaptation to droughts and floods in the face of a changing hydrological cycle, caused by the increase of greenhouse gases in the atmosphere due to anthropogenic emissions. The guiding premise is that adaptation processes should be developed based on the best available scientific knowledge, even though there are great uncertainties about changes in the incidence of these phenomena in the coming decades. In this regard, it should be borne in mind that actions to reduce these uncertainties will make a significant contribution to climate change adaptation.

10.1.2. Main figures of the sector or system

In recent decades, floods have caused almost half of the world's climate-related disasters and have affected more than two billion people (CRED, 2015). The relative importance of floods has also increased during this period, either in terms of economic losses (Kundzewicz et al., 2013), reinsurance losses (Mills, 2005) or the number of reported flood events (Munich Re, 2015). However, it is not yet clear why these observed changes happen. Possible causes include increases in the magnitude or frequency of extreme precipitation (IPCC, 2014) or changes in land use (Hall et al., 2014).

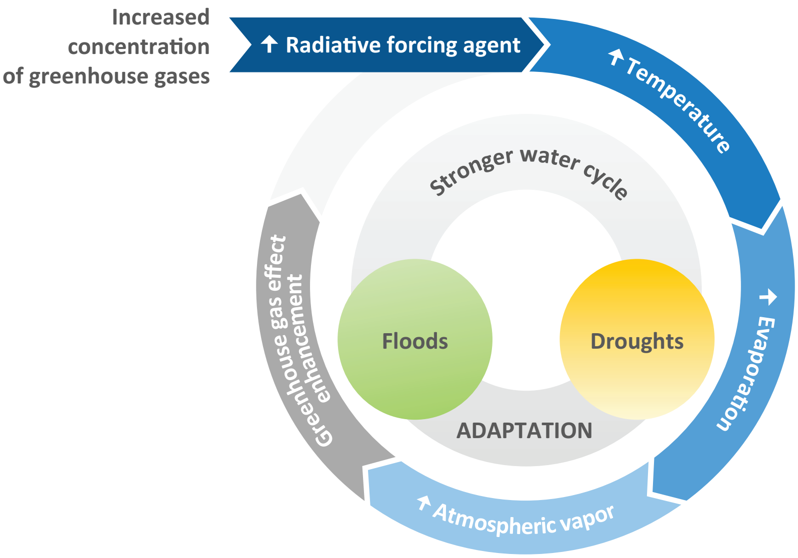

Figure 10.1. A conceptual framework linking the physical drivers of drought and floods with the need to implement adaptation measures. Source: prepared by the authors.

Between 2000 and 2019, 548 flood events were recorded in Latin America and the Caribbean, affecting a total of 41 million people and causing US$26 billion worth of damage (OCHA, 2019). Between 2005 and 2015, drought caused US$13 billion in damage to crops and livestock throughout the region (FAO, 2018).

10.1.3. Relationship of the sector or system with climate and climate change

10.1.3.1. Floods

A flood is defined as the overflow of water outside its normal boundaries (IPCC, 2012). Floods are a source of risk because they generally take place in areas that are either populated or sustain productive activities. In many cases, particularly in Latin America, risk is higher because these areas are home to highly vulnerable populations that live in poverty. This chapter categorizes floods according to the type of climatic (or other) phenomenon that causes them, as well as their associated impacts.

Types of floods

Very localized, short-term floods. From the point of view of potential damage to the population, including loss of life, intense precipitation resulting from convective systems in steep areas is the greatest danger, because they may cause sudden floods and landslides. Tropical storms and cyclones produce these effects in the Caribbean region, in Central America and on the Mexican coast (see **Chapters 9 and 11** of this report). In lowland plains at subtropical latitudes, convective mesosystems are equally dangerous. In a few hours, they can produce precipitations of several hundred millimeters over areas of hundreds of km^2 (Rasmussen et al., 2016).

River overflows. In Latin America there are many large rivers that upon overflowing can flood vast areas of tens of thousands of km^2. In the great plains of South America these floods can last months and even more than a year, such as the one that took place between 1982 and 1983 in the Argentinean basin of the Paraná River (Camilloni and Barros, 2003). The strong precipitation anomalies that cause them are also long-lasting and can take place hundreds and even thousands of kilometers upstream of the flooding areas. In that case, the flood wave takes weeks or months to arrive, making the flood predictable. This can buy enough time to make appropriate decisions that can minimize adverse impacts.

Flooding of large plains. In areas with very gentle slopes, such as the Pantanal or part of the Argentine plains, water runoff is low and the water balance between precipitation, evaporation and infiltration into the soil is predominantly nil. When there is heavy rainfall for prolonged periods of several months, the soil becomes saturated, ceasing to infiltrate and producing excess water on the surface. In the Pantanal, this type of flooding occurs regularly every summer, although it may be more widespread in some years. In the subtropical region of Argentina, since there is very little evaporation in the cold seasons, possible excess water in autumn or winter can persist until spring or summer. This type of flooding becomes aggravated by inappropriate soil management that leaves them without vegetation cover for several months (Taboada and Damiano, 2017).

Coastal flooding. On some coasts, storms in the surrounding sea that produce strong winds can push the surface waters, causing coastal flooding. These floods become even larger when they happen together with high astronomical tides. The height of the flood and its extent depend on the coastal topography and the storms that cause it. In the Caribbean, and the Pacific coast of Mexico and Central America, these floods are caused by tropical storms and cyclones; while in the Iberian Peninsula and subtropical South America they are due to extratropical cyclones. The most paradigmatic case is that of the southeastern areas of the Rio de la Plata estuary, which tend to flood the lower coasts on the Argentinean side. In the mid-latitudes of South America, this type of flooding is rare because the coasts on both oceans are very high. On the other hand, the entire Pacific coast of Latin America is threatened by tsunamis, which can cause very severe flooding on the lower coasts. Both tsunami and coastal storm flooding last only a few hours or days, although recovery from damage can take months or years. This type of flooding is discussed in more detail in **Chapter 9** of this report.

Flooding due to infrastructure collapse. Floods due to the bursting of a dam are very rare compared to other types of floods, but when they do occur they usually cause great damage and loss of life. The most dramatic and recent episode was the rupture of a tailings dam in the city of Brumadinho, Brazil, on January 25, 2019, which caused a mudslide and killed 300 people. The most frequent cause of a dam collapse is when it becomes so full that the flow exceeds its storage and discharge capacity. This is why increased intensity and frequency of extreme precipitation due to climate change may heighten the risk of this type of disaster, if dams have been designed without taking this into account and using low safety coefficients. Countries have adopted dam safety regulations, and some of them (for example, Uruguay and Argentina) have adapted them to withstand new extreme precipitation conditions.

Seasonal snowmelt flooding. Because snow-covered surfaces in Ibero-America are relatively small and limited to the highest areas, this type of flooding is rare in the region. Liquefaction and thawing in the mountains takes place in springtime, as the seasonal 0°C isotherm rises.

Observed changes

Figure 10.2 shows the trends in magnitude of flooding events derived from the maximum daily flow for each year of between 1955 and 2014 for a number of stations estimated by Do et al. (2017). In the RIOCC region, significant negative trends are found mainly in northeastern Brazil and Mexico, while positive ones can be seen in the Plata and Amazon basins.

More recently, Najibi and Devineni (2018) analyzed flood incidence trends between 1985 and 2015 from the Dartmouth Flood Observatory database. The findings suggest a global increase in the frequency of flooding, as well as an increase in the occurrence of medium (8 to 20 days) to long (more than 21 days) lasting events. Najibi and Devineni (2018) also identified the countries with the highest number of flooding events during the study period, which included Brazil (96 events), Mexico (80 events), Colombia (44 events) and Peru (43 events).

10.1.3.2. Droughts

A drought is characterized by a prolonged period of abnormally dry weather that produces serious hydrological imbalances (IPCC, 2012). The severity of the drought is determined by the intensity, duration, and geographic extension of the specific episode. Intensity refers to how much precipitation decreases, together with the severity of its associated impacts. In terms of duration, droughts usually require a minimum of 2-3 months to be considered as such, although they can continue over several consecutive years. The magnitude of the drought's impacts is closely related to the time when the decrease in precipitations begins, as well as its intensity and duration.

Types of droughts

Meteorological drought. Precipitation scarcity. Often aggravated by high temperatures that induce high evapotranspiration

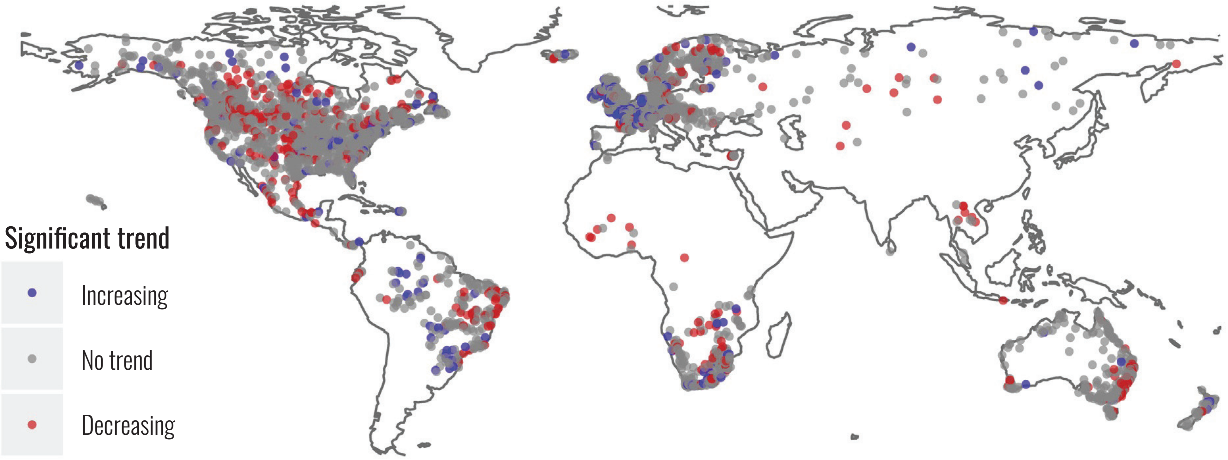

Figure 10.2. Trends in flood event magnitude. The blue (red) dots show stations with statistically significant upward (downward) trends for a 10% confidence level. The gray dots indicate non-statistically significant trends. Source: Do et al. (2017).

rates. This type of drought is based on climate data and is expressed by the deviation of precipitation from the average over a given period of time.

Hydrological drought. This refers to a shortage in the flow or volume of surface or ground water (rivers, reservoirs, lakes, etc.). The frequency and severity of a hydrological drought are usually characterized by the drought's influence on river basins.

Agricultural drought. This happens when there is not enough humidity in the soil to allow certain crops to develop in any of their growth phases. The water demand of a plant depends on meteorological conditions, specific biological characteristics of the plant, its growth stage, and the soil's physical and biological properties.

Socioeconomic drought. This happens when water availability decreases to the point of producing damage (economic or personal) to the population of the area affected by the scarcity of rainfall or when the demand for water exceeds availability, thus affecting a community. Socio-economic drought links the supply and demand of a particular economic good or service with meteorological, hydrological and agricultural droughts.

Figure 10.3 shows the types, forces and interrelations between the aforementioned droughts. Although precipitation deficit is considered a primary cause of drought, excessive evapotranspiration can constitute an additional driver for hydrological or agricultural droughts. However, it should be noted that lack of soil moisture is also a conditioning driver for evapotranspiration. Furthermore, pre-existing soil moisture conditions, as well as surface or groundwater storage are also relevant for the incidence and duration of this type of drought. Socio-economic drought links the supply and demand of a particular economic good or service with meteorological, hydrological and agricultural droughts.

Observed changes

In recent years, many regions of Latin America have suffered frequent and prolonged droughts. Some examples include the droughts that took place in the Iberian Peninsula between 2005 and 2007 (Spinoni et al., 2015), in 2005, 2010 and 2015/2016 in the Amazon region (Marengo et al., 2008; Lewis et al., 2011; Jiménez-Muñoz et al., 2016), in central-northern Mexico during 2011 and 2012 (Neri and Magaña, 2016) and in central Chile between 2010 and 2015 (Garreaud et al., 2017). While climate variability is often the main cause of individual drought events, the increase in the occurrence of severe cases during recent years in many regions is consistent with results derived from forced simulations with increases in greenhouse gas concentrations (Dai and Zhao, 2017).

To quantify the drought and monitor its evolution, many indices have been developed and applied. One of the most widely used ones is the Palmer Drought Severity Index (PDSI) (Palmer, 1965), whose value is derived from data on precipitation, air temperature and local soil moisture, together with earlier values from these measurements. One of the most widely used variants of PDSI is the annual index *sc_PDSI_pm* (Dai, 2011; Dai and Zhao, 2017).

Day and Zhao (2017) have analyzed a worldwide linear trend of the *sc_PDSI_pm* annual index between 1950 and 2014 calculated on the basis of observational data. Its results show progressively drier areas mainly in the Iberian Peninsula (IBE), Central America and the Caribbean (CAC), the Amazon (AMZ) and southwest South America, which is explained by the rising regional temperatures that increases the capacity of air to hold water vapor, along with the observed precipitation trends (see **Figure 1.7** in **Chapter 1**).

