# CE LEVEL ANALYSIS OF PROJECTED CLIMATE CHANGE EFFECTS AND INDUCED RISKS ON URBAN WATER SYSTEMS

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# 1. INTRODUCTION

In 2007, in Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) we can read that "*most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations*", six years later Fifth Assessment Report (AR5) concluded that "*it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century*". The concertation of $CO_2$ in the atmosphere in 2018 is 47% higher than the pre-industrial level (in 1750) (UNFCCC, 2019). Based on long-term warming trend since pre-industrial times, IPCC Special Report on the impacts of global warming of 1.5°C reported that observed global mean surface temperature for years 2006–2015 was 0.87°C higher than the average of the second half of the nineteenth century (1850–1900) (IPCC,2018a) and decade 2009–2018 was 0.91 °C to 0.96 °C warmer than the pre-industrial average (EEA, 2019b). In addition, it warns that global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate 0.2°C per decade due to past and ongoing greenhouse gas emissions. "Warming greater than the global annual average is being experienced in many land regions and seasons, including two to three times higher in the Arctic" (IPCC,2018b). Temperatures increase with different speeds but generally warming over land is higher than over ocean area. The IPCC AR5 estimated that global mean sea level rose by 19.5 cm in the period between 1901 and 2015 as a result of global warming.

In the EU Member States, 91 455 fatalities caused by weather and climate-related extremes were noted over the period 1980-2017, monetary losses of disasters amounted to EUR 426 billion, 85% of fatalities were connected to heatwave events (EEA, 2019a).

# 2. OBSERVED CLIMATE CHANGE IN EUROPE

The climate change in Europe can be observed in many variables: increasing land and sea temperatures; changing precipitation patterns; declining sea ice extent; decreasing of glacier volume and snow cover; rising sea levels; increasing frequency and intensity of climate-related extremes such as heat waves, heavy rainfall and droughts in many regions. Moreover, the probability of disasters such as flooding and wildfires is also increasing. The analysis of series of weather data from 1950-2018 shows that the number of extreme heat days in Europe has tripled since 1950, while the number of extreme cold days decreased by factors of two or three depending on the region (Lorenz, R. et al., 2019) . The trends in observations of climate indicators for Europe are summarised in table below.

| Indicators | Observed changes |
|---|---|
| **temperature** | Europe is warming faster than many other parts of the world. The average annual temperature for the European land area for the years 2009–2018 was between 1.6 °C and 1.7 °C above the pre-industrial level. Climate reconstructions show that summer temperatures in Europe in the three decades (1986–2015) have been the warmest for at least 2 000 years. Observed climate trends show regionally varying changes in temperature and rainfall in Europe. Impacts vary across the EU, but the Mediterranean basin, mountain areas, densely populated floodplains, coastal zones, outermost regions and the Arctic are particularly vulnerable to climate change impacts.<br>Temperature in all of Europe has risen significantly since the 1960s. The regionally and seasonally different rates of warming being greatest in high latitudes in Northern Europe. Since the 1980s, warming has been strongest over Scandinavia, especially in winter, whereas the Iberian Peninsula warmed mostly in summer. |

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| **high-temperature extremes** | Since 1950, high-temperature extremes like hot days, tropical nights, and heat waves, have become more frequent, while low-temperature extremes like cold spells, frost days, have become less frequent.<br>Heatwave in central and western Europe in summer 2003 caused about 70 000 excess deaths.<br>On August 12, 2019, 11 cities in Italy had the highest alert due to hot weather. The temperature near the ground reached 50ºC. |
| **precipitation** | Since 1950, annual precipitation has increased in northern Europe, and decreased in parts of southern Europe. Winter snow cover extent has a high interannual variability and a nonsignificant negative trend over the period 1967–2007. |
| **precipitation extremes** | The intensity of heavy precipitation events in summer and winter have increased in northern and north-eastern Europe since the 1960s. Different indices show diverging trends for south-western and southern Europe.<br>Extreme rainfall and flooding in May/June 2013 in Central Europe affected Germany, Czech Republic, Austria, Switzerland, Slovakia, Belarus, Poland, Hungary and Serbia and was a reason of 25 deaths.<br>At least 4 people have died in Italy in October 2015 as a result of floods and landslides in several regions across the country caused by heavy rain. At the same time heavy rain and flooding has affected Croatia, Bosnia, Serbia, Romania. |
| **hail** | Most extreme hail events occur in the summer over Central Europe where convective energy is greatest. Hail occurs most frequently in mountainous areas, especially the Alps, due to moisture convergence and upward forcing, but is less frequent over the central Alps due to reduced uplift. Satellite data show a higher incidence of hail in elevated regions, for example northern Italy and southern Germany.<br>Three hailstorm events in Germany in Summer 2013 damaged infrastructure, buildings, crops, vehicles, solar panels and costed around 4.2 billion EUR. |
| **windstorms** | Storm location, frequency and intensity have shown considerable decadal variability across Europe over the past century, such that no significant long-term trends are apparent. |
| **sea ice** | The extent and volume of the Arctic sea ice has declined rapidly since global data became available (1979), especially in summer. The Arctic sea ice is getting thinner and younger; recent analysis has found that annual mean ice thickness has decreased by 65 % in less than 40 years. The maximum sea ice extent in the Baltic Sea shows a decreasing trend since about 1800. The decrease appears to have accelerated since the 1980s, but the interannual variability is large. |
| **ice sheets** | The Greenland and Antarctic ice sheets play an important role in the global climate system. They have significant effects on global sea level. Moreover, they modify ocean temperatures and circulation, vegetation and land-surface albedo. Both ice sheets have been losing large amounts of ice at an increasing rate since 1992. |
| **glaciers** | Glaciers and ice caps influence river flow and freshwater supply. The melting of glaciers is contributing significantly to global sea level rise.<br>A general loss of glacier mass since the beginning of the measurements has occurred in all European glacier regions, except some glaciers in Norway. The Alps have lost roughly 50 % of their ice mass since 1900, with acceleration since the 1980s. |
| **snow cover** | Snow covers a large area, but has a relatively small volume. Its reflection of light is important for climatic conditions, it insulates the soil in winter and is an important source of temporary water storage. A decrease in snow cover accelerates climate change. Snow cover extent in the northern hemisphere has |

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| | declined significantly over the past 90 years, with most of the reductions occurring since 1980. |

**Figure 1. Observed climate change in Europe**

Source: EEA, 2017a; EEA, 2019b; IPCC, 2014c.

