CONHAZ
Costs of Natural Hazards

Methods for Assessment of the Costs of Droughts

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The ConHaz EU project

Cost assessments of damages of, prevention of, and responses to natural hazards provide crucial information for decision support and policy development in the fields of natural hazard management and planning for adaptation to climate change. There is a considerable diversity of methodological approaches and terminology being used in costs assessments of different natural hazards. This complicates the assessment of comprehensive, robust and reliable costs figures, as well as comparison of costs across hazards and impacted sectors. This report is part of the EU project ConHaz. The first objective of ConHaz is to compile state-of-the-art methods and terminology as used in European case studies. This compilation will consider droughts, floods, storms, and alpine hazards, as well as various impacted sectors, such as agriculture, health and nature. It will consider direct, indirect and intangible costs. ConHaz further examines the costs and benefits of risk-prevention and emergency response policies. The second objective of ConHaz is to evaluate the compiled methods by considering theoretical assumptions underlying cost assessment methods and issues appearing in application of the methods, such as availability and quality of data. ConHaz will also assess the reliability of the end results by considering the accuracy of cost predictions and best-practice methods of validation, and will identify relevant gaps in assessment methods. The third objective of ConHaz is to compare available assessment methods with end-user needs and practices, so as to better identify best practice and knowledge gaps in relation to policy-making. A final objective of ConHaz is to give recommendations about best practices and to identify resulting research needs.

Abstract

Drought is a natural hazard which causes many economic, social and environmental problems in different parts of the world. It is expected that the intensity and frequency of droughts are going to increase in the future due to climate change. In Europe, a warmer and dryer climate is expected in many countries, particularly in the Mediterranean region. It is predicted that there will be a considerable enhancement in inter-annual variability in the summer climate, associated with higher risks of heat waves and droughts, already experienced in recent years. The existing literature on the costs of drought is scarce, fragmented and heterogeneous and there is a need for comprehensive costs estimations to help designing effective policy responses. For these reasons, it is becoming increasingly important to identify and evaluate different approaches for estimating the costs of droughts in order to provide recommendations on best practices.

This report explains the terminology and classifications which are used in the literature to describe the impacts and costs of droughts. Furthermore, it describes and compares the main methods for assessing all types of drought costs, i.e. direct, indirect and intangible costs. To acquire all relevant information, the study has combined a review of the relevant literature and an expert and stakeholder workshop held on 3-4 February 2011 at Universitat Autònoma de Barcelona. The report considers the suitability of existing drought cost assessment methods for estimating costs in different economic sectors, their underlying theoretical assumptions, and application issues, such as their precision, reliability, data needs (and availability), and financial and human resources required. In addition to reviewing the methods for assessing drought costs, the report briefly examines potential policies for drought mitigation and adaptation. The latter covers discussions of drought risk assessment (including drought indicators), predicted future changes concerning droughts in the light of expected climate change, drought preparedness, mitigation and adaptation measures, the costs of such measures, legislation related to drought in the European Union, and international cooperation on drought mitigation. Finally, recommendations for good practices and main disadvantages of the methods for assessment of drought costs are discussed. The report also provides a set of recommendations for drought mitigation and adaptation measures. It concludes with identifying knowledge gaps and further research needs.

Structure

1. Introduction

When studying the economic consequences of droughts, it is useful to have a clear definition and thus a common understanding of what is a drought. Drought can in a broad sense be defined as a temporary lack of water caused by abnormal climate which is damaging to an activity, group of people or the environment (Kallis, 2008). However, a variety of definitions of "drought" have been proposed by different disciplines. Most frequently, a distinction is made between meteorological, hydrological, agricultural, and socio-economic droughts (Wilhite and Glantz, 1985). *Meteorological* (or climatological) drought is defined as a reduction in rainfall supply compared with a specified average condition over some specified period of time (Hulme, 1995). Thus, intensity and the duration of the dry period are the key characteristics of this definition. Meteorological drought definitions usually relate actual precipitation departures to average amounts on monthly, seasonal, "water year", or annual time scales. *Hydrological* drought is associated with the impacts of a reduction in precipitation on surface or subsurface water supply (i.e., streamflows, reservoir levels, lakes, groundwater) rather than with precipitation shortfall itself. When the actual flow for a selected time period falls below a certain threshold, then hydrological drought is considered to be occurring (Wilhite, 2000). However, defining the threshold and the time period is somewhat arbitrary and will vary between streams and river basins. *Agricultural* drought is defined as a reduction in moisture availability below the optimum level required by a crop during different stages of its growth cycle, resulting in impaired growth and reduced yield (Benson and Clay, 1998). Finally, *socio-economic* drought relates the supply and demand of an economic good or service with the elements of meteorological, hydrological or agricultural drought. For example, according to this definition drought occurs when the demand for a good exceeds its supply as a result of a weather-related supply shortage (Wilhite, 2000).

It is important to distinguish drought from the concepts of water scarcity and aridity. Water stress or scarcity is an excess of water demand over available supply. Unlike meteorological drought, it need not have a climatic origin or be temporary. It can result from human-driven factors such as overuse or misallocation of the water resource as well as from altered climatic conditions (i.e. climate change). Aridity, unlike drought, is not abnormal or temporary but is a permanent feature of certain regional climates, such as desert environments (Kallis, 2008). Moreover, drought is considered by many to be the most complex and least understood of all natural hazards. In addition, according to Wilhite et al. (2007) drought affects more people than any other hazard.

The Working Group on Water Scarcity of the European Union reports that over the past 20 years there have been four significant large-scale droughts, which covered more than 800.000 km^2 of EU territory (equal to 37%), affecting more than 100 million people (EU, 2006). A study of the European Commission (2007a) estimates the costs of droughts in Europe over the last 30 years to be at least 100 billion €. Moreover, the European Environmental Agency reported that the annual average economic impact from water scarcity and droughts doubled from 1976-1990 and 1991-2006 periods, rising to 6.2 billion € per year in recent years (EEA, 2010). The drought which occurred in Central and Western Europe in 2003 has caused an estimated economic damage of more than 13 billion USD (Munich Re, 2004). To provide another indication, Martin-Ortega and Markandya (2009) appraised the total losses of the drought which affected the Spanish region of Catalonia during 2007 and 2008 at 1.661 billion € for a one-year period. This corresponds to almost 1% of the Catalonian GDP. In addition, the World Meteorological

Organization reports that from 1991 to 2000 alone, droughts have caused over 280.000 deaths (WMO, 2011).