Other frequently used indices are the Standardized Precipitation Index (SPI; McKee et al., 1993; Guttman, 1999), which is based on precipitation only, and the Standardized Precipitation-Evapotranspiration Index (SPEI; Vicente-Serrano et al., 2010; Beguería et al., 2014), which is based on the difference between precipitation and potential evapotranspiration (including temperature). Recently, Spinoni et al. (2019) developed a database of meteorological droughts occurring between 1950 and 2016 using the SPI and SPEI indices and calculated the changes in frequency and severity for the indices considering a 12-month accumulation period (SPI-12 and SPEI-12). **Figure 10.4** shows a comparison between 1951-1980 and 1981-2016. It appears that some parts of the RIOCC region such as Mexico, the Amazon and northeast Brazil, Patagonia and the Iberian Peninsula experienced a higher frequency of droughts based on both indicators (although more frequently based on the SPEI-12 index). The

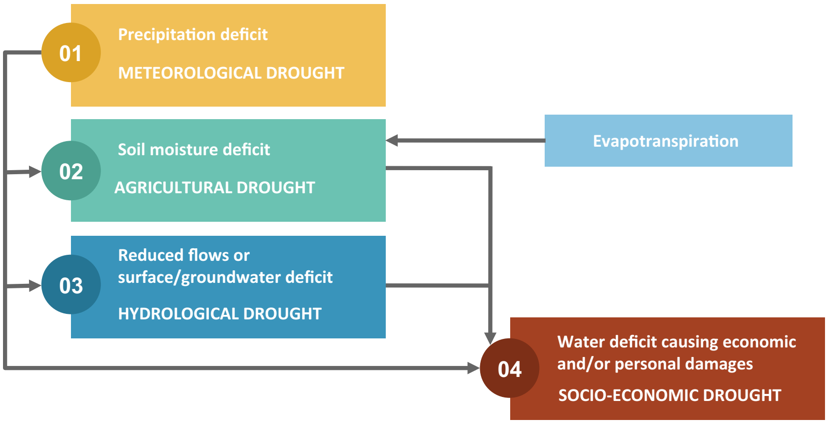

Figure 10.3. Drivers (colored boxes) and interrelationships (arrows) between different types of droughts. Source: adapted from IPCC 2012.

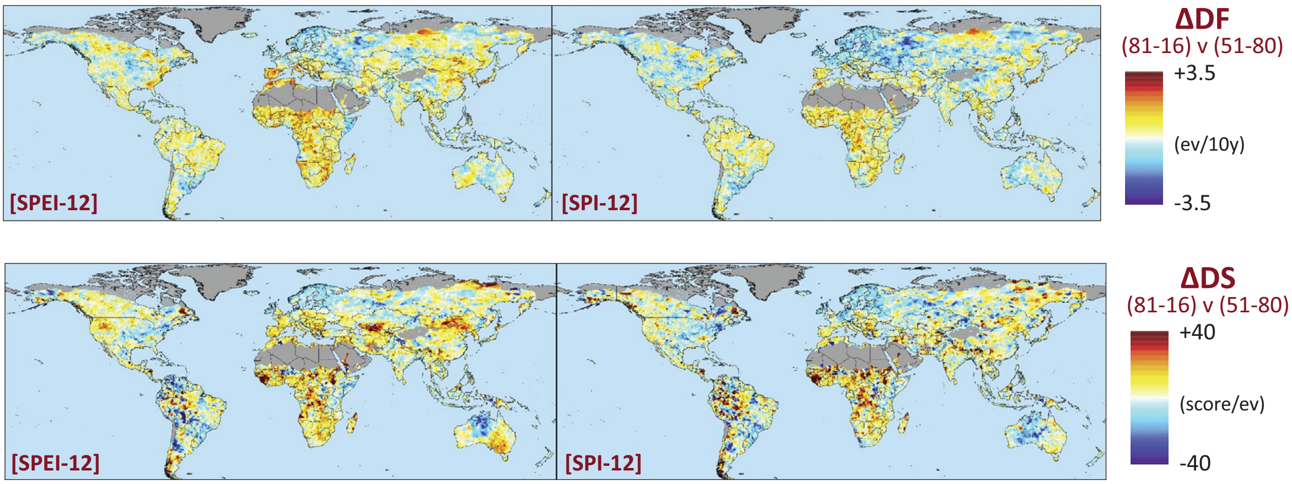

Figure 10.4. Change in frequency of occurrence (maps above; ΔDF expressed as events/10 years) and severity (maps below; ΔDS>0 indicates increased severity, ΔDS<0 indicates a decrease in the severity) of droughts between 1951-1980 and 1981-2016 according to the Standardized Precipitation-Evapotranspiration Index (SPEI-12) (left) and the Standardized Precipitation Index (SPI-12) (right). Source: Spinoni et al., 2019.

most relevant decrease can be found in the north of Argentina and Uruguay. Compared to 1951-1980, during 1981-2016 meteorological droughts were more severe for both SPEI-12 and SPI-12 in parts of Patagonia and southern Chile, Nicaragua, Honduras, southern Mexico and Baja California, and the Iberian Peninsula. In contrast, southeastern Brazil experienced less severe droughts. **Figure 10.5** shows annual evolution of the drought-covered area according to the SPI-12 and SPEI-12 indices for five regions that include all the RIOCC countries. The South of South America (SSA) and the Mediterranean region (MED) show a clear trend towards a greater percentage of areas with drought.

10.1.4. Review of previous reports

The Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC, 2012), prepared by the Intergovernmental Panel on Climate Change, as well as the Fifth Assessment Report prepared by the same Panel (IPCC, 2013) describe the extent to which observed and projected changes in climate affect the main characteristics of weather and climate extremes. The findings in both reports indicate that changing climate conditions lead to changes in the intensity, frequency, special extent, duration and timing of extremes such as floods and droughts. The projections presented for the remainder of this century suggest, with medium confidence, that droughts will intensify in some regions and times of the year due to reduced precipitation or increased evapotranspiration in areas such as Central America, Mexico and northeast Brazil (Seneviratne et al., 2012). Projections of increased heavy precipitation would contribute to increased flooding in some basins and regions, with average confidence (Seneviratne et al., 2012).

The IPCC Special Report Global Warming of 1.5°C was recently released, showing the impacts of global warming in comparison to the pre-industrial times and the related emission pathways. This report shows that the 1°C warming that has already taken place has caused quantifiable impacts on natural and human systems, and compares the risks under different global temperature rise scenarios (IPCC, 2018). The report particularly shows that the risks of drought and precipitation deficit will increase under temperature rises of 1.5°C and 2°C in some areas of the RIOCC countries, such as the Amazon, the northeast of Brazil and especially in the Mediterranean region. It also projects that human exposure to floods will be substantially lower in a world where the temperature rises by 1.5°C compared to 2°C, although with regionally differentiated risks largely due to different local socio-economic conditions.

10.2. Risk components in relation to the sector or system

10.2.1. Hazards

As a consequence of climate change due to anthropogenic greenhouse gas emissions and land-use change, it is expected that in many regions the frequency and intensity of precipitation events will increase (Wartenburger et al., 2017), which could consequently increase the likelihood of future flooding. Alfieri et al. (2017) evaluated changes in the frequency and magnitude of river flooding. Their findings show that the frequency of occurrence of extreme flow events with magnitudes greater than those considered in the construction

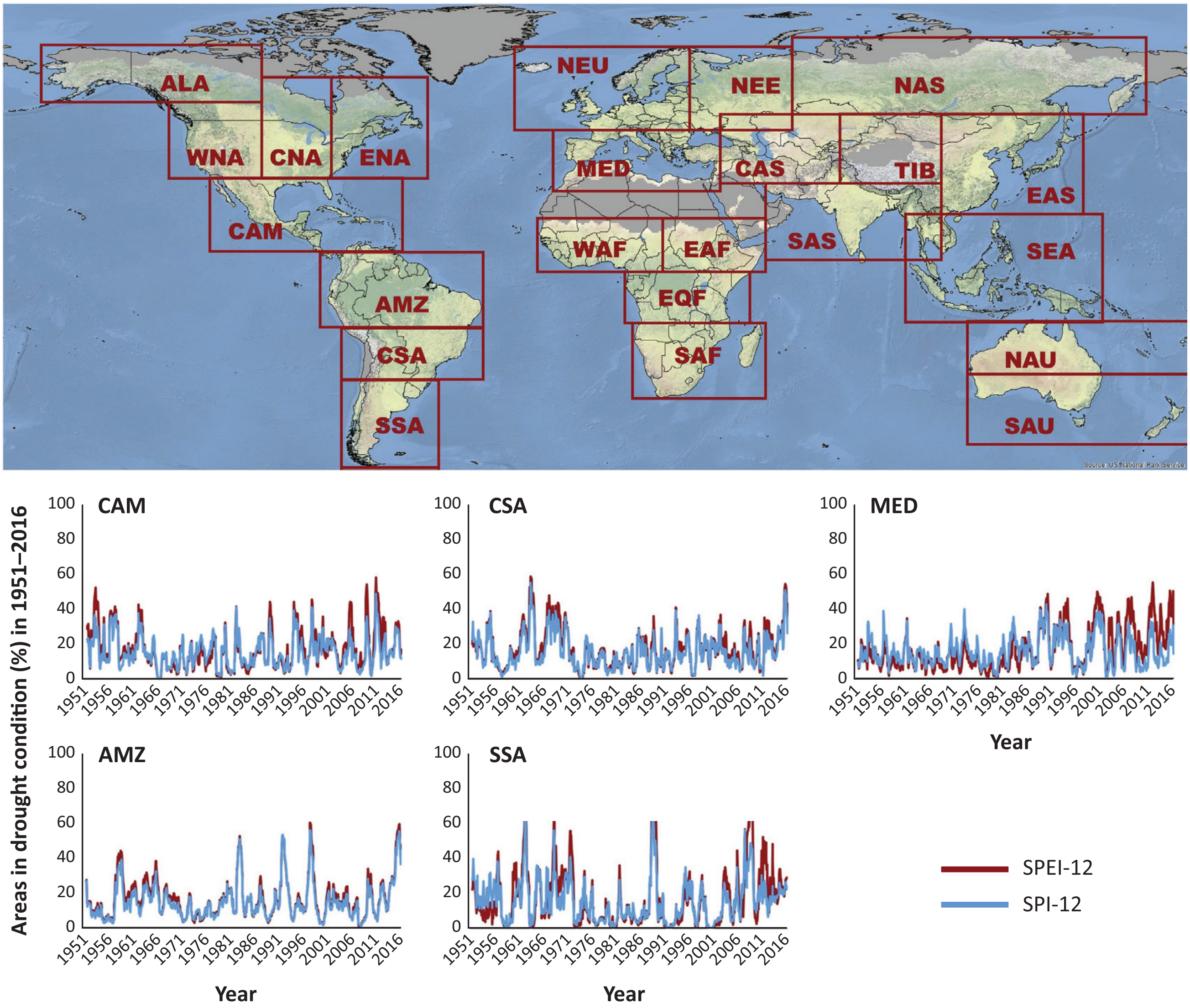

Figure 10.5. Annual area percentage under drought conditions for the five regions of the RIOCC countries according to the SPEI-12 (red line) and SPI-12 (blue line) indices. Source: Spinoni et al., 2019.

of current flood protections under the three global warming scenarios in consideration (1.5°C, 2°C and 4°C with respect to the pre-industrial period) would increase in all continents, leading to a general increase in flood risk.

Figure 10.6 shows the standardized global changes in extreme runoff between 2070 and 2099, compared to 1971-2000 under two emission scenarios (Asadieh and Krakauer, 2017). It has been observed that the projected changes are more intense in the RCP8.5 scenario than in the RCP2.6 scenario, where each one respectively represents a rise of 4°C and 2°C in global average temperatures by the end of the 21st century, compared to the pre-industrial era. In the RCP8.5 scenario, 37% of the continental surface area shows a 24.7% average growth in the magnitude of extreme flows, which could potentially translate into more floods in those regions. In the RCP2.6 scenario, increases in extreme flows in the RIOCC region are projected mainly for Colombia, Venezuela, Ecuador, the coastal region of Peru and the Plata basin. In the RCP8.5 scenario, the magnitude of the average increase in extreme flows is approximately twice as high. This scenario would include the abovementioned countries and regions, plus Central America and the Iberian Peninsula.