# 3. PROJECTED CLIMATE CHANGES IN EUROPE

Human activities that cause greenhouse gas emissions are a factor in changing the Earth's climate. "*Even if anthropogenic emissions of $CO_2$ and other greenhouse gases were to fall to zero in the very near future, the atmospheric residence time of greenhouse gases and the dynamics of the climate system would lead to further anthropogenic climate change for many decades, with rising temperatures, changing precipitation and drought patterns, more frequent and longer heat waves, and changes in other extreme climate events; sea levels would continue to increase for several centuries.*" is the one of the key messages from EEA report *Climate change, impacts and vulnerability in Europe 2016* (EEA, 2017a). Future projections of climate indicators for Europe are summarised in table below.

| Indicators | Projected changes |
|---|---|
| **Temperature** | Projections show greater warming over land than over the oceans. Projected warming in the Arctic is about twice the global average. Temperatures across Europe are projected to continue increasing throughout this century. Probably European land areas will warm faster on average than global land areas. The strongest warming is projected over north-eastern Europe and Scandinavia in winter and over southern Europe in summer. |
| **High-temperature extremes** | Under future climate change with continued warming, the number of heat waves is expected to increase, along with their duration and intensity for most European regions during the 21st century under all RCP scenarios. Extreme summer heat waves, such as the ones experienced in different parts of Europe in 2003 and 2010, will become much more common in the future. The projected frequency of heat waves is greatest in southern and south-eastern Europe. The most severe health risks are projected for low-altitude river basins in southern Europe and for the Mediterranean coasts, where many densely populated urban centres are located. |
| **Precipitation** | Projected changes in precipitation vary substantially across regions and seasons. Annual precipitation is generally projected to increase in northern Europe and to decrease in southern Europe. The projected decrease in southern Europe is strongest in the summer. |
| **Precipitation extremes** | Extreme precipitation is becoming more intense and more frequent in Europe, especially in central and Eastern Europe in winter, often resulting in greater magnitude and frequency of flooding. Global warming is projected to lead to a higher intensity of precipitation and longer dry periods in Europe. Projections show an increase in heavy daily precipitation in most parts of Europe in winter, by up to 35 % during the 21st century. Heavy precipitation in winter is projected to increase over most of Europe, with increases of up to 30 % in north-eastern Europe. In summer, an increase is also projected in most parts of Europe, but decreases are projected for some regions in southern and south-western Europe. Events currently considered extreme are expected to occur more frequently in the future. |
| **Hail** | Future projections of hail events are subject to large uncertainties. However, model-based studies for central Europe show some agreement that hailstorm frequency will increase in this region. The projected changes are largest in |

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| | southern Germany. |
| **Windstorms** | Recent studies on changes in winter storm tracks generally project an extension eastwards of the North Atlantic storm track towards central Europe and the British Isles. Climate change simulations show diverging projections on changes in the number of winter storms across Europe. However, most studies agree that the risk of severe winter storms, and possibly of severe autumn storms, will increase for the North Atlantic and northern, north-western and central Europe over the 21st century. |
| **Sea ice** | Arctic sea ice will continue to shrink and thin. For high greenhouse gas emissions scenarios, a nearly ice-free Arctic Ocean in September (melt season) is likely to occur before mid-century. There will still be substantial ice in winter. Baltic Sea ice, in particular the extent of the maximal cover, is projected to continue to shrink. |
| **Ice sheets** | Model projections suggest further declines of the polar ice sheets in the future, but the uncertainties are large. The melting of the polar ice sheets is estimated to contribute up to 50 cm of global sea level rise during the 21st century. |
| **Glaciers** | The retreat of European glaciers is projected to continue throughout the 21st century. The volume of all European glaciers will decline between 22 and 84 % relative to their extent in 2006 under scenario RCP4.5 and between 38 and 89 % under RCP8.5. The relative volume loss is largest in central Europe (83 ± 10 % for RCP4.5 and 95 ± 4 % for RCP8.5). |
| **Snow cover** | Model simulations project widespread reductions in the extent and duration of snow cover in the northern hemisphere and in Europe over the 21st century. These changes can have strong negative effects to river flows. Occasional winters of heavy snowfall will uncommon towards the end of the 21st century. |

**Figure 2. Projected climate change in Europe**

Source: EEA, 2017a; EEA, 2019b; IPCC, 2014c.

# 4. CLIMATE CHANGE IMPACTS ON ENVIRONMENTAL SYSTEM – SELECTED ISSUES

Climate change is already effecting the environment, human health and economies across Europe. Changes in the hydrological cycle, in the freshwater system and in sea level are particularly important for safety and quality of life in the city. The table below contains the characteristics, the changes of which may affect the availability and quality of water.

| Characteristics | Impacts of changes in climate |
|---|---|
| **Seas and coastal areas** | Globally averaged sea surface temperature is projected to continue to increase, although more slowly than atmospheric temperature. All European seas have warmed considerably since 1870, and the warming has been particularly rapid since the late 1970s. The multi-decadal rate of sea surface temperature rise during the satellite era (since 1979) has been between 0.21°C per decade in the North Atlantic and 0.40°C per decade in the Baltic Sea. The Mediterranean Sea is expected to increase in temperature and also in salinity, triggered by higher evaporation and lower rainfall.<br>An increase in harmful algal blooms, with increased risks to human health, ecosystems and aquaculture, has been projected for the North Sea and the Baltic Sea as a result of the projected warming. A rise in water temperatures due to climate change in the Baltic Sea is also contributing to a further |

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| | expansion in oxygen-depleted “dead zones”. Europe is marked by increasing mean sea level with regional variations, except in the northern Baltic Sea, where the relative sea level decreased due to vertical crustal motion. Relative sea level change along most of the European coastline is projected to be reasonably similar to the global average (except the northern Baltic Sea and the northern Atlantic coast where sea level relative to land is rising slower than elsewhere or may even decrease). Sea level rise substantially increases the risk of coastal flooding, which affects people, communities and infrastructure. |
| **River flows** | Available studies suggest that run-off in near-natural rivers during the period 1963–2000 increased in western and northern Europe, in particular in winter, and decreased in southern and parts of eastern Europe, in particular in summer. Annual river flows are projected to decrease in southern and south-eastern Europe and increase in northern and north-eastern Europe. Climate change is projected to result in significant changes in the seasonality of river flows across Europe. Summer flows are projected to decrease in most of Europe, including in regions where annual flows are projected to increase. Where precipitation shifts from snow to rain, spring and summer peak flow will shift to earlier in the season. The reduction in winter retention as snow, earlier snowmelt and, in some cases, reduced summer precipitation are projected to lead to increases in river flows in winter and reductions in summer in the Alps. Reductions of flow can be exacerbated by water abstractions, especially in summer when consumption is highest and input is typically low. These changes result in a further decrease of water availability in summer |
| **River floods** | River floods are a common natural disaster in Europe, and — along with storms — are the most important natural hazard in Europe in terms of economic damage. They are mainly caused by prolonged or heavy precipitation events and/or snowmelt. Almost 1 500 floods have been reported for Europe since 1980, of which more than half have occurred since 2000. Global warming is projected to intensify the hydrological cycle and increase the occurrence and frequency of flood events in large parts of Europe. Pluvial floods and flash floods, which are triggered by intense local precipitation events, are likely to become more frequent throughout Europe. The strongest increase in flood risk is projected for Austria, Hungary, Slovakia and Slovenia. In regions with projected reduced snow accumulation during winter, the risk of early spring flooding could decrease. However, quantitative projections of changes in flood frequency and magnitude remain highly uncertain. |
| **Droughts** | Drought has been a recurrent feature of the European climate. From 2006-2010, on average 15 % of the EU territory and 17 % of the EU population have been affected by meteorological droughts each year. In the 1990s and 2000s the drought hotspots were the Mediterranean area and the Carpathian Region. The frequency of meteorological droughts in Europe has increased since 1950 in parts of southern Europe and central Europe (Austria and Hungary), but droughts have become less frequent in northern Europe and parts of eastern Europe. Trends in drought severity show significant increases in the Mediterranean region (in particular the Iberian Peninsula, France, Italy and Albania) and parts of central and south-eastern Europe, and decreases in northern and parts of eastern Europe. Available studies project large increases in the length, magnitude and area of meteorological and hydrological droughts events in most of Europe over the 21st century, except for northern European regions. The greatest increase in drought conditions is projected for southern Europe, where it would increase competition between different water users, such as agriculture, industry, tourism and households. |
| **Water temperatures** | Water temperatures is one of the parameters that determine the overall health of aquatic ecosystems. Water temperature in major European rivers have increased by 1–3°C over the last century. The annual average |