The Intergovernmental Panel on Climate Change (IPCC, 2007a) projects with a high degree of confidence that a warmer climate, with its increased precipitation variability, will increase the risk of a drought in many areas. It provides evidence for a climate-related trend of intensified droughts in certain drier regions since the 1970s and further anticipates that the frequency and intensity of drought events will increase, particularly in semi-arid, snow or glacier areas and coastal basins. It has been projected that the number of extreme drought events per 100 years and mean drought duration are likely to increase by factors of two and six, respectively, by the 2090s (Burke et al., 2006). IPCC (2007a) further predicts with a very high confidence that many semi-arid areas (e.g., the Mediterranean basin, the western USA, southern Africa and north-eastern Brazil) will suffer a decrease in water resources due to climate change. It foresees that there will likely be an overall increase of drought-affected areas by the end of the century.

The total area and population affected by water scarcity and drought in EU countries doubled from 6% to 13% from 1976-1990 to 1991-2006. In general, water is relatively abundant in Europe, with only 13% of the available resource abstracted each year (EEA, 2009), but water availability and population are unevenly distributed. Annual precipitation trends in the 20th century showed an increase in northern Europe (10-40%) and a decrease in some parts of southern Europe (up to 20%) (EEA-JRC-WHO, 2008). It is projected that water availability will generally further increase in northern parts of Europe, while Southern and south-eastern regions will be particularly exposed to reductions in water availability and experience an increase in the frequency and intensity of droughts (EEA, 2010).

This will certainly raise the importance of estimating drought damages. Thus, we first need to understand better various drought impacts in order to develop new as well as improve the existing methods for reliable drought cost assessment. Apart from this, establishing effective drought preparedness measures, mitigation and adaptation policies will become crucial in diminishing drought damages. Preparation and good implementation of such policies require information about the physical as well as monetary-economic consequences of droughts. A list of past and ongoing projects related to drought issues in Europe is provided in the Appendix. They serve as a useful source of information regarding various aspects of drought.

2. Costs of droughts

Compared to other natural hazards, such as floods or storms, droughts are harder to identify and more complex to measure because they entail particular, unique features. First of all, drought is a relative concept, because it depends on deviations from a historical record for a specific area. This means that droughts are not uniformly defined over space and time. For example, an annual rainfall of 500 mm may indicate drought for one region but not for another. In addition, there is no one-to-one relationship between amount of rainfall and drought, that is, depending on how annual precipitation is distributed over different seasons, an area may experience a drought or not. Moreover, drought develops at a much slower pace and lasts longer than other natural hazards (while its duration can vary considerably), making it particularly difficult to identify an onset or end of a drought. One should further realize that droughts usually cause fewer visible infrastructural damages (except for damages from subsidence and fires) and have more indirect and diffuse impacts (scattered in space and across activities rather than concentrated) in comparison with other natural hazards. For this reason, drought damages are more difficult to identify. The impacts of droughts are the result of an interplay between a natural event (e.g., precipitation deficiencies because of natural climatic variability) and the demand placed on water and other natural resources by human-use systems (Wilhite and Vanyarkho, 2000). The impacts of droughts of equal intensity can differ greatly depending on the hydro-environmental and socio-economic factors of the area affected by a drought. Hydro-environmental factors that determine the severity of drought impacts include, for instance, river flows, groundwater and dam reserves, and soil moisture, which are influenced by water management, water withdrawals, and land uses in an area. Examples of socio-economic factors are demography, production patterns, agriculture system (rain fed versus irrigated), dominant type of dwelling (e.g., with large gardens), and income. Vulnerability mediates hazard and impacts. It is defined as the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt (Adger, 2006). The vulnerability and costs of droughts depend largely on all these factors and consequently vary substantially among different regions and groups of the population.

2.1. Drought impacts and costs: Terminology and classifications

Impacts from droughts are commonly classified as direct versus indirect (Wilhite, 2000; Wilhite et al., 2007). Direct (also referred to as primary) impacts are usually of a biophysical nature, while the consequences of these impacts represent indirect or secondary impacts. For example, reduced crop productivity is a direct impact of drought, which leads to several indirect impacts, such as lower revenues in agriculture, job losses, increase in crop prices, and food shortages. Benson and Clay (1998) talk about the direct or physical impacts of droughts on the productive sectors (agricultural and livestock sectors, hydroelectric power generation, and other water-intensive activities), which are similar regardless of the economy, although their magnitude depends on specific country characteristics. They also identify a range of second round and subsequent impacts of a drought shock, including constrained productivity of related sectors and subsectors, loss of earnings, increased unemployment, reduced demand in the economy, inflation due to food and electricity shortages, and deteriorated budgetary and external trade balances. Another frequently used classification of drought impacts includes economic, environmental, and social categories (Wilhite, 1992; Wilhite, 1997; Cooley, 2006; Wilhite et al., 2007). The workshop participants mentioned that there might be an additional, separate category called luxury impacts, which may embrace impacts from tourism and golf courses, for example. Wilhite and Wood (1994) and the National Drought Mitigation Centre of the University of Nebraska – Lincoln (http://drought.unl.edu/risk/impacts.htm) present comprehensive lists of impacts associated with droughts according to this classification.

A classification of the *costs* related to droughts can distinguish between preparedness costs, which are fixed and occur now and drought costs which are uncertain and will occur later (Wilhite, 1996). Heathcote (1969) refers to these two categories as spasmodic and incessant effects of droughts. Some authors refer to direct and indirect losses from droughts stemming from their direct and indirect impacts. For example, Holden and Shifer (2004) and Horridge et al. (2005) refer to the losses from reduced production in agricultural and livestock industries as direct impacts from drought, while losses that occur in other economic sectors due to a multiplier effect, job losses, and impacts on household welfare are considered as indirect impacts of droughts. Mysiak and Markandya (2009) distinguish several categories of economic losses due to droughts, such as structural versus non-structural losses, direct versus indirect (or higher-order) losses, and intangible losses. Direct and indirect losses are further divided into stock losses (e.g. land, machinery or inventories) and flows losses (e.g. annual crop yield or energy produced). Another distinction is between output (interruption) and capital losses (destruction). Apart from this, the existing literature does not explicitly define or classify the costs stemming from droughts, as opposed to classifications of drought impacts.