Projections of changes in the future incidence of droughts depend on each representative indicator. This section shows projections that consider the abovementioned indices, namely PDSI and SPEI. **Figure 10.7** displays projections of chang-

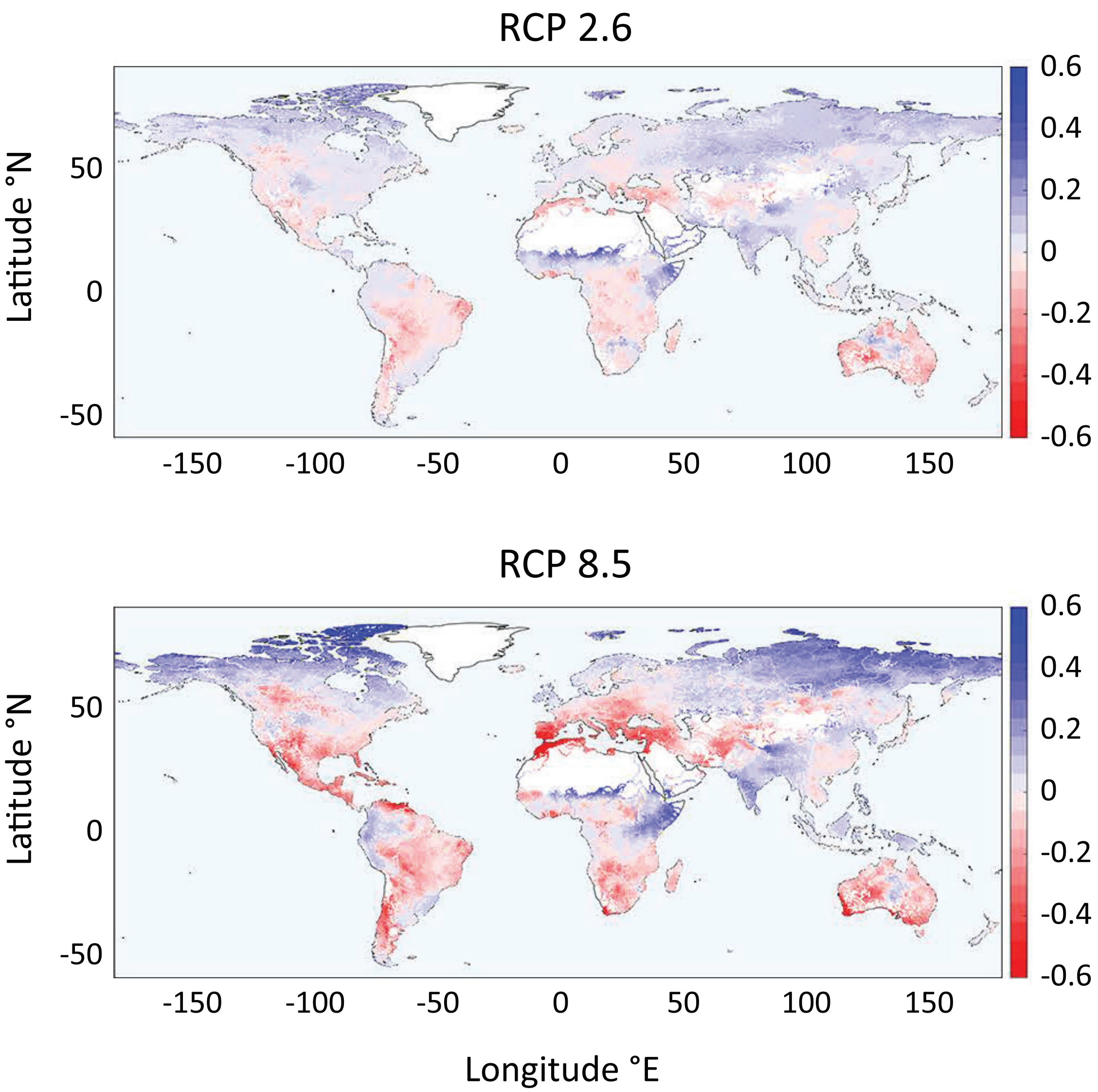

Figure 10.6. Standardized global changes in extreme runoff between 2070 and 2099, compared to 1971-2000 under the RCP2.6 and RCP8.5 emission scenarios. Negative values indicate the proportion of extreme runoff loss in 2070-2099 compared to 1971-2000, while positive values indicate an increase. Source: Asadieh and Krakauer, 2017.

es in the PDSI index as well as in the duration of droughts using the average of 11 global climate models belonging to Phase 5 of the Climate Model Intercomparison Program (CMIP5) for temperature rises of 1.5°C and 2°C with respect to 1986-2005, as estimated by Liu et al. (2018). The findings show that, for the 1.5°C scenario, the PDSI would decrease (more prone to drought) in the Amazon, northeast Brazil, southern Europe and the Mediterranean, and Central America and Mexico. The geographical pattern of changes in the PDSI for the 2°C scenario is quite similar to the 1.5°C one, but with an increased magnitude of change as can be seen from the differences between the two warming thresholds. The results for to the IBE region are consistent with those found in the CEDEX report (2017), which show that droughts will become more frequent over the course of this century.

Figure 10.8 shows the magnitude of the SPEI index for the reference period (1976-2005) and the relative changes (%) from the baseline for three warming scenarios compared to the pre-industrial period. The magnitude of droughts is projected to increase with warming, doubling by 30%, 38% and 51% of the global land surface (excluding deserts, hyper-arid and cold regions) under warming scenarios of 1.5°C, 2°C and 3°C, respectively (Naumann et al., 2018). In particular, in the IBE, MEX, CAC, AMZ and southern SSA regions, the water deficit could be five times that of the reference period.

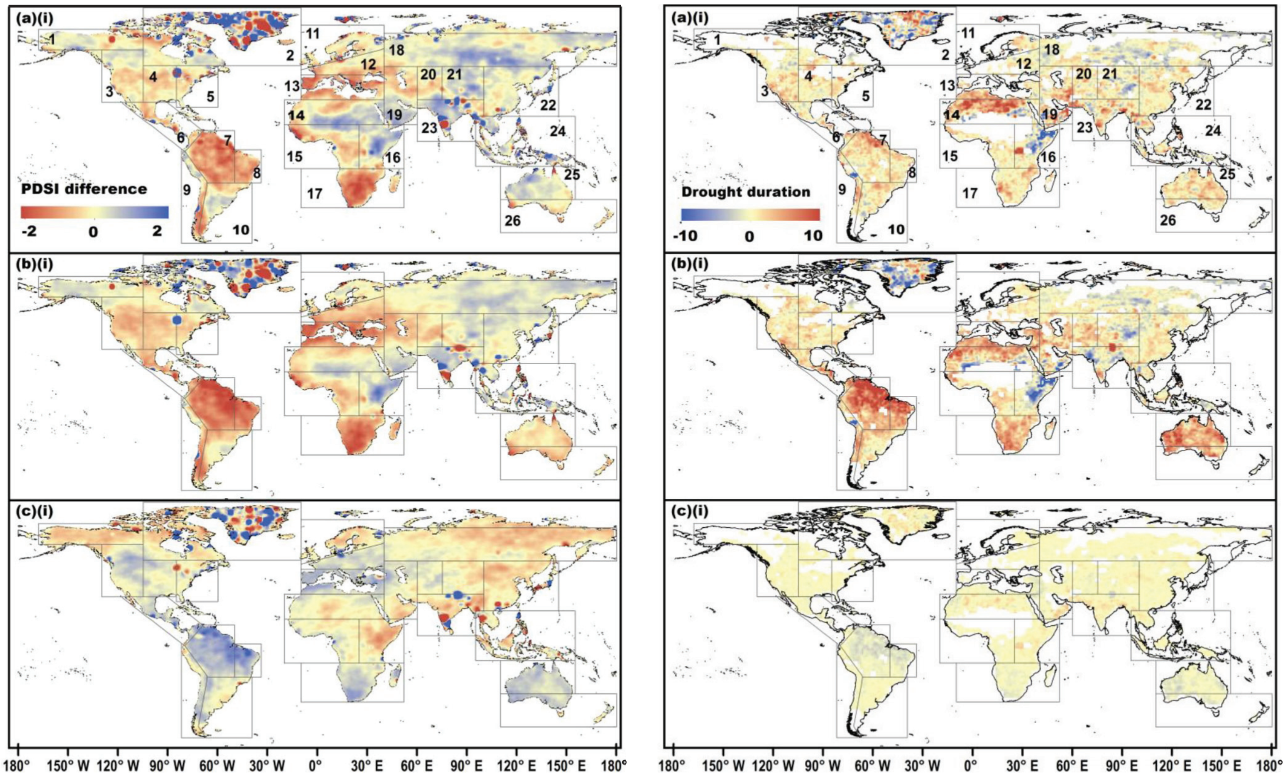

Figure 10.7. Projected change in PDSI drought index from 1986-2005 for 1.5°C (top panel) and 2°C (middle panel) global warming scenarios, and differences between the two (bottom panel) derived from an average of 11 global climate models. Source: Liu et al., 2018.

10.2.2. Exposure

Christenson et al. (2014) estimated the exposure of the population to drought and floods between 1980 and 2000, establishing a ranking by country for each phenomenon individually. Exposure was calculated from population density information and the frequency of occurrence of both events. Drought events were defined as those cases in which, during three consecutive months, monthly precipitation was less than or equal to 50% of the average long-term precipitation. The probability of occurrence of these cases was calculated by the International Research Institute for Climate Prediction (IRI) from information of the Weighted Anomaly Standardized Precipitation (WASP) index (Lyon, 2004; Lyon and Barnston, 2005). The probability of occurrence of floods was calculated considering 3,700 events that took place between 1985 and 2003, compiled by the Darmouth Flood Observatory using available satellite information. Flooding frequency was determined by considering the number of flooding events in each cell. For each phenomenon (drought/flood), Christenson et al. (2014) calculated an estimate of the exposed population from the output among the population in each cell and the probability of occurrence of the phenomenon in that cell. Finally, the proportion of the exposed population across the entire country was calculated as the sum of the exposure values of each cell divided by the total population of the country. The maximum countrywide theoretical exposure value is 1. **Figures 10.9** and **10.10** show the global ranking of population exposed to droughts and floods, respectively.

According to this methodology and an evaluation spanning 193 countries, the five Latin American countries with the largest populations exposed to droughts for the period under study were Guatemala, Chile, Ecuador, Mexico and Nicaragua. In the case of floods, the five most exposed countries were Guatemala, El Salvador, Honduras, Haiti and Colombia. **Table 10.1** shows the ranking of both events for all RIOCC countries over the worldwide total of 193 countries. Similarly, **Table 10.2** shows the percentage changes in the amount of population affected and flood damage for different levels of future warming (1.5°C, 2°C and 4°C) for the RIOCC countries in relation to the period 1976-2005. All scenarios entail an increase in the affected population, which in some cases —such as Colombia, Ecuador, Peru and Uruguay—exceeds 1000% for the highest warming scenario, with statistically significant changes. In terms of expected damages, they increase together with rises in average global temperature and exceed 1000% for the 4°C scenario in Ecuador, Panama, Peru and Uruguay.

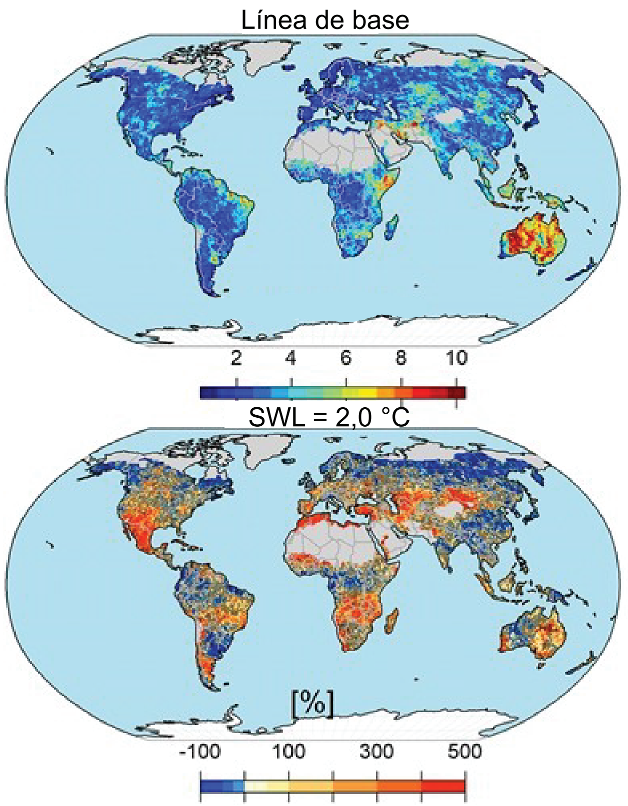

Figure 10.8. Drought magnitude and relative changes (%) in drought magnitude from baseline (1976-2005) for three warming scenarios compared to the pre-industrial period (1.5, 2.0 and 3.0°C). Changes that are not statistically significant at 10% are shaded in grey. Source: Naumann et al., 2018.

10.2.3. Vulnerability

Vulnerability to drought and floods is generally inversely related to the degree of economic and social development of the affected regions. Population growth, accelerated urbanization of informal human settlements, lack of well-planned and quality infrastructure, high rates of social inequality, poverty, agriculturally dependent economies and inadequate environmental practices, these are all socio-economic factors that foster vulnerability and result in water deficit and excess events having an even greater impact. There are four types of vulnerability according to exposure: (1) infrastructure exposure, (2) population exposure, (3) productive systems exposure, and (4) ecosystem exposure. Vulnerability can be separated into four types of fragility: (1) socio-economic fragility, (2) environmental fragility, (3) physical fragility and (4) institutional fragility. The components that determine vulnerability according to adaptive and response capacity are (1) savings and debt capacity, (2) risk perception, and (3) governance and territorial management capacity.

Neri and Magaña (2016) provide a list of factors that reveal vulnerability to drought at a given time and region:

1. Pressure on water resources (amount of water withdrawn for consumption vs. water renewal)
2. State of aquifers (number of overexploited aquifers or with saltwater intrusion problems)
3. Amount of treated wastewater
4. Cost of water in urban areas
5. Water productivity in irrigated areas (cost of water used for irrigation in relation to agricultural productivity)
6. Water storage capacity in large reservoirs vs. current storage

Vulnerability to floods can be classified into different types according to whether the exposed system is located in areas that are potentially sensitive to the hazard or according to its fragility (level of intrinsic susceptibility of the elements likely to be affected by an estimated magnitude of the hazard). A third type of vulnerability is determined by the capacity to adapt and respond (Vera Rodríguez and Albarracín Calderón, 2017).