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| | temperature of the Danube increased by around by 1°C during the 20th century. Several time series show increasing lake and river temperatures all over Europe since the early 1900s. Lake and river surface water temperatures are projected to increase further with projected increases in air temperature. Increased water temperature can result in marked changes in species composition and functioning of aquatic ecosystems. The number of days with water temperatures above 25°C, which is the threshold for significant stress to river fauna and flora, projected to increase. |
| **Freshwater ecosystems** | Freshwater ecosystems include lakes and ponds, rivers, streams, springs, bogs, and wetlands. Increasing water temperatures can lead to earlier and larger phytoplankton blooms and to species invasions. For example, the recent rapid spread of the highly toxic cyanobacterium *Cylindrospermopsis raciborski* throughout Europe and into other temperate regions has caused international public health concerns. |

**Figure 3. Impacts of changes in climate on selected environmental system characteristics in Europe**

Source: EEA, 2017a; EEA, 2017b

Climate change is already having wide-ranging consequences for ecosystems, economic sectors and people's health and well-being in Europe. All regions are affected, mostly negative, but not in the same way. The rise in sea level has increased flood risks and contributed to erosion along European coasts (for CE countries: Croatia, Italy, German and Poland). The observed increase in heat waves has had significant effects on human health, in particular in cities. Heat waves are also increasing the risk of electricity blackouts and forest fires in Continental and Mediterranean regions (all Central Europe countries). Transport and tourism (e.g., winter sports in the Alps) have also been affected by climate change, with large regional differences. Examples of beneficial impacts of climate change include a decrease in heating demand (but demand for cooling can rise) and some benefits to agriculture in northern Europe. The common-known figure prepared by EEA summarises the situation and provide projections for European regions (Fig. 4).

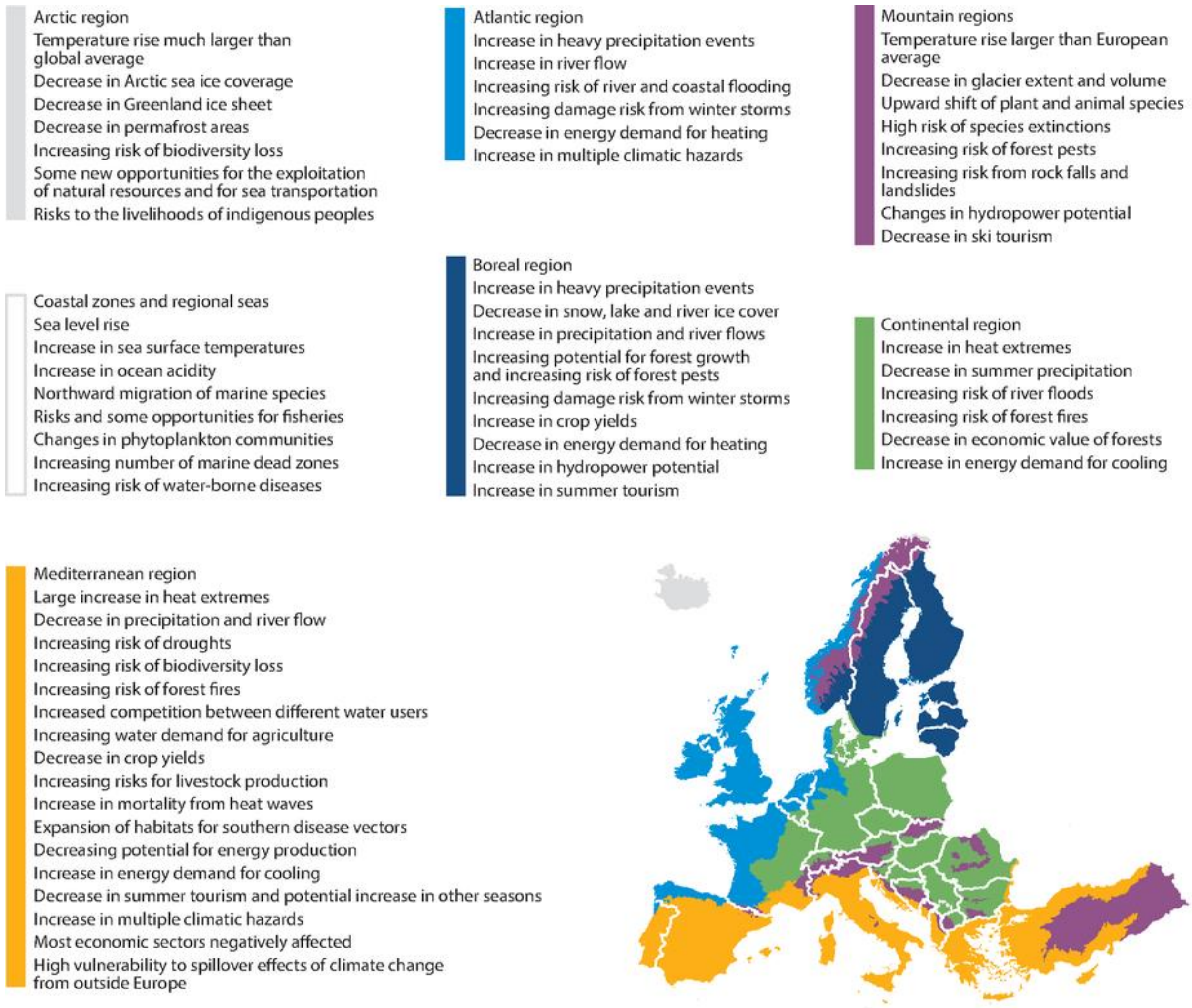


**Figure 4. Key observed and projected climate change and impacts for the main biogeographical regions in Europe**

Note: Central European countries by main biogeographical regions:
Austria – Mountain (the Alps), Continental regions,
Croatia – Coastal zone (the Adriatic Sea), Mediterranean and Continental regions,
the Czech Republic - Continental regions,
Hungary - Continental regions,
Poland – Continental, (the Baltic Sea), Mountain (the Carpathians) regions,
Slovakia - Mountain (the Carpathians), Continental regions
Slovenia - Continental, Coastal zone (the Adriatic Sea), Mediterranean, Mountain (the Alps) regions
Germany (eastern and southern) - Continental, Coastal zone (the Baltic Sea), Mountain (the Alps) regions
Italy (northern) - Mediterranean, Coastal zone (the Ligurian Sea, the Adriatic Sea), Mountain (the Alps) regions
Source: European Environment Agency (EEA)