It should be noted, however, that this is inconsistent with the classification of direct and indirect impacts of droughts explained in the first paragraph of this subsection, in which direct impacts are mainly biophysical, while indirect impacts cover economic losses due to such physical impacts. For this reason, trying to define direct versus indirect costs of this natural hazard is problematic. There are, nevertheless, many criteria that could be used for making a distinction between direct and indirect costs. For example, a classification could be based on causality (initial effects in the cause-effect chain leading to secondary effects), time scale (immediate versus later costs), or spatial distribution (where direct would indicate effects in the region affected by the drought and indirect outside the region). This raises the question which criterion is the most appropriate one? Possibly, some of these criteria are highly correlated in many drought cases, which would mean that the precise choice of a criterion would matter less.

In addition, as noted earlier, droughts differ considerably from other natural hazards because they develop at a much slower pace and last considerably longer. Therefore, regardless of the precise definition of costs, droughts generally may cause higher indirect and intangible costs than other natural hazards. However, as such costs may occur months or years after the event has started, they are difficult to be completely assessed and thus likely to be underestimated. Direct costs of droughts are associated with direct physical damages to buildings, infrastructure, and other assets, which stem mainly from subsidence and fires (droughts do not cause fires directly, but they increase the risk of fire by decreasing air humidity and increasing plant flammability). Even though such costs may be substantial, they hardly receive any attention in the literature. Such costs may vary considerably depending on the region where a drought takes place, although one might expect that for Europe they could be rather high. Losses (i.e. costs) associated with the disruption of production processes due to droughts are numerous and relatively well documented (e.g. withered crops and dead livestock, problems with cooling of electricity producing equipment and hydropower, and diminished opportunities for water transport because of low water levels in rivers and other flows). Distinguishing between direct and indirect costs of droughts is sometimes not very straightforward (e.g. in the case of tourism). On the other hand, intangible costs refer to non-market costs and are easily distinguished as different methods are used for their assessment. The term intangible might be somewhat confusing as it suggests that such impacts are invisible, which is not necessarily the case. Intangible costs may in fact be associated with impacts that are rather tangible or visible and which can therefore be considered as a sub-category of both direct and indirect costs. Immediate mortality due to, for instance, a flood suggests that certain intangible costs can be seen as a sub-category of direct costs. However, this type of direct effect is not very relevant for droughts. Here intangible costs will be mostly indirect costs. Even though the terms intangible and non-market costs are according to the workshop participants not completely the same, they consider that it is clear which kind of costs are embraced by these terms. Policy makers often use the term social costs instead. Some participants stated that intangible costs are actually external costs of droughts, but we feel that one should be careful here as the definitions of these are quite different. Note further that the term intangible costs captures well that often these costs are neglected when assessing the costs of droughts.

The ConHaz project distinguished in its original proposal between direct costs, losses due to disruption of production processes, indirect cost, and intangible costs. We had extensive debates about what is the best approach to classify damage costs of droughts (or hazards more generally). For example, the term intangible cost or impact is not used in the literature on droughts or in the literature on monetary valuation. In both, the term non-market value/cost is more common. Our suggestion would be to use a two-dimensional (matrix) categorization of drought costs, with direct and indirect costs in one dimension, where direct costs include impacts on resource-based sectors (possibly in some cases like floods also on infrastructure) and indirect costs include impacts on the rest of the economy. Market (tangible) and non-market (intangible) costs would then make up the second dimension of classification (see Table 1). Finally, losses due to disruption of production processes would in this case form part of either direct or indirect costs (and mainly tangible costs), rather than representing a separate cost category (or a third dimension?). More discussion is needed on this issue.

Table 1. Illustrative classification of the costs of droughts

		Measurement	
		Market (tangible)	**Non-market (intangible)**
Form of damage	**Direct**	- Losses in resource-based sectors like agriculture, such as reduced crop production and reduced livestock production - Losses of water-providing companies, hydroelectric production and water transport - Subsidence of buildings and infrastructure - etc.	- Damage to wildlife and fish habitat - Loss of biodiversity - Loss of wetlands - Deteriorated water and air quality - Losses due to restrictions of water supply in households - etc.
	Indirect	- Increased unemployment - Changes in prices of food and timber - Trade losses - Reduced tax revenues - Losses in economic sectors indirectly related to droughts (e.g. food industry) - etc.	- Animal diseases - Reduced quality or loss of recreational sites, aesthetic impacts - Increased human health costs (diseases, malnutrition) - Loss of human lives - etc.

Source: Adapted from Penning-Rowsell et al. (2003) and Smith and Ward (1998)

In addition to the costs of drought impacts, one can identify the costs of mitigation to avoid or reduce the risk of, and adaptation to, droughts. Such costs can also be classified into direct, indirect and intangible cost categories. Many of mitigation and adaptation costs are direct costs which have market values (e.g. new infrastructure or the costs of making infrastructure resilient to droughts) and are hence easy to estimate. Assessing the costs related to water demand management and other drought mitigation and adaptation measures is somewhat less straightforward and requires applying less straightforward cost assessment methods. The most difficult part is estimating emergency costs, as they can vary significantly depending on the adopted baseline for comparison. Namely, emergency costs may include investments in infrastructure that will serve for the next several decades; so it is important to set a baseline which will determine the share of these costs corresponding to the drought event. Assessment of the overall drought costs should include a category of the costs of emergency measures as they also form part of the costs stemming from drought (e.g. during the 2007-2008 drought in Catalonia boats were bringing water to Barcelona, the costs of which also represent part of the costs of this drought event). Finally, when developing drought management plans one should also take into account the transaction costs of implementing a new policy.