While vulnerability to droughts and floods differs greatly among the different RIOCC countries, it is essential that

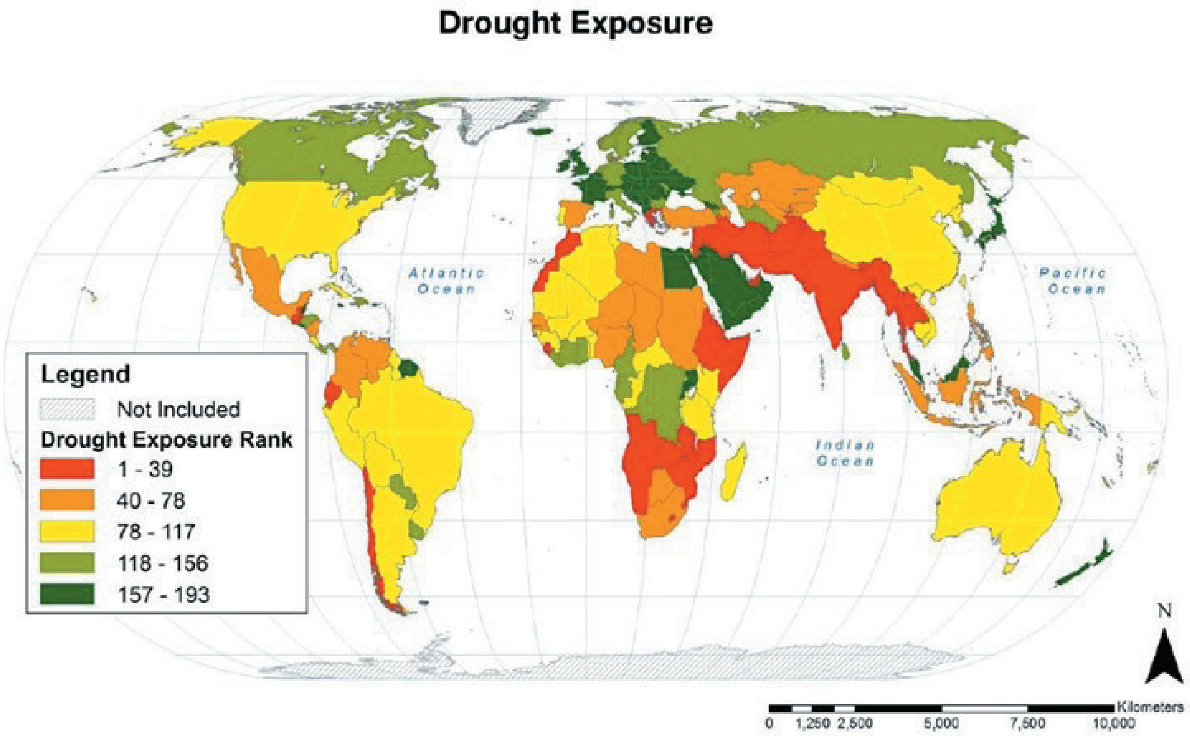

Figure 10.9. Ranking of population exposed to drought in each country for the 1980-2000 period, in quintiles. Source: Christenson et al., 2014.

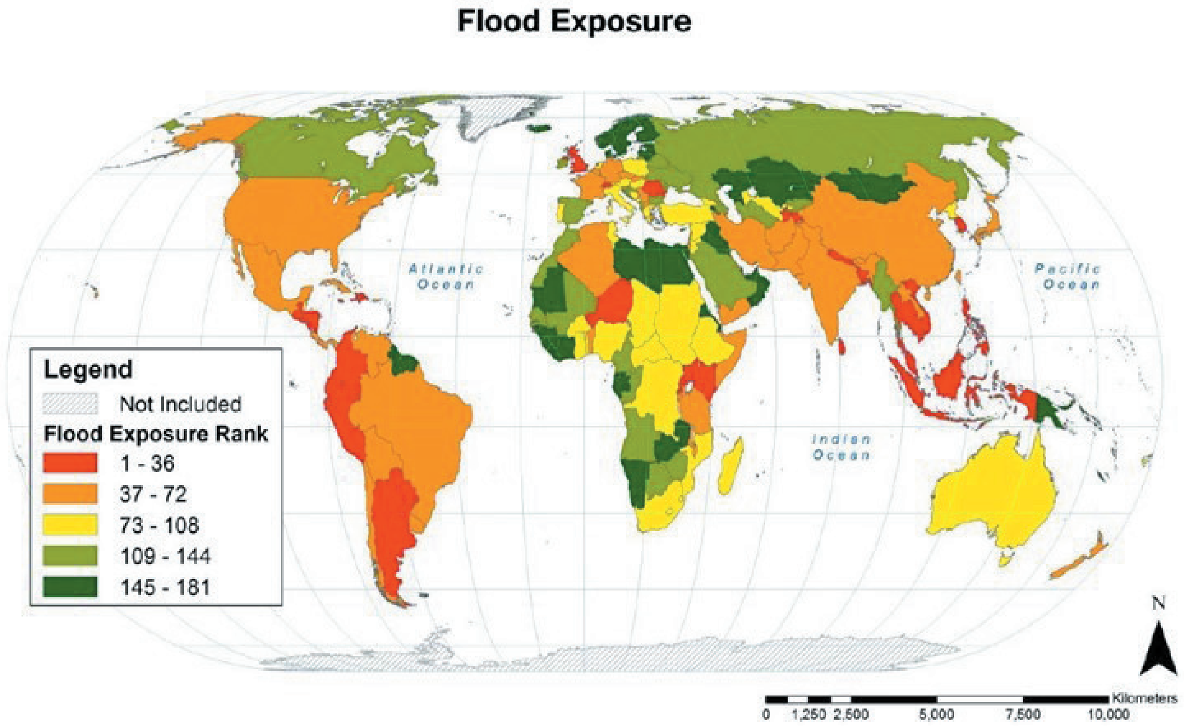

Figure 10.10. Ranking of population exposed to floods in each country for the 1985-2003 period, in quintiles. Source: Christenson et al., 2014.

Table 10.1. World ranking of populations exposed to droughts and floods in RIOCC countries for the 1980-2000 and 1985-2003 periods, respectively. Source: Christenson et al., 2014.

Country	Place in the drought exposure ranking	Place in the flood exposure ranking
Andorra	No data	No data
Argentina	92	36
Bolivia	101	39
Brazil	98	46
Chile	18	37
Colombia	55	16
Costa Rica	107	44
Cuba	97	60
Dominican Republic	154	24
Ecuador	27	17
El Salvador	183	9
Guatemala	10	5
Honduras	148	10
Mexico	40	52
Nicaragua	49	29
Panama	156	72
Paraguay	138	21
Peru	114	35
Portugal	79	81
Spain	64	109
Uruguay	129	61
Venezuela	73	38

efforts to reduce them be guided through collective action by the Ibero-American community. In this regard, Spain and Portugal act as a catalyst for sources of financing to improve adaptive capacity, as well as playing an important role in providing technical assistance through cooperation to build resilience and adaptive capacity throughout the region, especially in the most vulnerable countries. It is also important to multiply experiences of South-South cooperation, among countries in the region and with other regions (Martin Murillo et al., 2018).

Some regional factors to consider are that many of the floods and droughts in the Andes region occur during the extreme phases of El Niño-Southern Oscillation (El Niño and La Niña) (Poveda et al., 2020), and that watershed deforestation exacerbates the occurrence of hydrological extremes such as floods and droughts in many of the region's river basins, including the Amazon River basin (Salazar et al., 2018).

10.3. Characterization of risks and their impacts

10.3.1. Floods

Floods are a global phenomenon that can cause widespread devastation, economic damage and loss of life. Climate change repeatedly shows up as one of the possible causes of flooding. This is because, although it is associated with an increase in precipitation in some regions of the RIOCC countries on the one hand, it manifests itself to a greater extent as an increase in the frequency and intensity of heavy precipitation. When it falls on a territory that has been subject to unrestrained use, this significantly increases the chances of becoming a catastrophe. This has brought to light multiple causes of surface affectation that are necessarily linked to flood events. Some of them include deforestation, monoculture, specific interventions that modify natural runoff, and urban development in flood-prone areas.

For example, the types of floods that take place in Argentina are quite different (mostly urban, plain, riverside) and, according to a World Bank report (2016), they make up for 60% of the disasters that happen every year. Particularly in large cities, the impacts of heavy rainfall and lack of planning are exacerbated by the country's hyper-urbanization, where 9 out of 10 people live in cities (see **Chapter 13** of this report).

10.3.2. Droughts

Droughts hinder the economic, social and environmental development of a territory, and their consequences are manifold. This is largely because of the restrictions they place on the water supply to the population (see **Chapter 6**), agriculture (see **Chapter 7**) or industrial activity. The impacts caused by droughts are social, environmental and economic and include: degradation and loss of nutrients from unprotected soils due to wind and water erosion, degradation or destruction of forests (wildfires, see **Chapter 12**), dehydration and loss of vegetation, migration or loss of wildlife, decrease in aquifer recharge and overexploitation, effects on water quality, reduction in agricultural production, conflicts between different water users, deterioration in public health, migration, etc.

The duration and impacts of droughts may vary from country to country. While those lacking water storage infrastructure and whose water supply depends directly on precipitation, a decline in precipitation sustained over a few months can lead to drought. In other countries with sufficient water storage infrastructure, the greatest impacts are felt when water shortages occur over several consecutive years.

For example, in Bolivia, agriculture sustains the largest drought impacts because only 5% has complementary and/or supplementary irrigation, followed by the drinking water supply sector. This sector was not severely affected until the drought of 2015-2017, whose impacts were felt in ur-

Table 10.2. Changes (%) in affected population and flood damage for different warming scenarios in RIOCC countries between 1976 and 2005. Values with a confidence level of change below 90% are shown in italics. Source: Alfieri et al., 2017.

Country	Change (%) in affected population			Change (%) in expected damage		
	1,5 °C	2 °C	4 °C	1,5 °C	2 °C	4 °C
Andorra	No data	No data	No data	No data	No data	No data
Argentina	64	160	613	*32*	*94*	390
Bolivia	*50*	*70*	*53*	78	101	103
Brazil	104	150	445	101	158	390
Chile	*34*	*7*	*142*	*14*	*-15*	*-30*
Colombia	140	248	1022	*104*	162	662
Costa Rica	*40*	*3*	*268*	*24*	*7*	*260*
Cuba	*10*	*24*	*146*	*23*	*14*	*147*
Dominican Republic	74	35	91	77	51	65
Ecuador	292	552	*2695*	339	659	*3295*
El Salvador	42	26	*72*	51	32	*83*
Guatemala	20	20	*77*	21	23	*70*
Honduras	*51*	*27*	*62*	*55*	*26*	*51*
Mexico	29	*21*	*104*	34	*18*	*107*
Nicaragua	*23*	*15*	*38*	*30*	*24*	*53*
Panama	*8*	*88*	*1540*	*2*	*90*	1369
Paraguay	30	60	221	*-1*	*-5*	*58*
Peru	390	662	1430	675	1135	2724
Portugal	936	1237	*779*	901	1147	692
Spain	126	*140*	*55*	*165*	*170*	*51*
Uruguay	271	540	2306	320	573	1748
Venezuela	*36*	*57*	192	*-25*	*7*	*112*

ban areas, affecting seven cities across the country. The event showed that neither Bolivian cities nor their distribution systems are prepared for cuts in water distribution, causing conflicts over water use. In Brazil, drought has become commonplace in all regions. Between 2014 and 2016, some of its most important cities were on the verge of collapse due to limited water supply. The São Paulo Metropolitan Area, home to more than 20 million inhabitants, went through a severe drought that caused the worst water crisis the region has ever seen (Vásquez, 2018). This phenomenon even affected the Amazon, where, in recent years, drought has been identified as an aggravating driver for wildfires (UNESCO, 2018).

The historical record of the incidence of droughts in Chile shows the important impact that some events have had on the country's economic, social and political landscapes, particularly in the agricultural and forestry sectors, supply of drinking water, energy and the environment. In 2010 the phenomenon known as the 'Central Chile megadrought' began, characterized by a water deficit of approximately 30%. The impacts of this phenomenon are associated, among others, with a sharp reduction in water availability (70% deficit in average flows in the regions of Coquimbo and Valparaiso), a progressive decrease in groundwater levels, a notable deterioration of non-irrigated vegetation in central Chile, a 70% increase in burnt forest area, and the enactment of a significant number of Water Scarcity Decrees by the General Directorate of Water (UNESCO, 2018).

Spain has been particularly affected by drought. During the 1992-1995 period, agricultural organizations estimated losses of about 9 billion euros, while the 2017 event—considered one of the worst in recent years—had severe consequences on hydroelectric production, which saw a reduction of almost 50%. In Mexico, during the prolonged drought of 2011-2012—one of the most severe and harmful in recent decades—86% of the Mexican territory experienced a serious water crisis affecting more than 300,000 people in the agricultural and livestock sectors, 800,000 agricultural hectares and 1.3 million heads of livestock (CENAPRED, 2013).