# 5. CLIMATE CHANGES IMPACTS ON URBAN WATER SYSTEM

The complex systems operate within a city and service its citizens in areas of food, energy, water, waste, transport, etc. The changes in climate can affect proper operation these systems. The Word Bank report Cities and climate change: responding to an urgent agenda (Hoornweg et al., 2012) shows how varied impact these changes in climate can have on a city. Four categories of urban vulnerabilities associated with climate change were identified. The first three categories associated with extreme weather events:

alterations in temperature, alterations in precipitation, alterations in storm intensity and the fourth, associated with sea level change. The potential consequences for city are detailed in the table below.

| Categories of Urban Vulnerabilities | City Impacts |
|---|---|
| **I. Temperature change** | Heat island effect;<br>Increased demand for cooling and energy shortages;<br>Declining air quality in cities;<br>Reduced disruption to transport due to snow, ice;<br>Increased water demand;<br>Water quality problems;<br>Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated;<br>Reduction in quality of life for people in warm areas without appropriate housing; |
| **II. Alterations in precipitation**<br>▪ **Frequency of increase**<br>▪ **Drought** | Adverse effects on quality of surface and groundwater;<br>Contamination of water supply;<br>Waterborne diseases;<br>Poor solid waste disposal;<br>Increased risk of deaths, injuries, and infectious, respiratory, and skin diseases;<br>Disruption of settlements, commerce, transport, and societies due to flooding;<br>Large displacement of people;<br>Pressures on urban and rural infrastructures;<br>Destruction of urban infrastructure;<br>Loss of property;<br>In-migration from climate change affected areas;<br>Food and water shortage;<br>Increased price of food;<br>Increased migration to cities; |
| **III. Storm activity increase (high winds, cyclones, hurricanes, etc.)** | Power outages;<br>Distress migration to urban areas;<br>Disruption of public water supply;<br>Increased risk of deaths, injuries, water and food-borne diseases; post-traumatic stress disorders;<br>Disruption by flood and high winds;<br>Withdrawal of risk coverage in vulnerable areas by private insurers;<br>Potential for population migrations;<br>Loss of property; |
| **IV. Sea level change** | Decreased freshwater availability due to saltwater intrusion;<br>Increased risk of deaths and injuries by drowning in floods and migration related health effects;<br>Loss of property and livelihood;<br>Permanent erosion and submersion of land;<br>Costs of coastal protection versus costs of land-use relocation;<br>Potential for movement of populations and infrastructure; |

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| | Increased salinity in estuaries and coastal aquifers;<br>Rising coastal water tables and impeded drainage;<br>Degraded dykes that are unable to sustain future tides;<br>Encroachment of settlement onto low lying areas;<br>Destruction of urban infrastructure;<br>Effect on long-term economic growth. |

**Figure 5. Urban Vulnerabilities Associated with Climate Change**

Source: World Bank, 2012.

The Urban Water System (UWS) as physical infrastructure includes facilities between water sources and wastewater sinks allowing water supply (water acquisition and treatment, storage) and water distribution, water use, wastewater collection and treatment, and drainage to manage surface runoff (Fig.6).

As a result of heavy rainfall events, which lead to water runoff and flooding (flash flood), stormwater management has become a key challenge for many cities. There are two solutions: (1) combined sewer systems and (2) separate storm sewer systems. Combined sewer systems collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe and discharge them to treatment plants. Exceeding combined network capacity during heavy precipitation events, lead to discharges of untreated wastewater directly to nearby water bodies. In separate systems, stormwater does not mix with sewage.

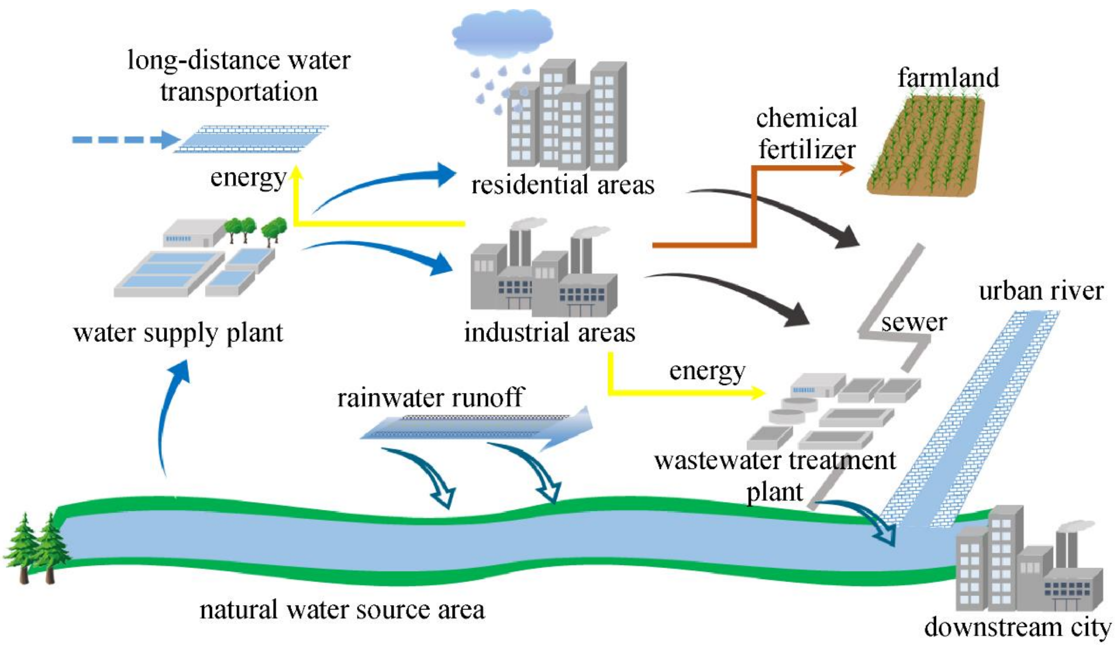


**Figure 6. Scheme of Urban Water System**

Note: Blue arrows represent water flow, gray - wastewater flow, brown -resource and yellow - energy

Source: Nanqi RenQian WangQiuru WangHong HuangXiuheng Wang, Upgrading to urban water system 3.0 through sponge city construction, Frontiers of Environmental Science & Engineering, Vol. 11, August 2017, https://link.springer.com/article/10.1007%2Fs11783-017-0960-4, accessed November 10, 2019

Increasing frequency of extreme weather events, such as heat waves, and heavy rainfall, rising sea levels and changes in surface water and groundwater put additional pressure on existing urban water systems, that are often not adapted to the upcoming climate change. City's lack of resistance to climate change can lead to negative impacts for human health and well-being, economies, and the environment. Changes in water resources and in demand for water (for example during heat wave) can case deficits in urban water supply and limited availability and high cost of water as a result.