2.2. Overview of drought costs

2.2.1. Direct costs and costs caused by the disruption of production processes

The most significant direct costs of droughts are related to their biophysical impacts. They include reduced crop production in agriculture; reduced range land and forest productivity; lower income for farmers and agricultural businesses; losses in livestock production; increased livestock and wildlife mortality; higher risks of fire hazard (in combination with high temperatures); reduced surface and groundwater levels; lower crop quality; insect infestation (invasion); tree and plant diseases; and wildlife damage to crops. Furthermore, due to diminished water availability, droughts generate losses for (drinking) water-providing companies, hydroelectric production (because of low reservoir levels), cooling of the power-producing equipment (because of high water temperatures for cooling), water transport because of impaired navigation possibilities through rivers and canals (Jonkeren et al., 2007), irrigation, fishing industry, tourism industry (resource-based), gardening and flower production companies, and swimming pool companies. For instance, the cost of low hydroelectric production due to drought in Portugal in 2005 was estimated at 883 million € (Demuth, 2009), while France reported losses of 144 million € in tourism during the winter 2006-2007 in the Alps-Savoie (EEA, 2010). Lower water levels are also likely to induce emergency costs of securing water availability through water transport or transfer. An example is the drought in Barcelona in 2008 which forced the local government to bring water to the city with tankers (boats). The costs of these shipments are estimated at 18 million € (EEA, 2010). Regarding direct impacts on buildings and infrastructure (e.g. roads), droughts can cause subsidence of the ground, although this impact seems not to have been discussed much or at all in the existing literature. A reason may be the lack of data on the damage from subsidence. For example, in the UK there is an insurance against subsidence, as a result of which data on these damages exists. However, in most countries such insurance does not exists and hence no such data is available. Dlugolecki (2007) reports that subsidence of buildings during droughts has costed insurers in UK and France many billions of dollars in recent decades. Figure 1 clearly shows a negative correlation between the amount of precipitation and subsidence damage of household buildings in the UK between 1988 and 2006. Corti et al. (2009) estimated building damages from soil subsidence in France for the period 1989-2002 at 237 million € per year. Their results also revealed a doubling of damages in this period compared to 1961-1990, when damages totaled 115 million € per year. The difference between the two periods is mainly a consequence of increasing temperatures, indicating a causal relationship with climate change. Based on these results, the authors conclude that the costs of damages to buildings due to droughts can be as large as for floods in some regions. So while subsidence damages from droughts might actually be substantial, they are being overlooked due to a lack of information on it. Subsidence-related costs of droughts are likely to differ both between and within regions as they depend on meteorological factors, soil type and even building features (e.g. the age of buildings and foundation depth. More generally, the multi-causality of damages makes cost assessment of droughts a more difficult exercise than of many other natural hazards.

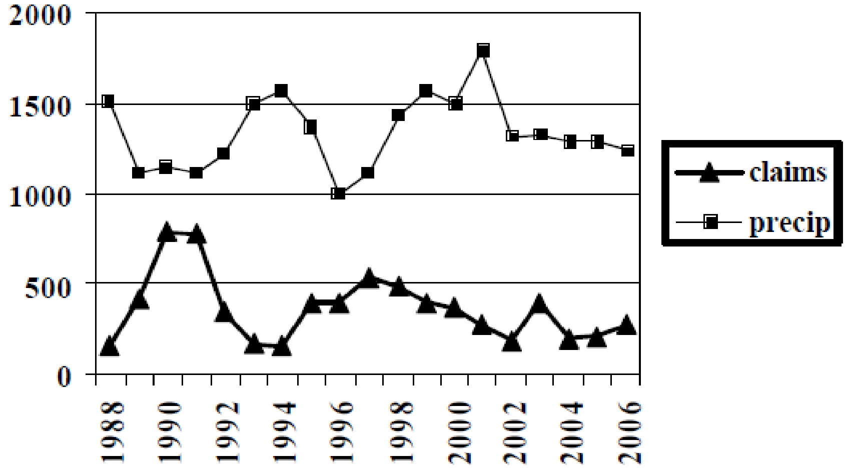

Figure 1. Correlation between UK household buildings subsidence damage and drought (1988-2006)

Legend: Subsidence damage measured in 2003 million £. Data supplied by the Association of British Insurers. Drought intensity measured in accumulated precipitation over the 18 months prior to September of the corresponding year (in mm).

Source: Dlugolecki (2007)

2.2.2. Indirect costs

Indirect costs from droughts occur as a consequence of the physical-ecological impacts on the economy as a whole, that is, through changes in resource-based activities on the rest of the economy (and hence often occur later than direct costs). For example, reduced crop, range land and forest productivity, and associated lower income for farmers and agricultural businesses, leads to increased unemployment, changes in the prices of food and timber, diminished trade (e.g., due to decreased export of agricultural products or increased import of such products at higher costs), reduced national, regional or local government tax revenues (lower tax base), increased pressure on financial institutions (higher credit risks, capital deficits), losses of farmers through bankruptcy due to foreclosures, and losses of industries related to the agricultural sector (e.g. food and timber industries, producers and distributors of fertilizers and machinery used in agriculture). A reduction in water levels may cause decreased revenues of tourism and recreation industries (non-resource based) and an increase in the price of electricity. Finally, droughts can lead to higher costs of health care (e.g., respiratory problems due to a higher concentration of dust particles in the air). One of the main concerns with respect to indirect costs of droughts is that they might often be underestimated because they can continue or appear long after a drought has ended.

2.2.3. Intangible (environmental and health) costs

In the ConHaz project it was decided to include the category of intangible costs which denotes non-market costs associated with environmental and health impacts of droughts, or natural hazards in general. Environmental impacts from droughts embrace damage to wildlife and fish habitat, animal disease, loss of biodiversity, loss of wetlands, deteriorated water and air quality (e.g. salt concentration, pH, dissolved oxygen, dust, pollutants), soil erosion, intrusion of saltwater, reduced quality or loss of recreational sites, and aesthetic impacts. Health impacts from droughts primarily refer to an increased risk of diseases as well as malnutrition and famine due to food shortages. Droughts also have other intangible costs, such as a loss of human lives, migration (usually from rural to urban areas), social conflicts, increased crime rates, changes in income distribution, social welfare losses due to restrictions of water supply in households (e.g. prohibition of water use for swimming pools, gardens or car washing), and other kinds of social welfare loss (e.g. in rural areas in India, households affected by droughts stop sending children to school; Chatterjee et al., 2005). Even though droughts might cause serious food shortage problems and there are currently hardly any public food reserves, this issue has received surprisingly little attention in the literature. Note that some of the above-mentioned intangible costs are more likely to occur in developing than developed countries (e.g. loss of human lives or food shortage). The main feature of intangible costs is that they relate to effects, goods and services outside markets for which no price can be observed. In the literature on economic-monetary valuation the term for this category is non-market value, associated with non-market valuation methods which try to capture such non-market effects (discussed in the next section). The terms tangible and intangible might hence be preferable for classifying drought impacts, while market and non-market could be used for classifying drought costs.