A recent report (Christian Aid, 2018) highlights the ten most destructive extreme weather events (droughts, floods, fires, heat waves, typhoons, hurricanes) in 2018. This list includes one in Latin America: the Argentinean drought that took place between late 2017 and April 2018. During this period, precipitation in some parts of the country declined by more than 50%, making it the worst drought to hit the country in 50 years. As a result, Argentina's soybean and corn crop yields were 31% and 20% lower than the previous year, which translated into economic losses of US$6 billion.

10.4. Adaptation measures

10.4.1. Adaptation options

This section lists a number of possible planned adaptation options to minimize the consequences of floods and droughts. As can be seen further below, these measures can be both structural and non-structural, for both phenomena. Those that involve building infrastructure can be costly and difficult to reverse should they become obsolete as more knowledge is acquired or uncertainties about future climate scenarios decrease. In contrast, there are other measures, such as those linked to training, promoting research or strengthening monitoring systems that will be easier to reverse in the face of changes in future climate prospects. On the other hand, when selecting which measures to implement, each of their co-benefits should also be assessed. Consequently, designing an adaptation plan requires an in-depth analysis of each situation, consideration of social, economic and cultural aspects, as well as of the resources and capacities of those responsible for its implementation.

Below is a list of possible flood adaptation measures:

1. Strengthening of water resources management plans among basin authorities due to water surpluses.
2. Development of specific flood risk management plans that consider the influence of climate change.
3. Carrying out flood defence works and conducting or retaining water surpluses and floods due to the frequency of extreme rainfall in urban and rural areas.
4. Development of urban-environmental management plans that take into account risk levels.
5. Investment in equipment and development of human resources for hydrological warning systems.
6. Redefining and adapting design parameters for infrastructure works taking into account new climatic conditions.
7. Recovery of the fluvial space, lamination of avenues and reduction of the force of flow, improvement of the state of conservation of the aquatic ecosystems and recovery of river connectivity.
8. To stop the accelerated processes of deforestation of river basins and to implement reforestation programs with native species.

Possible adaptation options to mitigate the risk of drought include the following:

1. Protecting water recharge areas.
2. Minimizing water losses in the distribution system.
3. Monitoring groundwater levels in aquifers to activate possible overextraction warnings, thereby adjusting pumping scenarios.
4. Developing management initiatives aimed at reducing net demand through pricing policies or water use restrictions.
5. Improving water use efficiency for irrigation through changes in the methods used.
6. Developing infrastructure works to increase water supply in the region.
7. Implementing fiscal incentives that favor crop diversification, with greater benefits for those drought resistant varieties.
8. Promoting research and development of new, more drought-resistant crop varieties.
9. Training farmers to adjust farm management methods (e.g., changes in sowing/harvesting dates based on new climate conditions).
10. Strengthening the environmental monitoring system by installing automatic weather stations that provide free access to information in real time.

10.4.2. Planned adaptation activities

This section provides some examples of activities in the Ibero-American region that involve adaptation to climate change from a broad perspective, i.e., that includes droughts and floods, but is not necessarily restricted to these phenomena. More examples on adaptation to drought can be found in **Chapters 6** and **7**, and to floods in **Chapters 9, 11, 13** and **14** of this report.

10.4.2.1. Supranational scale

In 2013, the Development Bank of Latin America (CAF) presented its climate change adaptation program. It includes a set of proposals and concrete actions to promote and support planned adaptation processes with regard to policies, plans, programs and projects, in order to steer sustainable development in all member countries in Latin America and the Caribbean. This program runs along five strategic lines:

1. Promoting access to the flow of financial resources for adaptation.
2. Strengthening the institutional capacity of the public and private sectors for adaptation.
3. Promoting concrete adaptation actions on-site, in response to each country's most pressing needs.

4. Supporting the generation and management of knowledge.
5. Developing measures aimed at strengthening CAF's internal capacities, and to integrate climate considerations into all the operations supported by the bank.

In parallel, the Inter-American Development Bank (IDB) formed the Climate Change Network, which is made up of high-level public officials in charge of climate change policies in Latin America and the Caribbean. The purpose of the network is to create a channel where the main actors in the region can discuss with IDB specialists. The network focuses on two lines of activities:

1. Actions by national governments to implement climate change strategies and programs, and adopting climate change mitigation and adaptation measures in key economic sectors.
2. Integrating climate change into the development policy of the borrowing member countries.

In 2013, the European Commission adopted the European Union (EU) Adaptation Strategy to coordinate national sectors and policies and to address some cross-border climate issues between Member States. The specific objectives of the strategy are as follows:

1. Enhancing the resilience of EU countries, regions and cities.
2. Making more informed decisions.
3. Enhancing the resilience of key vulnerable sectors and integrating adaptation.

The member states that have a national adaptation strategy in line with this proposal include Spain and Portugal.

In 2019, the World Bank Group launched its Action Plan on Climate Change Adaptation and Resilience (World Bank, 2019), which will increase direct funding for climate change adaptation projects to US$50 billion over the 2021-2025 period. This will support activities such as:

1. Improving the quality of forecasts, early warning systems and climate information services.
2. Supporting 100 river basins via climate-sensitive management plans or improved management.
3. Developing social protection systems that can respond better to climate change.

10.4.2.2. National and sub-national scale

There are many cases of adaptation at the national level. For example, Spain is highly irregular with regard to temporal and spatial distribution of water resources, and many areas throughout its territory are affected by water shortages and frequent droughts. The implementation of policies and actions such as setting up a countrywide system of indicators, developing drought management plans in the Basin Organizations and involving users and civil society are helping to minimize the socioeconomic and environmental impacts of droughts. Most of these policies were put in place after the severe drought that hit in Spain between 1991 and 1995. Its massive economic, social and environmental impacts helped to raise awareness about the need for subsequent administrations to consider drought as a normal and recurrent event in Spanish climate and for drought management policies to move away from a crisis management approach to planned drought risk management schemes.

Costa Rica is highly vulnerable to the adverse effects of climate change. The risks of extreme hydrometeorological events are significant and currently manifest themselves in increasing losses and damages (MINAE, 2018). These events, added to the conditions of exposure and vulnerability where large parts of the population live, generate social conflicts and a permanent erosion of the country's development assets. The specific objectives of this policy are as follows:

1. Strengthening resilience capacities and conditions.
2. Reducing vulnerability/damage and loss.
3. Seizing opportunities.

The Plan for Risk Management and Adaptation to Climate Change in Peru's Agricultural Sector for the 2012-2021 period (MINAG, 2012) is a management tool that provides strategies, policy guidelines, proposals and actions that have been agreed upon with the regions. It is intended to reduce risks and vulnerabilities and reduce the effects of climate change that directly impact medium and small-scale agricultural production, putting the food security of vulnerable populations at risk. Four climatic hazards were given priority with regard to agricultural risk management, two of which were droughts and floods.

Mexico's National Strategy on Climate Change (ENCC, 2013) defines three strategic pillars to adapt to a set of climatic phenomena. These include droughts and floods as major hazards, to which the country is particularly vulnerable. These pillars are as follows:

1. Reducing vulnerability and increasing the resilience of the social sector to the effects of climate change.
2. Reducing vulnerability and increasing the resilience of strategic infrastructure and productive systems to the effects of climate change.
3. Conserving and sustainably using ecosystems and maintaining the environmental services they provide.

In the case of Argentina, both droughts and floods are recurrent and extremely severe adversities that affect various regions of the country, causing significant economic losses, disruptions in industrial processes and important alterations in social activities. Methodologies are currently being developed to reduce vulnerability and risk to both events, particularly for the most sensitive areas and social sectors within the framework of the International Strategy for Disaster Reduction (ISDR). Furthermore, Law 27,287, passed in 2016, created the National System for Disaster Risk Reduction and

Civil Protection (SINAGIR) with the aim of realizing the efforts and consensus necessary for the state to design a disaster risk reduction and civil protection policy.

10.4.2.3. Local or municipal scale

The initiatives undertaken by many cities in the RIOCC region are generally aimed at mainstreaming knowledge and guiding action on climate change among the different areas or departments of local administrations, so as to influence decision-making and policy development. Many cities in the region have local adaptation plans and/or are part of international city groupings such as C40 (Barcelona, Bogotá, Buenos Aires, Curitiba, Guadalajara, Lima, Lisbon, Madrid, Medellín, Mexico City, Quito, Rio de Janeiro, Salvador, Santiago, São Paulo, https://www.c40.org/) and the Covenant of Mayors for Climate and Energy (mostly cities in the Iberian Peninsula and only three in Latin America, http://pactodealcaldes-la.eu/). Networks of cities have also been created at the national level, such as the Resilient Cities Network in Mexico, the Spanish Network of Cities for Climate (http://www.redciudadesclima.es/) and the Argentinian Network of Municipalities facing Climate Change (https://www.ramcc.net/). Below are some examples of adaptation measures against drought and floods, implemented by urban centers in the region.

The most serious case of flooding in an Argentinean city took place on April 2, 2013. On that day, more than 400 millimeters fell in four hours in the city of La Plata (800,000 inhabitants), causing dozens of deaths. In response to this event, the Integrated Hydro-Environmental Monitoring and Early Warning System (SIMATH, https://www.gba.gob.ar/ciencia/simath) was implemented. This involved coordinating different hydrometeorological/environmental measurement networks to detect floods and droughts at an early stage, and as an instrument to anticipate and implement measures for taking action in 135 municipalities in the province of Buenos Aires (Argentina).

The water supply to the city of Trujillo (Peru) originates from two different sources: the Moche River Basin and the Santa River Basin. The irrigation sector is very important for Trujillo's economy and its social sustainability. Given the projected massive growth of the urban population and its corresponding increase in water demand over the coming decades, as well as the system's capacity to meet current demand, Trujillo's water supply system is both sensitive and vulnerable to changes in water availability. Proposed adaptation measures under drier climate conditions include monitoring groundwater levels to activate possible overextraction warnings and changing pumping scenarios accordingly to minimize losses in the distribution system (pressure reduction and/or replacement works) (IDB, 2015).

10.4.3. Autonomous adaptation activities

While planned approaches to adaptation based on vulnerability assessments are key, it is equally relevant to understand and enable the adaptive responses that take place spontaneously in society. Autonomous adaptation normally takes place when the benefits accrue primarily to those involved in adaptation. In this regard, education and capacity building are essential not only to promote adaptive responses, but also to prevent adverse effects of autonomous adaptation measures. For example, in drought-prone regions, individuals could adapt by using more water for irrigation or by drilling their own wells, although this would probably aggravate the situation by reducing overall water availability. With regard to flood events, many of the autonomous adaptation measures envisage building various types of hydraulic defense infrastructure (dikes, embankments, retaining walls, channels, diversion of watercourses and construction of artificial dams and reservoirs), which could cause negative impacts, as they are not part of integrated water resource planning, thus aggravating the conditions of water excess/deficit in neighboring areas.

Cutwaters stand out among some of the examples to ensure water availability, encouraging its efficient use during times of shortage. They are reservoirs with a curtain of rammed earth that stops runoff and helps to form a lake. These structures are frequently used in livestock farming as a supplementary source of water for animals or pastures in Uruguay, Argentina and Paraguay (Magrin, 2015). Similarly, holding ponds (*atajados*) are ponds built in the ground that are used to collect rainwater, to be used when there is not enough availability. Experiences obtained in Cochabamba (Bolivia) shows that families with a holding pond (*atajado)* reduce the risk of loss or complete crop failure and have the possibility of diversifying and intensifying agricultural production and producing fodder for livestock (Magrin, 2015). More examples of autonomous adaptation to water stress and shortages can be found in **Chapters 6** and **7** of this report.

10.5. Barriers, opportunities and interactions

One of the main adaptation planning obstacles that have been identified concerning droughts and floods is the funding required for integrating and collecting information and to develop plans. Each situation's existing institutional, regulatory, administrative, economic and social contexts may interfere with securing financial resources and technical and institutional capacity to implement concrete adaptation measures. Other barriers include limited knowledge of climate variability and uncertainties about the future climate, insufficient awareness of both political actors and the general population, lack of regulations and sometimes poor communication of adaptation needs.

In terms of opportunities, including participatory approaches with different sectors of society as part of the development and implementation of adaptation plans is greatly important, as it allows to strengthen local capacities in relation to the challenges borne out of climate change impacts. It also allows taking into account the experiences and local knowledge present in the communities in order to prioritize appropriate measures.

One of the greatest challenges involved in designing climate change adaptation measures is to think of these measures as being integrated with mitigation measures, in order to generate synergies between them. In other words, seeking to maximize the benefits of mitigation and adaptation on the one hand, while minimizing the potential trade-offs in order to promote sustainable development on the other. For example, green roofs or terraces remove carbon dioxide from the atmosphere through photosynthesis, thereby contributing to mitigate climate change. They are also efficient at retaining rainwater and therefore constitute an adaptation measure to prevent flooding. One example of the feasibility of this strategy is the analysis on the use of green terraces as a flood mitigation strategy, conducted in the central region of Chile (Mora-Melià et al., 2018).

10.6. Measures or indicators of adaptation effectiveness

This section provides some examples of the metrics used to assess progress in adaptation to droughts and floods in the face of climate change. The indicators listed below are part of the Repository of Adaptation Indicators (GIZ, 2014).