According to the approach presented in ARC3.2, in regard to climate change, water is both a resource and a hazard (IPCC, 2018c). The availability of good-quality water is crucial for the well-being of people living inside cities. The availability of water is also critical for many economic activities. Water is a hazard when excess precipitation or drought occur. Risk for health is related to increased concentration of pollutants in sewerage (lack of adequate water flow). Risk for physical assets is related to damage power of water.

## Climate risk to Urban Water System

The projected climate changes will be a challenge for cities in the 21st century in terms of water supply, distribution, wastewater collection and rainfall/ stormwater runoff. Risks to the proper functioning of UWS, identified in ARC3.2 (IPCC, 2018c), include:

- increasing temperatures (with attendant changes in evaporative demands, availability, and quality);
- changing precipitation regimes;
- changing extreme weather regimes;
- sea level rise and storm surges;
- changing surface-water and groundwater availability and conditions.

The table below describes the effects of climate change- related hazards on the water system in the city.

| Climate risks | Potential consequences for UWS |
|---|---|
| **Warming temperatures** | Warmer temperatures result in larger demands for water, particularly for household consumption and power plants cooling. Higher temperatures and heat waves typically increase water use for shower or bath and for irrigation / watering greens.<br>In the heat waves, water supply companies can help residents survive the hottest days by installing sprinklers and pouring water on the streets. Greater water consumption also results from urban greenery watering.<br>An increase in temperature can change water balance. Increased evaporation will lead to reduction of surface water resources and of river and stream flows. Further increases in temperature and the occurrence of droughts may limit the availability for industry and for power generation. Fossil-powered and nuclear electricity generators are sensitive to a reduced availability and increased temperature of cooling water, and to increased air temperature, which reduces their efficiency. The coal power plants with open cooling system require huge amounts of water for cooling (the 500 MW power plant draws approximately 500 million $m^3$ of water annually). This may affect the operation of water supply, treatment and wastewater disposal system which is also energy-consuming. |
| **Changing precipitation regimes** | Changing precipitation patterns, generally make wet regions in Europe wetter, particularly in winter, and dry regions drier, particularly in summer. Change in the nature of summer rainfall (more heavy than light precipitation), and winter (rain rather than snow) are expected in response to atmospheric warming. Consequently more runoff is taking the form of floods (e.g. flash flood) rather than steadier, more reliable, and manageable flows. Such changes in the timing and form of precipitation impacts the balance between the management of water supply and flood risk in cities. |

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| | Heavy precipitation and flood can cause landslides damaging infrastructure. These mass movements are also danger for UWS.<br><br>Urban water systems that depend on local surface water supply may be most instantly at risk related to water availability to changing precipitation regimes. Warmer temperatures and changing precipitation conditions can also impact cities depended on groundwaters, which have a much slower recovery rate than surface water sources.<br><br>Climate change is likely to decrease surface water quality due to higher temperatures and changes in precipitation patterns. |
| **Sea level rise and storm surges** | The impacts of elevating sea level and extreme sea level fluctuations (e.g., inter-annual fluctuations, wind-driven waves, storm surges) will be superimposed. In cities located in coastal settings wastewater and sanitation systems have important hubs (e.g., treatment plants and outfalls) located at or very near sea level to take advantage of the gravity-feed and marine-outfall options. These hubs and systems will be among the infrastructure that is most immediately at risk by sea level rise and/or increased storm surge conditions. The human health may be at risk because of wastewater back up.<br><br>Coastal cities with water supply systems depend on local groundwater sources can face risks of increased seawater intrusion into freshwater aquifers / reservoirs. The aquifer salinization can be caused by overexploitation of groundwater resources /coastal aquifers and changing precipitation, increased storm frequency, and sea level rise will exacerbating these problems. It can threat freshwater supply in long term. |
| **Extreme events / heavy precipitation** | More extreme precipitation could result in changes in frequency, extent, timing, and rapidity of stormwater runoff (flash floods). This could cause flooding in many urban settings, especially given the impervious surfaces of most cities. Furthermore, this could pose added risks to public health and safety, property, and infrastructure (including UWS). Water quality could be affected by these extreme runoff events due to the increased concentration and build-up of contaminants during dry or low-flow conditions that are then released into the water supply with increased water flow. |
| **Changing water availability** | Climatic pressures will impact on water availability, which depends not only on the amount of different water sources, but also on water quality. The combined effect of precipitation decrease and near-surface air temperature increase is expected to affect the hydrological cycle with a general decline in water availability (mainly Mediterranean area). The increased risks of water restrictions in Southern, Central, and Atlantic sub-regions can be expected. The hydrological system is projected to become more sensitive to extreme weather events like heat waves and droughts. Additionally decreasing ice cover in winter affects river and groundwater recharge. Another impact is modification of the annual water budget of river basins and the timing and seasonality of river flows, including an earlier decline in high flows from snowmelt in spring, an intensification of low flows in summer.<br><br>The water availability can be also affected by river abstraction and from groundwater resources. The competition between different water users like agriculture, industry, energy and cities can rise in the dry period.<br><br>With the projected increase in heavy rainfall events, the risk of surface and groundwater contamination is expected to rise.<br><br>Hazards ranging from an increased concentration of pollutants (with negative health consequences) can be leaded by excess precipitation or drought, lack of adequate water flow for sewerage, and flood-related damage to physical assets. |

**Figure 7. Climate risk to Urban Water System**

Source: IPCC, 2018c.

# 6. ADAPTATION NEEDS AND OPTIONS

It is estimated that around 70% of the European population lives in urban areas. As we read in European Commission' report called *Cities of tomorrow - Challenges, visions, ways forward* (EC, 2011) "European Cities of tomorrow are places of green, ecological or environmental regeneration:… with high energy efficiency and use of renewable energies, low carbon emissions, and resilience to the effects of climate change". The complex systems operate within a city and service its citizens in areas of food, energy, water, waste, transport systems, etc. The changes in climate can affect proper operation these systems. The Word Bank report *Cities and climate change: responding to an urgent agenda* (Hoornweg et al., 2012) shows how varied impact these changes can have on a city. Four categories of urban vulnerabilities associated with climate change were identified. The first three categories associated with extreme weather events: alterations in temperature, alterations in precipitation, alterations in storm intensity and the fourth, associated with sea level change. The potential consequences for city are detailed in table below.