3. Overview of methods for drought cost assessment

Traditionally, more emphasis has been placed on identifying and estimating the economic than environmental or social impacts of droughts. This particularly holds true for the agricultural sector, which usually is the sector that is the first and most affected by droughts. Hence, the impacts of drought in a resource-based sector like agriculture are direct and consequently better understood and quantified more easily than (indirect) impacts on other, non-resource-based sectors of the economy. Impacts on resource-based sectors like water supply and hydropower have received less attention. The effects of droughts on other sectors, such as tourism, transport and energy, have steadily begun to gain more attention in the literature. Social and environmental drought impacts are still not very well understood and are difficult to quantify. Nevertheless, there is nowadays more awareness of the importance of social and environmental drought impacts and their inclusion as part of the total drought costs. Several approaches for their assessment exist and many studies have already applied them in order to assess the intangible costs of droughts. In this section we provide an overview of methods for assessing different types of drought costs – direct, indirect and intangible costs. Some of the methods serve for estimating only one cost type (e.g., only intangible costs), while others may be used to asses two or even all three types of drought costs. Table 2 provides a theoretical overview of available methods for estimating different types of costs and values. It is worthwhile noting that some of these methods can assess drought costs only once a drought has occurred (ex post costs), while others allow cost assessment of both a historical and a hypothetical drought (ex post and ex ante costs, respectively). Hence, ex ante and ex post costs are distinguished on the basis of the timing of the cost assessment. Uncertainty about estimate precision is evidently larger in the former case. Even though the travel cost method and the cost of illness approach could theoretically be used to estimate some of the intangible drought costs, such as reduced quality or loss of a recreational site in the former case, and costs of treating illness or lost income due to illness caused by a drought in latter case, we have not found studies which have actually applied these methods in the context of drought damage cost estimation. For this reason, these two methods do not receive detailed attention in this report. Birol et al. (2008) presents an overview of appropriate economic valuation methods for different components of the total economic value of water resources (many of which are relevant to droughts).

Table 2. Available assessment methods according to the types of costs and values

Market valuation techniques (Mainly tangible/market costs, both direct and indirect)	**System approaches (Mainly indirect tangible/market costs)**	**Non-market valuation techniques (Mainly intangible/non-market costs, both direct and indirect)**	
(Mainly use values)	(Use and non-use values)	Revealed preference / surrogate markets (Use values)	Stated preference (Use and non-use values)
Market prices	Assessing effects on GDP and agricultural production	Hedonic pricing (including Ricardian modeling)	Contingent valuation method
Production function (also for nonuse values)	Input-output analysis	Travel cost method	Choice experiments
Avoided cost (also for nonuse values)	Computable general equilibrium analysis	Cost of illness approach	Life satisfaction analysis
Replacement and repair cost (also for nonuse values)	Biophysical-agroeconomic modeling		
	Coupled hydrological-economic modeling		
Benefit or value transfer			

3.1. Market valuation techniques

Economists generally prefer to use direct, observable market interactions for placing a monetary value on goods and services (NOAA, 2011). Various specific methods are consistent with this market valuation approach. These include using the prices of goods and services which are being traded in markets, a production function approach, assessing costs of avoided damages, and determining replacement or repair costs of damages.

The market price method estimates the economic value of any product or service that is bought and sold in commercial markets. It can be used to value changes in the quantity or quality of a good or service. The estimation starts with assessing the quantity people purchase at different prices and the quantity supplied at different prices. In the case of quality change, one observes a change in market demand function for a good or service and a change in benefits or losses of producers. This information is then used to estimate consumer and producer surpluses. The sum of these represents the total net economic benefit of a good or service in a market. For example, the direct costs of a drought in agriculture can be assessed by observing the quantity of crops lost due to a drought and their prices (or a shift in demand because of deteriorated quality). Based on this information, one can estimate consumer and producer surpluses before and after the event. The difference represents the crop production costs due to drought.

A production function approach estimates a function that specifies the output of a company, an industry or the whole economy based on the combination of inputs, i.e. the factors of production. It takes the form $Q = f(L,K,E)$, where L denotes labour, K capital and E an environmental indicator. As factors of production, raw materials and environmental inputs are used in the production of other goods. Assuming that we know the algebraic form of the production function and the parameter values, we can introduce a change of the environmental input (e.g. a deterioration of water quality) and estimate its effect on the output in monetary terms (e.g. a decline in the production of a fishing industry or higher costs of its production). However, to obtain a monetary value it is not sufficient to simply multiply a change in the output by unit price, but one should also take into account damage costs and the elasticity of the demand function so as to arrive to a correct estimate (this is also known as a dose-response valuation technique). An important limitation of this approach is that production functions are often not known as precisely as needed for applying this technique and it is limited to those resources that are used in the production of goods and services sold in markets.

The avoided cost approach is a closely related technique (can in fact be seen as a special case of a production function approach). Here the production function has the form $Q = f(L,K,E,A)$, where A stands for some 'averting' input. In the case of a reduced environmental quality (e.g. air quality), expenditures can be made to mitigate these negative effects (i.e. by implementing air filters, or irrigating rain-fed agricultural land which is being subject to a drought). The value of the reduced air quality or less water available to agriculture due to a drought can then be valued in terms of expenditure on compensating air filters or irrigation (A).

A replacement or repair cost approach assumes that the costs of replacing or repairing an ecosystem good or service represents a reasonable estimate of its value. Nevertheless, it is best seen as a lower bound to the real value of the good or service, certainly in the case of replacement. An example is assessing the cost of soil erosion due to a drought by estimating the costs of physically recovering and replacing lost soil, nutrients and water.

Studies that have used market valuation techniques (by estimating consumer surplus) for assessing losses caused by rationing policies during drought include Woo (1994), Garcia-Valiñas (2006) and Grafton and Ward (2008).

Example:

Grafton, R.Q., Ward, M.B. (2008). Prices versus rationing: Marshallian surplus and mandatory water restrictions. The Economic Record, 84: S57-S65.

• *Explanation*: The study estimates an aggregate per capita water demand for Sydney for the period 1994-2005. The estimated demand function is used to calculate the difference in Marshallian (consumer) surplus between using the metered price of household water versus mandatory water restrictions to regulate total water consumption for the drought period 2004/2005. The total cost is estimated at AUD $235 million for a 12-month period, which equates to AUD $55 per person or AUD $150 per household.