These indicators can be differentiated between those that measure climate impact, those that seek to monitor the implementation of adaptation measures (e.g., number of organized awareness workshops, percentage of updated building codes, etc.) and those that aim to evaluate the results of adaptation strategies (e.g., percentage increase in crop yield per hectare during a dry period) where the results can be understood in terms of increased adaptive capacity or reduced sensitivity to climate stress, or a combination of the above.

Some of the indicators proposed to measure the climate impact are as follows:

- Number of households affected by drought
- Total percentage of livestock killed by drought
- Number of people living in flood-prone areas
- Number of flooded properties per year
- Number of properties located on river/coastal floodplains
- Number of companies located in areas at risk of flooding/coastal erosion
- Number of hospitals located in areas at risk of flooding/coastal erosion
- Number of households within the most marginalized communities located in areas at risk of flooding/coastal erosion
- Total forest area affected by wildfires per year
- Total length of sewerage and drainage network at risk from climate hazards
- Climate-related power failure
- Financial losses due to extreme weather events
- Number of cases of waterborne diseases
- Number of people permanently displaced from their homes as a result of floods or droughts

Some of the indicators that allow monitoring the implementation of adaptation measures are as follows:

- Number of methodological guides produced to assess the impacts of climate events
- Number of climate-sensitive tools that have been developed and tested
- Number of vulnerable actors using climate-sensitive tools to respond to climate variability or change
- Number of communication tools incorporating climate change adaptation
- Number of public awareness campaigns on water efficiency
- Number of visitors to the national climate adaptation website
- Percentage of chambers of commerce and industry actors that use and distribute climate information
- Number of disseminated best practices for urban adaptation
- Percentage of the population living in flood- and/or drought-prone areas with access to rainfall forecasts
- Number of government officials who have received adaptation training
- Level of integration of climate change into development planning
- Number of policies and coordination mechanisms that explicitly address climate change and resilience
- Number of introduced or adjusted policies, plans or programs that integrate climate risks
- Adaptation performance indicators include the following:
- Percentage of impoverished people in drought-prone areas with access to safe and reliable water
- Percentage of households with reduced flood risk due to new or improved defenses
- Reduced costs of flood damage and disaster relief in cities by raising standards of flood protection and improving flood emergency preparedness
- Percentage of arable land covered by crop insurance
- Percentage of additional fodder for grazing livestock

- Increased agricultural productivity through irrigation of harvested land
- Increase in percentage of climate-resilient crops being used
- Percentage of area cultivated with drought-resistant varieties

10.7. Case Studies

10.7.1. Integrated Climate Change Plan for the Department of Chocó (PICC-Chocó), Colombia

10.7.1.1. Case summary

The Department of Chocó (Colombia) is one of the regions with the highest precipitation worldwide. This, together with its high poverty levels, make it highly vulnerable to floods and landslides. PICC-Chocó seeks to create tools that will safeguard the evolutionary processes and environmental supply in the region, as well as create strategies to address climate change. It also aims to raise awareness of its situation and thus prepare the territory to make the right decisions in the face of climate change and the socio-environmental implications it entails. This plan is built around six programs that are based on the country's political, normative and conceptual framework. They are supported by the territorial and thematic context information that was collected during a diagnostic phase.

10.7.1.2. Introduction to the case problem

The Department of Chocó is located on the Pacific coast and is home to one of the rainiest regions in the world, with an average annual precipitation between 12,000 and 13,000 mm (Poveda and Mesa, 2000). This makes it highly vulnerable to flooding and landslides. Furthermore, this is one of Colombia's poorest and most socio-economically underdeveloped regions, which exacerbates socio-environmental vulnerability. PICC-Chocó, developed through an agreement between the Ministry of Environment and Sustainable Development and the Pacific Environmental Research Institute, seeks to prepare the department for greenhouse gas mitigation and adapt it to extreme weather events.

10.7.1.3. Case description

IPCC-Chocó (MADS, 2016) was designed to address the hazards related to climate change. This Plan was divided into six programs: (1) Environmental education, as the foundation, support and structure of a new citizen and institutional culture to confront climate change in Chocó; (2) The production of data, information and knowledge as the basis for innovation and decisions to confront climate change in Chocó; (3) The timely and effective management of knowledge and information as a strategy for informed decision-making on climate change; (4) Coordinating and strengthening institutions and communities, to jointly address climate change in the Chocó; (5) Environmental and productive land management, returning to a sustainability-based development model to address climate change in the Chocó; and (6) Reducing vulnerability and improving adaptive capacity, mechanisms for comprehensive care of communities in the face of climate change (see **Figure 10.11**). These programs are based on Colombia's political, regulatory and conceptual framework, and are supported by the territorial and thematic contextual information collected during the diagnostic review process in the Chocó department.

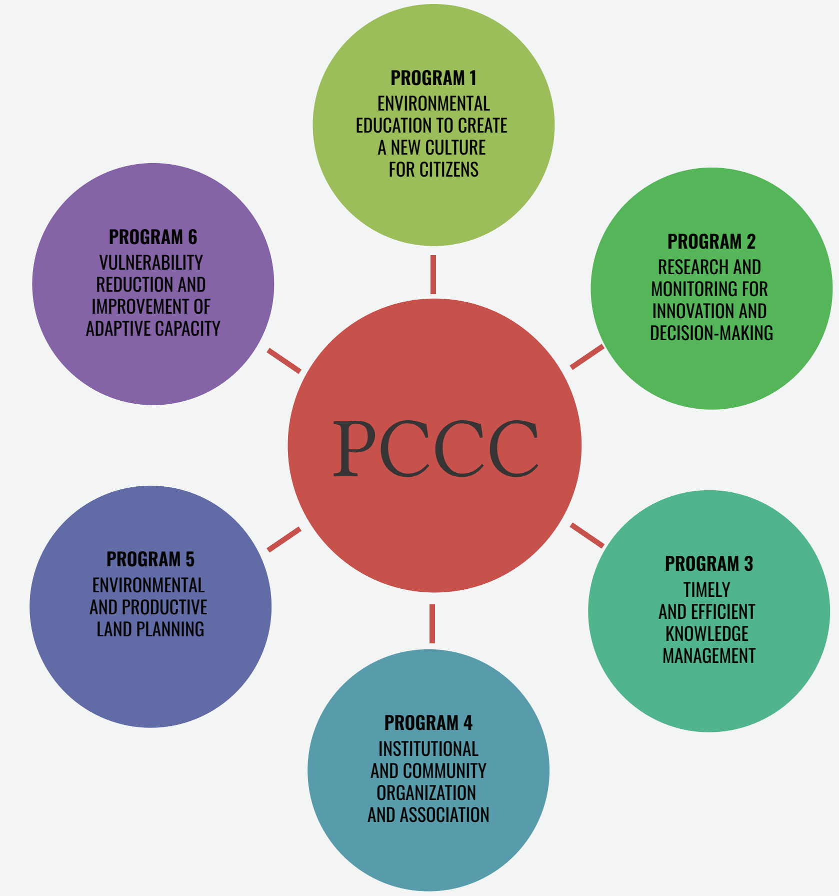

Figure 10.11. Conceptual diagram of the Integrated Plan for Climate Change in the Department of Chocó, Colombia. Source: MADS, 2016.

10.7.1.4. Limitations and interactions

PICC-Chocó includes a draft action plan to ensure its implementation in the short term, fostering ongoing development assessments so that corrective measures can be carried out in a timely manner, where necessary. To this end, it specifies the institutions and social actors responsible for each activity, giving priority to the most urgent measures, establishing a timeline for their implementation, defining the sites where these measures should be carried out and, finally, proposing a follow-up and monitoring mechanism. On the other hand, the plan's implementation should go hand in hand with a consolidation and coordination process for work strategies within the territory, taking into account the new coexistence scenarios across the region, driven by the signing of the peace agreements and regional dialogue instances. This will guarantee a collective development process for the department that will allow it to decisively combat the culture of illegality that exists both in its territorial management and in the use of its natural resources.

10.7.1.5. Lessons learned

PICC-Chocó is not only a tool to implement climate change measures in the region, but also an instrument for territorial empowerment, and a key element to consolidate autonomy and governance across the territory.

10.7.2. Project on adaptation and resilience of family agriculture in northeast Argentina (NEA) in the face of climate change impact and variability

10.7.2.1. Case summary

In northeast Argentina (NEA), the most important climatic influence is the variability of precipitation, which makes it go through intense droughts and floods in short periods of time. This variability limits the access to water for productive and multipurpose use, in an area where most producers are small family farmers. The general objective of the project implemented between 2013 and 2018 and funded by the Adaptation Fund established by the United Nations Framework Convention on Climate Change, was to increase the adaptive capacity and resilience of 3,591 small family farmers to the impacts of climate change and variability, especially those resulting from more intense hydro-meteorological events such as floods and droughts.

10.7.2.2. Introduction to the case problem

NEA spans 338,679 km^2 (12.1% of the country's continental surface, **Figure 10.12**) and is environmentally heterogeneous. 80% of the producers are small-scale family farmers and engage in the production of cotton, yerba mate, goats and cattle. The region also has a large forestry and timber industry. Another element that stands out in this region is the existence of native peoples' communities. The most pronounced climatic influence is variability, especially inter-annual variability, which leads to substantial rainfall variation, limiting access to safe water both for human consumption and for productive purposes.

10.7.2.3. Case description

Between October 2013 and December 2018, the former Unit for Rural Change (UCAR)—now the General Directorate for Sectoral and Special Programs and Projects of the Ministry of Agriculture, Livestock and Fisheries—implemented a project in the NEA financed by the Adaptation Fund established by the United Nations Framework Convention on Climate Change to increase the adaptive capacity and resilience of small family farmers to the impacts of hydro-meteorological events, such as floods and droughts.

Achievements include access to safe water for more than 1,300 families and 800 students and teachers from 12 schools, optimization of agricultural practices (crop protection structures such as macro-tunnels, greenhouses, half-shade and drip irrigation systems), strengthening of agro-meteorological and agro-productive monitoring systems (installation of new automatic weather stations and progress in integrating the agro-meteorological networks of various public and private actors in the region) and increasing institutional capacity for decision-making and management of climate change adaptation measures and actions and its variability (training of technicians, producers and original peoples in the approach to climate change and water harvesting technologies, agricultural optimization practices and risk transfer).

10.7.2.4. Limitations and interactions

The project was implemented by three organizations working together: the National Institute of Agricultural Technology (INTA), the Agricultural Risk Office (ORA) of the Ministry of Agriculture, Livestock and Fisheries, and the National Directorate of Climate Change of the Secretariat of the Government of Environment and Sustainable Development. It also benefited from the collaboration of the Ministry of Production and Labor through its job training programs, which conducted trainings in horticultural, livestock and beekeeping production and in the promotion of access to and efficient use of water.

10.7.2.5. Lessons learned

When the project was conceived and during the first years of its implementation, there were no national, sectoral or provincial adaptation plans in Argentina. Consequently, the project has set an important precedent to raise awareness of the issue both nationwide and provincially.

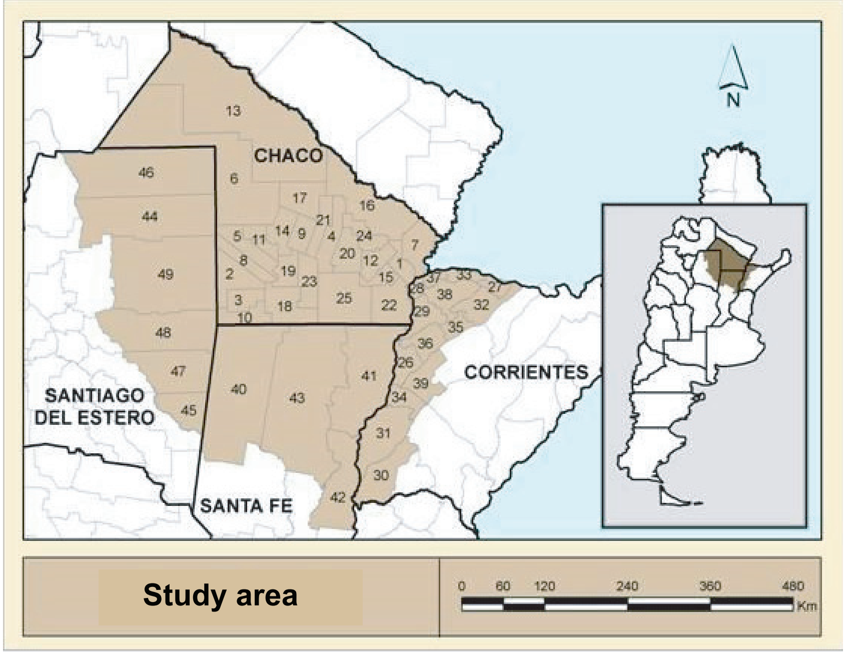

Figure 10.12. Coverage area of the project on adaptation and resilience of family agriculture in northeast Argentina (NEA) in the face of climate change impact and variability.

The project involved a large number of stakeholders in the exchange of information, as well as in the design, implementation and monitoring stages. The experience and knowledge of the executing agencies, producer and civil society organizations, insurance companies, municipalities and universities contributed successfully to the project's design and its implementation. The gender issue was mainstreamed into all stages of the project, resulting in a significant impact on the lives of women from traditional water-carrying families. Thus, by having access to safe water on their lands, the women were able to take advantage of up to four hours per day for other purposes.