To build the city's resistance the effects of climate change, it is necessary to recognize the circumstances requiring action to ensure the safety of populations and security of assets in response to the anticipated risk or experienced impacts of climate change, i.e. adaptive needs should be identified (IPCC, 2014a). According to the IPCC terminology in AR5, adaptation needs are the gap between what might happen as the climate changes and what we would desire to happen. Adaptation needs are diverse and affected by geographical location, biophysical conditions, institutional and regulatory arrangements as well as the availability of resources, including access to technology and socio-economic stability. Different stakeholder groups may have different adaptation needs. A variety of stakeholders are involved in the management of water, wastewater, and sanitation systems at the city level: public or private owners of physical infrastructure, municipal governments, community organizations, nongovernmental organizations, industries and individual consumers. Adaptation needs can change over time, and future adaptation needs depend on the decisions and mitigation measures taken today. In AR5 (IPCC, 2014b), adaptation needs are divided into five groups:

1. **Biophysical and Environmental Needs**

Climate change causes changes in ecological systems and their services, affects biodiversity, and causes extinction of native species. Natural systems form the basis of life, health, well-being, and food security. Therefore, there is a need to protect and monitor ecological systems and their resources, improve and maintain, better understand and value ecosystem services, even maintaining wetlands and green areas can control the outflow and floods associated with increased rainfall.

2. **Social Needs**

The vulnerability of the community to climate threats depends on gender, age, health, economic and social status, and geographical location. Due to limited financial resources, often worse health, living and nutrition conditions, the poor, the sick and the elderly are exposed to an increased risk of injury, physical and mental illness and death due to the effects of climate change, e.g. heat waves. Extreme events can cause post-traumatic stress disorder. Therefore, social needs include perception and understanding of risk and dealing with the effects of climate change. In addition, social needs include people's security needs, human capacity and social capital to implement adaptation, education / learning on adaptation and access to information.

3. **Institutional Needs**

There is a need for institutions that provide conditions conducive to the implementation of adaptation activities, creating guidelines, incentives or restrictions, creating adaptation policies and programs, providing a clear legal framework, regulations and financing mechanisms that meet / reconcile the needs of various stakeholders. Commitment and cooperation is needed at every level: national government, local governments, local communities, social organizations and NGOs.

4. **Need for Engagement of the Private Sector**

The private sector should be understood as different types of private enterprises, from small farmers to small and medium-sized enterprises (SMEs) to international enterprises, insurance and financing companies. Climate hazards are compared to the threat of terrorism. There is a need to manage climate risk within companies to protect their own interests, continuity of supply and markets. The private sector is a stakeholder and should therefore participate in adaptation activities and cooperate with other stakeholders. The adaptation creates new business opportunities in the areas of health, waste management, water management, sanitation, housing, energy and information.

5. **Information, Capacity, and Resource Needs**

The successful implementation of adaptation measures depends on access to information, technology and financing. That is why there is a need to obtain and disseminate information, reliable scientific data, research and development, and transfer of knowledge and technology are needed. Implementing adaptation and responding to climate change requires financial resources.

Identifying needs provides a base for appraising and selecting adaptation options. According to the IPCC definition, adaptation options are the array of strategies and measures that are available and appropriate for addressing adaptation needs. They include a wide range of actions that can be categorised as structural, institutional or social (IPCC, 2014a). The table below is adopted from AR5 and summarises options which can be related to water system in city (Urban Water System).

| **Category** | | **Examples of options related to UWS** |
|---|---|---|
| **Structural / physical** | Engineered and built environment | Sea walls and coastal protection structures;<br>Flood levees and culverts;<br>Water storage and pump storage;<br>Sewage works;<br>Improved drainage;<br>Flood and cyclone shelters;<br>Storm and waste water management;. |
| | Technological | Efficient irrigation;<br>Water saving technologies;<br>Rainwater harvesting;<br>Hazard mapping and monitoring technology;<br>Early warning systems;<br>Reuse of wastewater;<br>Groundwater use;<br>Distribution efficiency improvements;<br>Transfer from other sectors;<br>Desalination;<br>Reservoirs/increase storage capacity. |
| | Ecosystem-based / green infrastructure | Ecological restoration including wetland and floodplain conservation and restoration; increasing biological diversity;<br>Afforestation and reforestation; |
| | Services | Social safety nets and social protection;<br>Municipal services including water and sanitation; |

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| | | Water treatment;<br>Essential public health services and enhanced emergency medical services. |
| **Social** | Educational | Awareness raising and integrating into education;<br>Sharing local and traditional knowledge including integrating into adaptation planning;<br>Knowledge-sharing and learning platforms;<br>International conferences and research networks;<br>Communication through media. |
| | Informational | Hazard and vulnerability mapping;<br>Early warning and response systems including health early warning systems;<br>Systematic monitoring and remote sensing;<br>Climate services including improved forecasts;<br>Downscaling climate scenarios;<br>Integrating indigenous climate observations;<br>Community-based adaptation plans and participatory scenario development. |
| | Behavioral | Household preparation and evacuation planning;<br>Soil and water conservation;<br>Livelihood diversification; |
| **Institutional** | Economic | Financial incentives including taxes and subsidies including index-based weather insurance schemes;<br>Payments for ecosystem services;<br>Water tariffs;<br>Restrictions and flow control;<br>Microfinance;<br>Disaster contingency funds; |
| | Laws and regulations | Water regulations and agreements;<br>Land use regulations;<br>Laws to support disaster risk reduction;<br>Laws to encourage insurance purchasing;<br>Defining property rights and land tenure security;<br>Protected areas;<br>Marine protected areas;<br>Patent pools and technology transfer;<br>Water quality standards. |
| | Government policies and programs | National and regional adaptation plans;<br>Sub-national and local adaptation plans;<br>Urban upgrading programs;<br>Municipal water management programs;<br>Disaster planning and preparedness;<br>City-level plans, district-level plans, sector plans, which may include integrated water resource management, landscape and watershed management, integrated coastal zone management, adaptive management, ecosystem-based management, sustainable forest management and community-based adaptation; |

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| | | Water demand management. |

**Figure 8. Categories and examples of adaptation options**

Source: IPCC, 2014b.

Most common risk for urban water system is related to water storage, water pollution and waterlogging. Adaptations options increasing the city's resilience rely on decentralised sewerage systems, sponge infrastructures (rain water harvesting) and reuse of wastewater. Scheme of resilience and sustainable urban water system is shown in the figure 9.