- *Cost types addressed*: Direct non-market costs (social welfare losses due to mandatory water restrictions).
- *Objective of the approach*: The results of the study provide insight into welfare losses caused by implementing a drought adaptation policy (mandatory water restriction) instead of a policy that raises the price of water charged to households that would ensure achieving the same level of consumption as with restriction.
- *Impacted sectors*: Households.
- *Countries of application*: Sydney, Australia.
- *Scale*: Local (city) level; Time scale: short-term (1 June 2004 – 1 June 2005).
- *Effort and resources required*: Medium.
- *Expected precision*: Good. Precision depends largely on the parameters included in the analysis, the type of model applied, and the quality of the (gu)estimate of choke and market-clearing prices. If the approach is applied correctly, the estimate precision is expected to be quite good.
- *Parameters used for determining costs*: Estimated water demand for banned water uses is based on real volumetric water prices, daily maximum water temperatures (current and lagged), daily rainfall data (current and lagged), water restriction dummy variable; choke price (a price at which banned water use becomes zero); and market-clearing price (a price that would ensure the same total consumption as restrictions).
- *Results*: Cost (welfare loss) due to the introduction of mandatory water restrictions, benefit (welfare increase) due to hypothetical reallocation of water uses through lifting restrictions and increasing the water price, and net cost (the difference of the previous two), all in monetary values.
- *Result precision*: One figure for the total welfare loss.
- *Is the method able to deal with the dynamics of risk?* Yes.
- *Skills required*: Econometric modeling (regression analysis).
- *Types of data needed*: Water consumption, water prices, water temperature, rainfall data, all before and after restrictions.
- *Data sources*: Water-providing companies; the meteorological office; the statistics office; researcher's own estimates; previous scientific research.
- *Who collects the data*: Water-providing companies; the meteorological office; the statistics office; scientists.
- *How is the data collected*: Measurements (temperature, rainfall, water consumption); previous scientific studies; researcher's own estimates.
- *Is data derived ex ante or ex post*: Ex post (empirical historical observations).
- *Data quality*: The meteorological data, water consumption and water prices are usually standardized. Estimation of the price elasticity of water demand is more problematic.

3.2. Assessing effects on GDP and agricultural production

This approach explores the relationship between a drought and the economic performance of a country. It compares a change in real GDP (Gross Domestic Product) of the agricultural sector and a change in the total GDP of a country, for a year in which a severe drought occurred with a year prior to drought. It has been used by the World Bank to study the role of the economic structure of a country on the sensitivity to drought in order to enable incorporating drought shocks into economic and development planning and to suggest structural adjustments programs to reduce drought vulnerability. Even though it is not clear the method will generally provide an estimate of indirect drought impacts, it can provide insight into the magnitude of indirect effects. Namely, if the fall in the agricultural GDP is higher than a fall in the total GDP of a country, it implies that the economy is predominantly agrarian and that drought principally affects the agricultural sector, having smaller effects on other economic sectors (i.e. indirect effects are relatively small). Similarly, if the total GDP of a country experiences a stronger decrease than the agricultural GDP, drought is likely to adversely affect not only agriculture but also other sectors. It means that the indirect effects are relatively high.

Example:

Benson, C., Clay, E. (1998). The impact of drought on Sub-Saharan African economies. World Bank Technical Paper No. 401. Washington, D.C.: The World Bank.

• *Explanation*: The performance of national GDP and GDP associated with agriculture of several sub-Saharan African countries, India and Australia is examined during years of widely recognized severe drought. The authors plotted the change in real GDP attributable to changes in agricultural GDP against the total change in GDP, comparing years of severe drought with performance in the previous year. For example, a 50 percent fall in agricultural GDP in an economy in which agricultural GDP had accounted for 20 percent of total GDP in the pre-drought year would translate into a 10 percent fall in GDP attributable to the decline in agricultural GDP.

• *Cost types addressed*: Direct costs (losses caused by the disruption of production processes), indirect costs (to a limited extent)

• *Objective of the approach*: It enables exploring the role of the economic structure of a country on the sensitivity to drought. The study concludes with recommendations for drought mitigation policy, which include elements of economic planning, water resource management and agricultural and food policies.

• *Impacted sectors*: Agriculture and national economies as a whole in terms of GDP.

• *Countries of application*: Australia, Burkina Faso, Ethiopia, India, Malawi, Niger, Nigeria, Senegal, South Africa, Sudan, Zambia, Zimbabwe (1983 and 1992).

• *Scale*: National level; Time scale: GDP in a drought year compared to the previous year in the period between 1979 and 1992, depending on the country.

• *Effort and resources required*: Low.

• *Expected precision*: Poor. Factors other than drought that could lead to a decrease of GDP are not taken into account; the method does not distinguish between drought effects on different sectors of the economy apart from agriculture; the assumptions are not very clear.

• *Parameters used for determining costs*: GDP and share of agricultural sector(s) in GDP in a drought year and a pre-drought year.

• *Results*: Percentage of a decrease in agricultural and total GDP of a country.

• *Result precision*: One figure for a decrease in agricultural GDP and one figure for a decrease in total GDP for each country.

• *Is the method able to deal with the dynamics of risk?* No.

• *Skills required*: Desk research skills.

• *Types of data needed*: Total GDP and GDP corresponding to agriculture.

• *Data sources*: Statistics office.

• *Who collects the data*: Statistics office staff.

• *How is the data collected*: The statistics office.

• *Is data derived ex ante or ex post*: Ex post (empirical historical observations).

• *Data quality*: The book System of National Accounts (1993), which was prepared by representatives of the International Monetary Fund, European Union, Organization for Economic Co-operation and Development, United Nations and World Bank provides an international set of rules and procedures for the measurement of national accounts, including GDP.