10.7.3. Change in hydroelectric operation of the São Francisco River, Brazil, because of drought

10.7.3.1. Case summary

The São Francisco River runs 2,700 km long and flows 2,810 m^3/s at its mouth into the Atlantic Ocean, making it the third most important river in Brazil. According to the last census (IBGE, 2010), about 20 million people live in its basin. During normal hydrological years, dam rules on the river operated properly. However, the sequence of very low flows in recent years caused the rules of operation to change, resulting in undesirable impacts and conflicts with other uses and users of the river's waters. This situation was particularly serious during the dry period between 2012 and 2016. This case illustrates the context in which new operating rules for the dams were developed as a result of this drought.

10.7.3.2. Introduction to the case problem

Historical uses of the waters of the São Francisco River include navigation along with water supply and fishing by the riverside communities. Furthermore, the river plays an essential role to sustain life in the semi-arid region by fertilizing its flood plains during the periodic rises, which allowed developing agriculture, livestock and establishing communities along the river. The seasonality of the São Francisco River became reduced from the second half of the 20th century, after large hydroelectric plants that regulated the flows were built. Investments in hydraulic and energy infrastructure together with population growth in the basin also led to the emergence of other water uses and actions on the river: water supply for irrigated agriculture, human and industrial consumption, flood control, fish farming, and urban and industrial effluent discharge. The importance of navigation has also increased, and the construction of the new São Francisco waterway is already in the pipeline.

Due to a drought in the northeast region of Brazil that began in 2012 and lasted several years, the volume of water in the reservoirs on the São Francisco River fell to minimum levels. This was coupled with an increase in demand for irrigation water and evaporation from the reservoirs. **Figure 10.13** shows the evolution of the naturalized flows to the Sobradinho dam, one of the most important uses of the São Francisco, for the 1930-2017 period. It may be observed that since 2000 there has been a decline in tributary flows below the historical average for the 1931-1999 period, which becomes more pronounced from 2012 onwards. The sequence of unfavorable flows from 2012 was the most critical on record (França et al., 2017), and the hydrological year of 2015-2016 has been the worst one yet.

10.7.3.3. Case description

As a result of the sharp reduction in the flow of the São Francisco River since 2012, it became necessary to modify the operation of the reservoirs—whose design had been established in the 1970s—in order to preserve the water stocks available and supply the various water uses, mainly the water supply of several cities along the river and large irrigation projects.

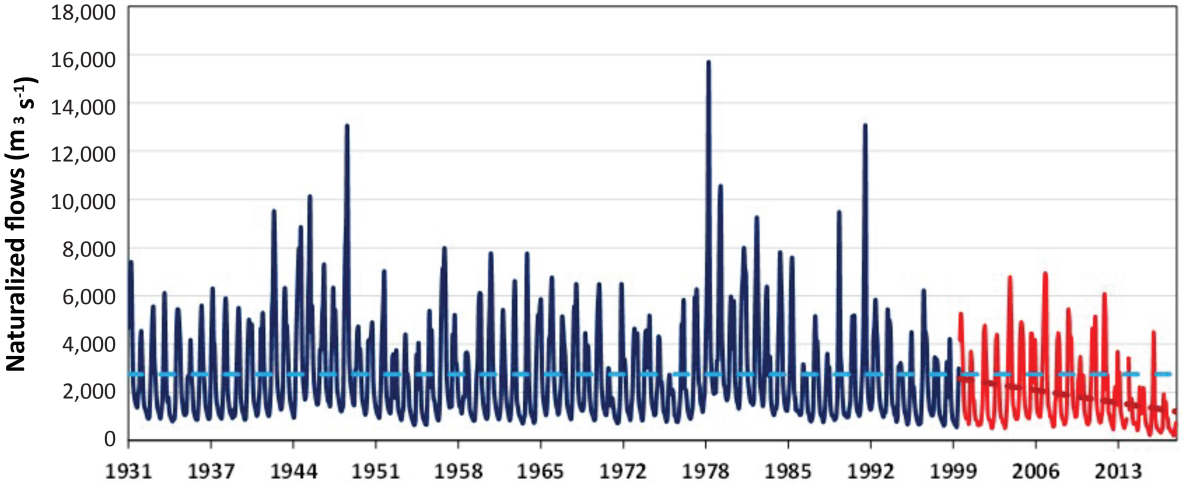

Figure 10.13. Naturalized flows to Sobradinho dam on the São Francisco River between 1930 and 2017. The light blue dotted line shows the average flow rate between 1931 and 1999, with the hydrological year 2015-2016 being the least favorable. Source: França et al., 2017.

Based on the lessons learned from managing the water scarcity crisis experienced in the basin between 2012 and 2016, it also became evident that the operational rule to be implemented should be associated with an agile decision-making process that would lead to greater water security for the basin. By means of National Water Agency Resolution No. 2081/2017 (ANA, 2017), operation strips were established in the reservoirs of the São Francisco River dam cascade. The new operating rules per strip are an important paradigm shift in the Brazilian electricity system, which has more than 100 working dams that are interconnected.

10.7.3.4. Limitations and interactions

The creation of the dams and the regularization of flows in the São Francisco River basin brought important benefits. These works resulted in the installation of more than 10,000 MW of hydroelectric generation capacity together with operational criteria of the dam cascade, seeking to maximize power generation by storing excess water from rainy periods and using this stored reserve when there is a drought. Against this backdrop, one of the major sources of conflict in dam operation concerns the minimum flow rate, which can translate into restrictions on its various uses downstream.

10.7.3.5. Lessons learned

The new rules for operating reservoirs on the São Francisco River seek to address the need to adapt the water system to a new hydrometeorological benchmark, recognizing the importance of the impacts of climate change on water resources. At the same time, the principles of multiple, rational and integrated use of water resources are deemed essential to guarantee the water security of the basin.

10.8. Main knowledge gaps and priority lines of action

Climate change is causing and will continue to cause changes in the water deficit and excess patterns of the RIOCC region. Climate change adaptation measures and policies should aim to address changes that have already taken place and those that are projected to take place in the near future. However, in order for the adaptation strategies to be truly effective, it is imperative that uncertainties regarding projected changes be reduced. This can only be done if research on climate science is made a priority in order to accurately assess observed changes and future prospects for the region, and if improvements are made to climate and hydrological monitoring and warning systems.

10.9. Conclusions

Climate change is already having significant impacts on economic activity, social conditions and ecosystems. The capacities of the region—particularly Latin American countries—to withstand and adapt to its negative impacts and future risks are weakened by the high incidence of poverty, which is associated with inadequate infrastructure, as well as limited access to services. A significant proportion of Latin American residents live in substandard housing on slopes or plains prone to flooding, making them vulnerable to storms and floods. Moreover, the incidence of droughts in Ibero-America poses a limitation on its economic, social, and environmental development, because of the restrictions associated with the provision of water to populations, agricultural activities, and industry. Therefore, adaptation to water extremes in the RIOCC region is a social issue that must be included in each government's short-term priority agenda.

This chapter has provided a variety of examples indicating that in Latin America the process of adaptation to climate change with regard to droughts and floods has already begun. However, in order to accelerate adaptation, countries must take measures such as collecting better data on climate risks, building planning and response capacities, and improving disaster management and insurance.

Frequently Asked Questions

1. How does climate change affect the water cycle?

In short, the water cycle can be described as the process by which water evaporates from the earth's surface and the oceans, condenses in the atmosphere, and finally returns to the earth as rain and snow. Climate change intensifies this cycle because as the air temperature rises, evaporation increases. Warmer air can contain more water vapor, which in some regions can lead to more intense rainfall, causing floods, while in other areas exacerbated evaporation results in drought.

2. What will happen to droughts if global temperatures continue to rise?

Future climate projections show that some areas will become wetter while others will get much drier. Under a temperature rise scenario of 1.5°C compared to the pre-industrial period, the risk of drought increases in many regions across the globe, such as the Mediterranean region in Europe, the Amazon and southern Africa. This risk becomes significantly higher in a 2°C scenario.

3. What will happen to floods if global temperatures continue to rise?

Rises in global temperature will increase the frequency of extreme flow events on all continents, leading to an increased risk of river flooding. This risk will be different across regions, largely due to the disparity in local socio-economic conditions.

4. How can science contribute to developing adaptation strategies for droughts and floods?

The decision-making process can be aided by a better understanding and use of hydrological event forecasts derived from high-resolution climate models, which can be used to predict and prevent the impact of extreme hydrometeorological events. For example, the predictions can be used to optimize the operating efficiency of the water system in the face of droughts, taking into account the needs of agriculture and hydroelectric power generation, or in the case of excess water, to prevent possible damage to the population.

Bibliography

ANA, 2017: Resolução Agência Nacional de Águas – ANA N.° 2081/2017. Disponible en: http://arquivos.ana.gov.br/resolucoes/2017/2081-2017.pdf

Alfieri, L., B. Bisselink, F. Dottori, G. Naumann, A. de Roo, P. Salamon, K. Wyser & L. Feyen, 2017: Global projections of river flood risk in a warmer world. *Earth's Future,* 5, 171-182, DOI: 10.1002/2016EF000485, http://doi.wiley.com/10.1002/2016EF000485

Arnell, N.W., Liu, C., R. Compagnucci, L. da Cunha, K. Hanaki, C. Howe, G. Mailu, I. Shiklomanov & E. Stakhiv, 2001: Hydrology and water resources. En: *IPCC Climate Change 2001: Impacts, Adaptation & Vulnerability, The Third Assessment Report of Working Group II of the Intergovernmental Panel on Climate Change (IPCC), 1000* [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken & K.S. White (eds.)]. Cambridge University Press, Cambridge, UK, pp. 133-191.

Asadieh, B. & N.Y. Krakauer, 2017: Global change in streamflow extremes under climate change over the 21st century. *Hydrol. Earth Syst. Sci.,* 21, 5863-5874.

Banco Mundial, 2016: *Argentina, country environmental analysis.* Disponible en: http://documentos.bancomundial.org/curated/es/218361479799045279/Argentina-Country-environmental-analysis-technical-report

Beguería, S., S.M. Vicente-Serrano, F. Reig & B. Latorre, 2014: Standardized precipitation evapotranspiration index (SPEI) revisited: Parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. *International Journal of Climatology,* 34(10), 3001-3023.

BID, 2015: *Casos de Estudios de Adaptación al Cambio Climático Impactos del Cambio Climático durante las Sequías en la ciudad de Trujillo, Perú.* Disponible en: https://www.uncclearn.org/sites/default/files/inventory/idb30052016_climate_change_adaptation_case_study_climate_change_impacts_during_droughts_on_the_city_of_trujillo_peru_es.pdf

Camilloni, I. & V. Barros, 2003: Extreme discharge events in the Paraná River and their climate forcing. *Journal of Hydrology,* 278, 94-106.

CEDEX, 2017: *Evaluación del impacto del cambio climático en los recursos hídricos y sequías en España,* 346 pp. Disponible en: http://www.cedex.es/NR/rdonlyres/3B08CCC1-C252-4AC0-BAF7-1BC27266534B/145732/2017_07_424150001_Evaluaci%C3%B3n_cambio_clim%C3%A1tico_recu.pdf

CENEPRED, 2016: *Plan Multisectorial de Prevención y Reducción de Riesgos ante Sequías.* Disponible en: https://reliefweb.int/sites/reliefweb.int/files/resources/Plan%20Multisectorial%20de%20Prevencion%20y%20reduccion%20de%20riesgos%20ante%20sequias%202016.pdf

CRED, 2015: *The Human Cost of Natural Disasters: A Global Perspective.* Centre for Research on the Epidemiology of Disasters, Brussels. Disponible en: https://www.preventionweb.net/files/42895_cerdthehumancostofdisastersglobalpe.pdf

Christenson, E., M. Elliott, O. Banerjee, L. Hamrick & J. Bartram, 2014: Climate-Related Hazards: A Method for Global Assessment of Urban and Rural Population Exposure to Cyclones, Droughts, and Floods. *Int. J. Environ. Res. Public Health,* 11(2), 2169-2192, DOI: 10.3390/ijerph110202169

Christian Aid, 2018: *Counting The Cost: A Year of Climate Breakdown.* Disponible en: https://www.christianaid.org.uk/sites/default/files/2019-01/Counting-the-Cost-report-dec-2018.pdf

Dai, A., 2011: Characteristics and trends in various forms of the Palmer Drought Severity Index 16 (PDSI) during 1900-2008. *J. Geophys. Res.,* 116, D12115, doi:10.1029/2010JD015541.