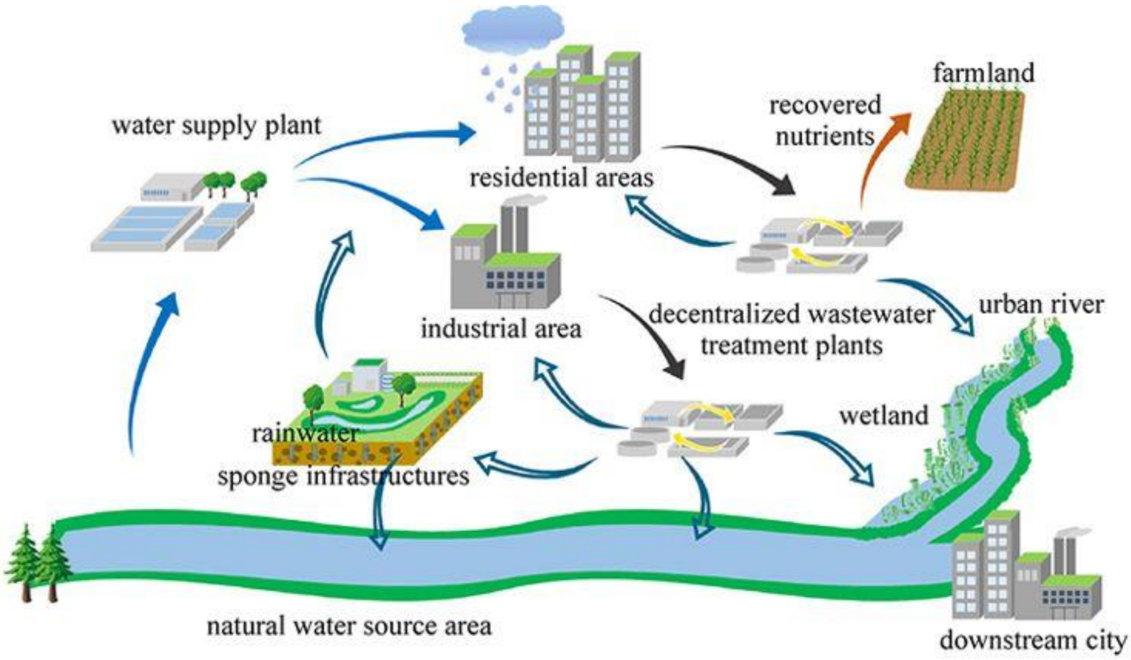


**Figure 9. Scheme of resilience Urban Water System**

Note: Blue arrows represent water flow, gray - wastewater flow, brown -resource and yellow - energy

Source: Nanqi RenQian WangQiuru WangHong HuangXiuheng Wang, Upgrading to urban water system 3.0 through sponge city construction, Frontiers of Environmental Science & Engineering, Vol. 11, August 2017, https://link.springer.com/article/10.1007%2Fs11783-017-0960-4, accessed November 10, 2019

# 7. THE STOCKTAKING AVAILABLE RISK ASSESSMENT METHODOLOGIES

Identification of impacts related to climate change is the beginning of adaptation strategy development (see for example the main steps of the adaptation process of The Urban Adaptation Support Tool guides European adaptation decision-makers and practitioners in cities on https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-2-0). Assessment of risks and vulnerabilities is key for adaptation policy. The table below contains examples of risk (or/and vulnerability) assessment methodologies developed by different institutions.

| Risk assessment example and organisation | Output | Source |
|---|---|---|
| Natural disaster HotSpot<br><br>by World Bank | The analysis "Natural disaster HotSpot" by the World Bank assesses the risk of mortality and economic losses as disaster-related outcomes, estimating risk levels by combining hazard exposure with historical vulnerability. | Dilley, M. et al. 2005: Natural Disaster Hotspots: A Global Risk Analysis. Washington D.C.: World Bank. |
| Risk Assessment and Mapping Guidelines for Disaster Management<br><br>by EC | The focus of guidelines is on the processes and methods of national risk assessments and mapping in the prevention, preparedness and planning stages, as carried out within the broader framework of disaster risk management. The guidelines are based on a multi-hazard and multi-risk approach. These guidelines build on experience in the practical implementations of national risk assessments and mapping, in particular existing good practice risk assessments of major natural and man-made disasters available in Member States. | EC, 2011: Risk assessment and mapping guidelines for disaster management. European Commission Commission staff working paper, European Union, Brussels, 21.12.2010 SEC(2010) 1626 final.<br><br>Available at: https://ec.europa.eu/echo/files/about/COMM_PDF_SEC_2010_1626_F_staff_working_document_en.pdf |
| World Risk Index<br><br>by UNU-EHS | Indicates a level of exposure and vulnerability to extreme events tool to assess the disaster risk that a society or country is exposed to by external and internal factors. | Birkmann, J. et al. 2011: World Risk Index<br><br>Available at: http://www.ehs.unu.edu/file/get/9018 |
| Global Climate Risk Index<br><br>by German NGO Germanwatch | Determines the risk of becoming the victim of a disaster as a result of natural hazards for 173 countries throughout the world. | Available at: https://germanwatch.org/en/16046 |
| Comprehensive Approach for Probabilistic Risk Assessment<br><br>by World Bank, Inter-American Development Bank (IDB), International Strategy of United Nations for Disaster Reduction (ISDR) | CAPRA is a techno-scientific methodology and information platform, composed of tools for the evaluation and communication of risk at various territorial levels. This model allows the evaluation of probabilistic losses on exposed elements using probabilistic metrics, such as the exceedance probability curve, expected annual loss and probable maximum loss, useful for multi-hazard/risk analyses. | Cardona, O.D. et al. 2012: CAPRA - Comprehensive Approach to Probabilistic Risk Assessment: International Initiative for Risk Management Effectiveness.<br><br>Available at: http://www.iitk.ac.in/nicee/wcee/article/WCEE2012_0726.pdf |
| Catastrophe Simulation model (CATSIM) | CASTIM assesses the costs and risks of financial vulnerability and analysis selected | Mechler, R. et al. 2006: Assessing Financial |

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| by International Institute for Applied Systems Analysis (IIASA) | ex-ante financial instruments measures for reducing vulnerability. Helps policymakers, particularly in developing countries, devise public financing strategies to be implemented in both the pre- and postdisaster context. National data can be input into CATSIM allowing policy advisers to pose "what if" questions. The model will then show the best combination of financial strategies to suit current national circumstances. | Vulnerability and Coping Capacity: The IIASA CATSIM Model. In: Birkmann, J. (ed.): Measuring Vulnerability and Coping Capacity to Hazards of Natural Origin. Concepts and Methods. Tokyo: United Nations University Press, 380-398. |
| Handbook for Estimating the Socioeconomic and Environmental Effects of Disasters (also for postdisaster)<br><br>by Economic Commission for Latin America and the Caribbean (ECLAC) | Describes the methods required to assess the social, economic and environmental effects of disasters, breaking them down into direct damage and indirect losses and into overall and macroeconomic effects. | ECLAC (Economic Commission for Latin America and the Caribbean) 2003: Handbook for Estimating the Socio-economic and Environmental Effects of Disasters. Available at:<br><br>https://repositorio.cepal.org/bitstream/handle/11362/2782/S2003701_en.pdf?sequence=1&isAllowed=y |
| Community based disaster risk management (also for post-disaster)<br><br>by Asian Disaster Preparedness Center | Training manual for the inclusion of local actors in application of measures in risk analysis, disaster prevention and mitigation and disaster preparedness. The model offers specific methods for community based risk, needs and damage assessment. | ADPC (Asian Disaster Preparedness Center) 2006: Critical Guidelines of Community based Disaster Risk Management.<br><br>Available at: https://www.preventionweb.net/files/9440_ADPCCriticalGuidelines.pdf |
| Disaster Loss Assessment Guidelines<br><br>by Emergency Management Australia | Provide an explanation of the process of loss assessment, and lead the reader through the steps required to carry out an economic assessment of disaster losses. Helps to estimate the average annual damages (AAD) from a hazard such as flooding at a specified location, probably as an input to costbenefit analysis. | Emergency Management Australia 2002: Disaster Loss Assessment Guidelines.<br><br>Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/E3E6ADDEF123F1D3C1256D43005631D0-ema-loss-02.pdf |
| Climate Vulnerability and Capacity Analysis (CVCA)<br><br>by CARE | Methodology to help understand the implications of climate change for the lives and livelihoods of the most vulnerable. By combining local knowledge with scientific data, the process builds people's understanding about climate risks and | CARE 2009: Handbook. Climate Vulnerability and Capacity Analyses.<br><br>Available at https://www.care.org/sit |