3.3. Input-output analysis

The basic input-output model is generally constructed from observed economic data for a specific country or region (Miller and Blair, 2009). It describes the flows of products from each industry to each industry, final demand (such as production for personal consumption, sales to the government, and export), and value added. The latter comprises expenditures to labor and capital, taxes, and imports for a particular period of time (usually a year). Based on this information, it is possible to analyze the effects of a change in a price or output of one or several economic sector(s), a change in the final demand, or a change in one of the value added elements on the rest of the economy. In the context of droughts, this approach is particularly useful for assessing the indirect costs of droughts, i.e. the spillover effect of the losses in agriculture and water-providing sector on the quantities produced by the rest of the economic sectors, and their employment. Input-output analysis can be seen as a substitute approach for the computable general equilibrium analysis, discussed in Section 3.4. The advantage of the input-output model is that it is easier to apply and can include a very disaggregate sector structure, but it also implies more restrictive assumptions regarding substitution mechanisms and technology, and lacks price mechanisms. The studies that have assessed indirect costs of droughts by using input-output analysis involve Martin-Ortega and Markandya (2009) and Pérez y Pérez and Barreiro-Hurlé (2009). Input-output analysis has also seen some application in effect studies of different water policies. For instance, Llop (2008) used the method for evaluating the impact of alternative water policy scenarios on production and consumption prices, intermediate water consumption and private real income. Analyzed policies include the introduction of a tax on water used by sectors, improvement in the technical efficiency of water use, and a combination of the two measures. Velázquez (2006) applied the input-output model to determine which economic sectors in Andalusia consume the greatest quantities of water. The model also allows simulation of effects of different policies on water consumption and distribution among sectors.

Example:

Pérez y Pérez, L., Barreiro-Hurlé, J. (2009). Assessing the socio-economic impacts of drought in the Ebro River Basin. Spanish Journal of Agricultural Research, 7: 269-280.

- *Explanation*: The study estimates direct and indirect economic impacts of the drought in the Ebro River Basin that occurred in 2005. It uses regional input-output tables of four regions in Spain that comprise the Ebro River Basin. First, direct impacts are assessed for the two main sectors affected by the drought, agriculture and energy production, in terms of their contribution to the gross added value (GAV). These effects are then introduced into the Ghosh's supply-driven input-output model in order to estimate indirect impacts on the overall economy. The study found that drought induced the loss of direct gross added value of 482 million € in the two sectors and additional 377 million € of the indirect loss of production. The drought also caused a loss of 11.275 jobs.
- *Cost types addressed*: Direct costs (losses caused by the disruption of production processes), indirect costs (secondary-effects in all economic sectors and employment).
- *Objective of this approach*: The input-output analysis allows estimating economy-wide impacts in terms of production and employment loss of either historical or hypothetical drought, based on the economic structure of a region or a country.
- *Impacted sectors*: Sectors with production loss of over 15 million €: agrofood industry; agriculture, forestry and fishing; catering business; energy sector, distribution of energy, gas and water; motor vehicle sales and repair; and chemistry industries.
- *Scale*: Ebro River Basin region, Spain; the analysis embraces four regions (Navarra, La Rioja, Aragón and Cataluña); Time scale: short-term effects (only for the year 2005).
- *Effort and resources required*: Medium (data is easily available and modeling is not too complex).
- *Expected precision*: Good, although depends on the level of disaggregation of both sectors and regions.
- *Parameters used for determining costs*: Contribution of directly impacted economic sectors on gross added value (GAV) for the studied region (reduced by the potion of intermediate consumption in the decline of production due to drought); input-output tables.
- *Results and result precision*: Direct effects on GAV for the selected (most impacted) economic sectors and indirect effects on production of all sectors of the economy in monetary values, the number of jobs lost in all sectors.
- *Is the method able to deal with the dynamics of risk?* Yes.
- *Skills required*: Good skills in economic modeling.
- *Types of data needed*: National or regional input-output tables, and additional data sometimes (e.g. accounts for agricultural production).
- *Data sources*: The statistics office, although regional input-output tables are sometimes unavailable, so a researcher can try to estimate his/her own database using national input-output table and certain regional data, such as the distribution of industry outputs and of final demand aggregates between regions.
- *Who collects the data*: The statistics office staff.
- *How is the data collected*: The statistics office (for the EU countries).
- *Is data derived ex ante or ex post*: The approach allows deriving data both ex ante and ex post.
- *Data quality*: The System of National Accounts (1993) provides rules and procedures for the measurement and data collection for the input-output tables. In the EU the elaboration of the input-output tables is also established in the European Parliament and Council Regulation (EC) No. 1392/2007 which modifies the previous Regulation No. 2223/96.

3.4. Computable general equilibrium analysis

A computable general equilibrium (CGE) model represent one of the most sophisticated types of economic model, which is applied with the aim of examining the economy-wide impacts of a change in a policy (e.g. a tax reform, a change in trade, energy or agricultural policies), technology, exports, or other exogenous factors. CGE models are based on the core assumptions of optimizing behavior of consumers and producers and market clearing. In particular, consumers are assumed to maximize their utility or satisfaction, and producers to maximize profits (or minimize costs). Moreover, product and factor markets are assumed to be competitive and relative prices flexible and reflective of relative (demand-supply) scarcity. These attempt to represent the circular flow of goods and services and money in the economy, enabling an analysis of factors and mechanisms that determine relative prices as well as resource allocation and income distribution issues in market economies. CGE models use benchmark data on price elasticity, products and inputs substitution elasticity, household income elasticity, and sometimes also input-output relationships between industries (intermediate deliveries). In this way, they explore interactions between a large number of economic agents. This method can simulate the effects of a drought on the outputs and employment in different sectors of the economy at the regional or national level. The advantage of a CGE approach in comparison with other approaches is that it incorporates economy-wide feedbacks (including interaction between markets, income formation and spending effects, and input and output substitution) in examining different impacts on various sectors, and thus allows for an assessment of total effects. Studies that applied CGE models with the aim of estimating drought costs include Islam (2003), Horridge et al. (2005), Berritella et al. (2007), Boyd and Ibarrarán (2009), Pauw et al. (2010), and Wittwer and Griffith (2010). Salami et al. (2009) apply a slightly different systems approach (integrated linear programming and macroeconometric modeling), which obtained results very similar to those derived from the CGE models. Namely, they estimated a change in the value added of all economic sectors in Iran due to drought and its effects on investment, GDP, trade flows and inflation.

Example:

Horridge, M., Madden, J., Wittwer, G. (2005). The impact of the 2002-2003 drought on Australia. Journal of Policy Modeling, 27: 285-308.

• *Explanation*: The study uses a “bottom-up” CGE model called TERM (The Enormous Regional Model) for simulating the regional impacts of the Australian drought in 2002-2003. The database for the model incorporates a national input-output table together with regional data on output (for agriculture) and employment (in other sectors). The results show a decrease in outputs for 38 sectors in 45 regions, a reduction of the real GDP due to agriculture sectors (1%) and due to the rest of the economy (0.6%), and the effects on employment, real household consumption, real investment, real Gross Regional Product, and the real wage rate in different regions of a country.