Dai, A. & T. Zhao, 2017: Uncertainties in historical changes and future projections of drought. Part I: estimates of historical drought changes. *Climatic Change,* 144(3), 519-533, DOI: 10.1007/s10584-016-1705-2

Do, H.X., S. Westra & M. Leonard, 2017: A global-scale investigation of trends in annual maximum streamflow. *J. Hydrol.,* 552, 28-43, DOI: 10.1016/J.JHYDROL.2017.06.015

ENCC, 2013: *Estrategia Nacional de Cambio Climático. Visión 10-20-40.* Gobierno de la República. Disponible en: https://www.gob.mx/cms/uploads/attachment/file/41978/Estrategia-Nacional-Cambio-Climatico-2013.pdf

FAO, 2018: *2017, The impact of disasters and crises on agricultura and food security.* Disponible en: http://www.fao.org/3/I8656EN/i8656en.pdf

Fatichi, S., V.Y. Ivanov, A. Paschalis, N. Peleg, P. Molnar, S. Rimkus, J. Kim, P. Burlando & E. Caporali, 2016: Uncertainty partition challenges the predictability of vital details of climate change. *Earth's Future,* 4, 240-251, DOI: 10.1002/2015EF000336

França, E.H.F., V. Forain, L.G.F Guilhon & L.F.G. de Paiva, 2017: *Sobre uma regra para operacão dos reservorios da Bacia do Rio São Francisco.* Anais del XX Simpósio Brasileiro de Recursos Hídricos, Florianópolis. Disponible en: https://www.abrh.org.br/SGCv3/index.php?PUB=3&ID=155&PUBLICACAO=SIMPOSIOS

Garreaud, R.D., C. Alvarez-Garreton, J. Barichivich, J.P. Boisier, D. Christie, M. Galleguillos, C. LeQuesne, J. McPhee & M. Zambrano-Bigiarini, 2017: The 2010-2015 megadrought in central Chile: impacts on regional hydroclimate and vegetation, *Hydrol. Earth Syst. Sci.,* 21, 6307-6327, https://doi.org/10.5194/hess-21-6307-2017

GIZ, 2014: *Repositorio de Indicadores de Adaptación. Casos reales de sistemas de Monitoreo y Evaluación nacionales.* Disponible en: https://gc21.giz.de/ibt/var/app/wp342deP/1443/wp-content/uploads/filebase/me/national-level-me(2)/giz2014-es-climaadaptacion-indicadores-repositorio.pdf

Guttman, N. B., 1999: Accepting the Standardized Precipitation Index: A calculation algorithm. *J. Amer. Water Resour. Assoc.,* 35, 311-322.

Hall, J., B. Arheimer, M. Borga, R. Brázdil, P. Claps, A. Kiss, T.R. Kjeldsen, J. Kriauďčienč, Z.W. Kundzewicz, M. Lang, M.C. Llasat, N. Macdonald, N. McIntyre, L. Mediero, B. Merz, R. Merz, P. Molnar, A. Montanari, C. Neuhold, J. Parajka, R.A.P. Perdigão, L. Plavcová, M. Rogger, J.L. Salinas, E. Sauquet, C. Schär, J. Szolgay, A. Viglione & G. Blöschl, 2014: Understanding flood regime changes in Europe: a state-of-the-art assessment, *Hydrol. Earth Syst. Sci.,* 18, 2735-2772, https://doi.org/10.5194/hess-18-2735-2014

Hartmann, D.L., A.M.G. Klein Tank, M. Rusticucci, L.V. Alexander, S. Brönnimann, Y. Charabi, F.J. Dentener, E.J. Dlugokencky, D.R. Easterling, A. Kaplan, B.J. Soden, P.W. Thorne, M. Wild & P.M. Zhai, 2013: Observations: Atmosphere and Surface. En: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom y New York, NY, USA.

Hawkins, E. & R. Sutton, 2011: The potential to narrow uncertainty in projections of regional precipitation change, *Clim. Dyn.,* 37, 407-418, DOI: 10.1007/s00382-010-0810-6

Held, I.M. & B.J. Soden, 2000: Water vapor feedback and global warming. *Annu. Rev. Energy Environ.,* 25, 441-475.

Huntington, T.G., 2006: Evidence for intensification of the global water cycle: review and synthesis. *J. Hydrol.,* 319, 83-95.

IPCC, 2012: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor & P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK y New York, NY, USA, 582 pp.

IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom y New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.

IPCC, 2014: Summary for policymakers. En: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects* [Field, C.B. *et al.* (eds.)]. Cambridge University Press, Cambridge, United Kingdom y New York, NY, USA, pp. 32.

IPCC, 2018: Summary for Policymakers. En: *Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, Maycock, M. Tignor & T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

Jiménez-Muñoz, J.C., C. Mattar, J. Barichivich, A. Santamaría Artigas, K. Takahashi, Y. Malhi, J.A. Sobrino & G. van der Schrier, 2016: Record-breaking warming and extreme drought in the Amazon rainforest during the course of El Niño 2015-2016. *Scientific Reports,* 6 (33130), DOI: 10.1038/srep33130

Kundzewicz, Z.W. *et al.,* 2013. Flood risk and climate change: global and regional perspectives. *Hydrol. Sci. J.*, 59 (1), 1-28.

Lewis, S. L., P. M. Brando, O. L. Phillips, G. M. F. van der Heijden & D. Nepstad, 2011:, *The 2010 Amazon drought, Science,* 331, 554, doi:10.1126/science.1200807.

Liu, W., Sun, F., Lim, W. H., Zhang, J., Wang, H., Shiogama, H., and Zhang, 2018: Global drought and severe drought-affected populations in 1.5 and 2 °C warmer worlds, *Earth Syst. Dynam.,* 9, 267-283, https://doi.org/10.5194/esd-9-267-2018.

Lyon, B., 2004: The strength of El Niño and the spatial extent of tropical drought. Geophys. *Res. Lett.,* 31, L21204.

Lyon, B. & A.G. Barnston, 2005: ENSO and the spatial extent of interannual precipitation extremes in tropical land areas. *Journal of Climate,* 18, 5095-5109.

MADS, 2016: *Plan Integral de Cambio Climático del Departamento de Chocó (PICC-Chocó).* Ministerio de Ambiente y Desarrollo Sustentable – Instituto de Investigaciones Ambientales del Pacífico. Disponible en: http://www.minambiente.gov.co/index.php/gestion-territorial-decambio-climatico#planes-formulados-a-la-fecha

Magrin, G.O., 2015: *Adaptación al cambio climático en América Latina y el Caribe.* Comisión Económica para América Latina y el Caribe (CEPAL). Disponible en: https://repositorio.cepal.org/bitstream/handle/11362/39842/S1501318_es.pdf;jsessionid=D4C3492388908CD6D5F1D34E80A2D3E9?sequence=1

Marengo, J.A., C.A. Nobre, J. Tomasella, M.D. Oyama, G.S. Oliveira, R. de Oliveira, H. Camargo, L.M. Alves e I.F. Brown, 2008: The drought of Amazonia in 2005, *J. of Climate,* 21, 495-516.

Martin Murillo, L., J. Rivera Alejo & R. Castizo Robles, 2018: *Cambio climático y desarrollo sostenible en Iberoamérica.* Observatorio de Desarrollo Sostenible y Cambio Climático de La Rábida. Disponible en: https://issuu.com/segibpdf/docs/resumen_informe_la_rabida_huelva_20

McKee, T.B., N.J. Doesken & J. Kliest, 1993: *The relationship of drought frequency and duration to time scales.* En: Proceedings of the 8th Conference of Applied Climatology, 17-22 de enero, Anaheim, CA. American Meteorological Society, Boston, MA. 179-184.

Mills, E., 2005: Insurance in a climate of change. *Science,* 309.

MINAE, 2018: *Política Nacional de Adaptación al cambio climático de Costa Rica, 2018-2030.* Disponible en: http://www.pgr web.go.cr/DocsDescargar/Normas/No%20DE-41091/Version1/Politica_ADAPTACION_24_abril.pdf

MINAG, 2012: *Plan de Gestión de Riesgos y Adaptación al Cambio Climático en el Sector Agrario Periodo 2012-2021.* Disponible en: http://www.fao.org/fileadmin/user_upload/FAO-countries/Peru/docs/Plangracc_RESUMEN.pdf

MITECO, 2018: *Incorporación del cambio climático en la evaluación preliminar del riesgo de inundación (EPRI) en el segundo ciclo de aplicación de la directiva de inundaciones (2007/60/CE).* Ministerio para la Transición Ecológica, España. Documento web consultado en: https://www.miteco.gob.es/ca/agua/temas/gestion-de-los-riesgosde-inundacion/cambio-climatico-en-la-epri-metodologia-general_tcm34-485704.pdf

Mora-Melià, D., C.S. López-Aburto, P. Ballesteros-Pérez & P. Muñoz-Velasco, 2018: Viability of Green Roofs as a Flood Mitigation Element in the Central Region of Chile. *Sustainability,* 10, 1130, DOI: 10.3390/su10041130

Munich Re, 2015: *NatCatSERVICE: Loss events worldwide 1980-2014.* Munich Re, Munich.

Najibi, N. & N. Devineni, 2018: Recent trends in the frequency and duration of global floods. *Earth Syst. Dynam.,* 9, 757-783.

Naumann, G., L. Alfieri, K. Wyser, L. Mentaschi, R.A. Betts, H. Carrao, J. Spinoni, J. Vogt & L. Feyen, 2018: Global changes in drought conditions under different levels of warming. *Geophys. Res. Lett.,* 45, 3285-3296.

Neri, C. & V. Magaña, 2016: Estimation of vulnerability and risk to meteorological drought in Mexico. *Weather, Climate and Society,* 8, 95-110.

OCHA, 2019: *Desastres naturales en América Latina y el Caribe 2000-2019.* United Nations Office for the Coordination of Humanitarian Affairs (OCHA). Sitio web consultado en: https://reliefweb.int/sites/reliefweb.int/files/resources/OCHA-DESASTRES_NATURALES_ESP%20%281%29.pdf

Palmer, W.C., 1965*: Meteorological drought,* Tech. Rep. Weather Bur. Res. Pap (vol. 45). Washington DC, United States Department of Commerce.

Poveda, G. & O.J. Mesa, 2000: On the existence of Lloro (the rainiest locality on Earth): Enhanced ocean-atmosphere-land interaction by a low-level jet. *Geophysical Research Letters,* 27, 1675-1678.

Poveda, G., J.C. Espinoza, M.D. Zuluaga, S.A. Solman, R. Garreaud & P.J. van Oevelen PJ, 2020: High Impact Weather Events in the Andes. *Front. Earth Sci.,* 8:162, DOI: 10.3389/feart.2020.00162

Rasmussen, K.L., M.M. Chaplin, M.D. Zuluaga & R.A. Houze Jr., 2016: Contribution of Extreme Convective Storms to Rainfall in South America. *Journal of Hydrometeorology,* 17, 1, 353-367.

Salazar, J. F., J.C. Villegas, A.M. Rendón, E. Rodríguez, I. Hoyos, D. Mercado-Bettín & G. Poveda, 2018: Scaling properties reveal regulation of river flows in the Amazon through a «forest reservoir». *Hydrol. Earth Syst. Sci.,* 22, 1735–1748. doi: 10.5194/hess-22-1735-2018

Seneviratne, S., N. Nichols, D. Easterling, C. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera & X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. En*: IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation,* Capítulo 3. Cambridge University Press, Cambridge y UK, New York, NY, USA.

Spinoni, J., G. Naumann, J.V. Vogt & P. Barbosa, 2015: The biggest drought events in Europe from 1950 to 2012. *Journal of Hydrology: Regional Studies,* 3,509-524.

Spinoni, J., P. Barbosa, A. De Jager, N. McCormick, G. Naumann, J.V. Vogt, D. Magni, D. Masante & M. Mazzeschi, 2019: A new global database of meteorological drought events from 1951 to 2016. *Journal of Hydrology: Regional Studies,* 22, 100593, https://doi.org/10.1016/j.ejrh.2019.100593.

Taboada, M.A. & F. Damiano, 2017: Inundación y manejo de suelos en Argentina. En: *Inundaciones y manejo de cuencas* [Waldman, S. (coord.)]. CADIA, 145-169.

UNESCO, 2018: *Atlas de sequías de América Latina y el Caribe.* Disponible en https://unesdoc.unesco.org/ark:/48223/pf0000265894

Vásquez, P., I.L., L.M.N. de Araujo, L.C.B. Molion, M. de Araujo Abdalad, D. Medeiros Moreira, A. Sanchez, H. Alves Barbosa & O. Corrêa Rotunno Filho, 2018: Historical analysis of interannual rainfall variability and trends in southeastern Brazil based on observational and remotely sensed data. *Climate Dynamics,* 50: 801-824, https://doi.org/10.1007/s00382-017-3642-9

Vera Rodríguez, J.M. & A.P. Albarracín Calderón, 2017: Metodología para el análisis de vulnerabilidad ante amenazas de inundación, remoción en masa y flujos torrenciales en cuencas hidrográficas, *Ciencia e Ingeniería Neogranadina,* 27, 109-136. DOI: http://dx.doi.org/10.18359/rcin.2309

Vicente-Serrano, S.M., S. Beguería & J.I. López-Moreno, 2010: A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index. *Journal of Climate,* 23, 1696-1718.

Wartenburger, R., M. Hirschi, M.G. Donat. P. Greve, A.J. Pitman & S.I. Seneviratne, 2017: Changes in regional climate extremes as a function of global mean temperature: an interactive plotting framework. *Geosci. Model Dev.,* 10, 3609-3634.

World Bank, 2019: *The World Bank Group Action Plan on Climate Change Adaptation and Resilience.* Washington DC.

Disponible en: http://documents.worldbank.org/curated/en/519821547481031999/The-World-Bank-Groups-Action-Plan-on-Climate-Change-Adaptation-and-Resilience-Managing-Risks-for-a-More-Resilient-Future.pdf

Zhao, T. & A. Dai, 2017: Uncertainties in historical changes and future projections of drought. Part II: model-simulated historical and future drought changes. *Climatic Change,* 144, 535, https://doi.org/10.1007/s10584-016-1742-x