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| | adaptation strategies. It provides a framework for dialogue within communities, as well as between communities and other stakeholders. | es/default/files/documents/CC-2009-CARE_CVCAHandbook.pdf |
| Assessing Damage after Disasters: A participatory Framework and Toolkit<br><br>by Organisation for Development Education (UNNATI) | Tool for field practitioners working in postdisaster humanitarian response, a participatory and vulnerability focused framework and appropriate effective tools to carry out the multi -sectoral damage assessment. Includes the assessment of psycho-social impacts of disasters as important aspect of non-economic losses. | UNNATI 2007: Assessing damages after disasters. A participatory framework and toolkit.<br><br>Available at: http://www.unnati.org/pdfs/books/damage_assessment_toolkit.pdf |
| Climate Vulnerability Monitor<br><br>by DARA | The Monitor comprises 34 indicators of the economic, human and ecological effects of climate change and the carbon economy. Indexes form the backbone of each indicator and are responsible for generating the relative level of vulnerability registered for each country. Each index is determined exclusively on the basis of mortality and/or GDP per capita data, capturing only the climate change or carbon economy effect in isolation from other factors. | DARA and the Climate Vulnerable Forum 2012: Climate Vulnerability Monitor 2nd edition.<br><br>Available at: https://daraint.org/wp-content/uploads/2012/09/CVM2ndEd-FrontMatter.pdf |
| Participatory Vulnerability and capacity assessment (part of Participatory Assessment of Disaster Risk (PADR))<br><br>by British Overseas NGOs for Development (BOND); Tearfund | Tool for participatory assessment of vulnerability on the local level by using meetings with community leaders, focus group meetings and informant interviews. The assessment includes: 1.Elements at Risk, 2. Unsafe Conditions, 3. Dynamic Pressures and 4. Underlying causes. | British Overseas NGOs for Development (BOND) / Tearfund 2005: Participatory assessment of disaster risks.<br><br>Available at: https://www.preventionweb.net/files/8678_drrgtearfundpadrpresdec05.pdf |
| The vulnerability sourcebook<br><br>by GIZ (the Deutsche Gesellschaft für Internationale Zusammenarbeit) | Standardised approach to vulnerability assessments covering a broad range of sectors and topics (e.g. water sector, agriculture, fisheries, different ecosystems) as well as different spatial levels (community, subnational, national) and time horizons (e.g. current vulnerability or vulnerability in the medium- to long-term). | GIZ 2014: The Vulnera-bility Sourcebook. Concept and guidelines for standardised vulnerability assessments.<br><br>Available at:<br><br>https://gc21.giz.de/ibt/var/app/wp342deP/1443/wp-content/uploads/filebase/va/vulnerability-guides-manuals-reports/Vulnerability_Sourcebook_-_Guidelines_for_Assessme |

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| | | nts_-_GIZ_2014.pdf |
| Climate Risk Assessment for Ecosystem-based Adaptation<br><br>by GIZ with Eurac Research and United Nations University - Institute for Environment and Human Security (UNU-EHS) | A guidebook helps planners and practitioners in designing and implementing climate risk assessments in the context of Ecosystem-based Adaptation projects. | GIZ, EURAC & UNU-EHS (2018): Climate Risk Assessment for Ecosystem-based Adaptation - A guidebook for planners and practitioners. Bonn: GIZ.<br><br>Available at: https://www.adaptationcommunity.net/wp-content/uploads/2018/06/giz-eurac-unu-2018-en-guidebook-climate-risk-asessment-eba.pdf |
| Climate Change Risk Assessment<br><br>by Department for Environment, Food and Rural Affairs of the United Kingdom of Great Britain and Northern Ireland | Analyses the key risks and opportunities that changes to the climate bring to the UK. Provides a baseline that sets out how climate risks may manifest themselves in the absence of current and planned actions. The baseline of the CCRA Evidence Report allows Government and others to assess the extent to which our actions and plans are climate resilient, and to judge what more needs to be done. | DEFRA (Department for Environment, Food and Rural Affairs 2012: The UK Climate Change Risk Assessment 2012 Evidence Report.<br><br>Available at: http://randd.defra.gov.uk/Document.aspx?Document=TheUKCCRA2012EvidenceReport.pdf |
| Climate change and Environmental Degradation Risk and Adaptation Assessment (CEDRA)<br><br>by Tearfund | CEDRA helps agencies working in developing countries to access and understand the science of climate change and environmental degradation and compare this with local community experience of environmental change. Climate change cannot be addressed in isolation from environmental degradation as the two are very closely inter-linked. CEDRA takes a risk management approach to prioritizing hazards to address. | Tearfund 2009: CEDRA. Climate change and Environmental Degradation Risk and Adaptation assessment. An environmental tool for agencies in developing countries.<br><br>Available at:<br><br>https://www.preventionweb.net/files/11964_CEDRAClimatechangeandEnvironmentalD.pdf |
| Coastal Climate Adaptation Decision Support (C-CADS)<br><br>by CoastAdapt | C-CADS is the decision support tool supporting coastal managers to make effective adaptation decisions. | Available at: https://coastadapt.com.au/how-to-pages/how-to-conduct-a-climate-change-risk-assessment |
| Climate change risk assessment<br><br>by Department of | Guide to Climate Change Risk Assessment for NSW Local Government offers a step-by-step process to conduct or revise a climate change risk assessment. Helping councils | DPIE, 2019: Guide to Climate Change Risk Assessment for NSW Local Government, State of |

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| Planning, Industry and Environment (DPIE) | to:<br>▪ undertake a climate change risk assessment using an approach based on standardised methods;<br>▪ refine previous climate change risk assessments;<br>▪ generate information that can be used to develop adaptation strategies and make decisions under conditions of risk and uncertainty. | New South Wales and Department of Planning, Industry and Environment<br>Available at: https://climatechange.environment.nsw.gov.au/Adapting-to-climate-change/Local-government/Identify-risks-and-vulnerability |

**Figure 10. Risk and vulnerability assessment - selected examples**

Source: Schäfer, L. and K. Balogun, 2015.

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