• *Cost types addressed*: Direct costs (losses caused by the disruption of production processes), indirect costs.

• *Objective of this approach*: The method provides a sophisticated modeling framework in which welfare effects can be estimated. It can serve as a useful tool for policy making and planning by assessing drought vulnerability of various economic sectors and geographical regions.

• *Impacted sectors*: Various agricultural and livestock sectors (sheep, barley, wheat, other broadacre, beef cattle, dairy cattle, rice, cotton, fruit and nuts, grapes, multi-grape, sugar cane, pasture irrigation, vegetables, etc.), trade, transport, and construction industry.

• *Scale*: Australia; analysis at the regional level (45 regions); Time scale: short-term effects (one year, 2002-2003).

• *Effort and resources required*: High effort due to data collection and modeling skills required; medium resource requirements in financial terms.

• *Expected precision*: Good, although depending primarily on the level of sectoral and regional disaggregation.

• *Parameters used for determining costs*: Input-output tables (delivered value of demand for each good in each destination region for each user – industries, households, investment, government, and exports), trade flows, values of margin for each good, revenue and production taxes, values of input factors, changes in stocks, price elasticities of demand for different commodities (own-price elasticities), and elasticities of substitution between different commodities and between input factors (cross-price elasticities).

• *Results and result precision*: Percentage of a change in output of each industry in each region in a drought year compared to a pre-drought year, percentage of a change the real in GDP and other macroeconomic indicators in each region (real consumption, real investment, export and import volumes, export prices, employment, and the average wage rate).

• *Is the method able to deal with the dynamics of risk?* Yes.

• *Skills required*: Good skills in economic modeling and programming.

• *Types of data needed*: National or regional input-output tables, trade matrices, matrix of the value of margin good required to facilitate trade flows, tax matrix of commodity tax revenues, the value of input factors (wages, capital rentals, land rentals), production tax, stock changes of domestic output and of imports.

• *Data sources*: The statistics office; researcher's estimates; estimates from the literature.

• *Who collects the data*: The statistics office staff; scientists.

• *How is the data collected*: The statistics office, other administrative institutions, previous scientific studies.

• *Is data derived ex ante or ex post*: The approach is able to derive data both ex ante and ex post.

• *Data quality*: As mentioned in Section 3.3, there is an established procedure for elaborating input-output tables. A number of parameters of CGE models are calibrated to benchmark data from input-output tables in a certain year. Besides this, to calibrate free parameters to benchmark data, CGE models include estimates of all sorts of elasticities that are simply borrowed from other studies.

3.5. Biophysical-agroeconomic modeling

Biophysical-agroeconomic models integrate crop biophysical models with agro-economic models, providing a comprehensive insight on the feedback effects between human activities and natural resources. In biophysical-agroeconomic models crop physiology models are forced with climate scenarios (temperature-precipitation inputs) from hypothetical or historical droughts. They provide biophysical estimates (yield, water and nutrient use) of crop responses to climate events. This approach hence serves to predict how drought conditions affect crop yields and water use. Often, spatially explicit models are used. These can be applied to different geographical scales, depending on the (dis)aggregation level of the data used. The simulated yield estimates are then incorporated into socio-economic models, usually first for predicting farm-level decisions, which are then aggregated to market levels to predict changes in supply, prices, and consequently also economic welfare. It is also referred to as a “bottom-up” approach because it starts at the finest level of interactions of climate and biophysical or hydrological processes and then aggregates up to larger-scale socio-economic processes. Applications of this method can be found in Kulshreshtha and Klein (1989), Rosenberg (1993), Holden and Shiferaw (2004), and Fischer et al. (2005).

Example:

Holden, S., Shiferaw, B. (2004). Land degradation, drought and food security in a less-favored area in the Ethiopian highlands: a bio-economic model with market imperfections. Agricultural Economics, 30: 31-49.

• *Explanation*: The biophysical-agroeconomic model in this study analyzes the combined effects of land degradation, population growth, market imperfections and increased risk of drought on household production, income, welfare, and food security. It estimates direct production effects of drought and indirect effects on household welfare due to price changes for crops and livestock.

• *Cost types addressed*: Direct costs (losses caused by the disruption of production processes), indirect costs.

• *Objective of the approach*: The approach uses biophysical models for crop growth simulation and introduces meteorological and landscape data in order to estimate crop yields. These results are then aggregated for larger areas and used in economic models dealing with both farmer income optimization and agricultural market equilibrium. The approach can therefore have an important role in decision making for both farmers and policy makers. For example, Holden and Shiferaw (2004) consider the effects of provision and adoption of credit for fertilizer on grain production, household welfare and food security, which can serve as an input for designing future credit policies.

• *Impacted sectors*: Agriculture sector (including livestock).

• *Scale*: Ethiopia; the analysis includes a local case study in Anit Tid at the household level; Time scale: mid-term (predictions for a 5-year period).

• *Effort and resources required*: High (detailed biophysical and socio-economic data needed on the plot and household levels, respectively; measurements, observations, experiments and surveys required).

• *Expected precision (validity)*: Good. The detailed disaggregation level makes its estimates precise, but on the other hand modeling interactions between crop physiology, climate conditions and economic factors is too complex to be very precise.

• *Parameters used for determining costs*: For determining crop yield: soil erosion (soil type, soil depth and slope, rainfall, crop choice), nutrient depletion (nitrogen and phosphorus), and use of conservation technology. For determining livestock production: productivity of the livestock, birth rates, mortality, feed requirements, milk production, ploughing capacity, manure production, culling rates, labor and other input costs. Parameters for market characteristics: credit demand, labor (wage rate and time worked), land rental, oxen rental, fodder, seed and output prices.

• *Results and result precision*:

–Predicted changes in cropped areas for three different household groups, 6 different crop types, with and without credit constraints for each year over a 5-year period.

–Yield estimates of barley in two different seasons, on four different land classes, with and without conservation technologies and with and without fertilizer or manure for each year over a 5-year period.
–Household utility, income per capita, crop sale, drought risk premium, total labor on farm (man days), formal credit demand, all for both 10% and 20% risk of drought, for constrained and unconstrained access to credit for fertilizer, and for each year over a 5-year period.
• *Is the method able to deal with the dynamics of risk?* Yes, to some extent. The method is able to take into account the probability of drought as well as a wide range of biophysical, climatic and socio-economic factors determining the severity of a drought.
• *Skills required*: Both natural and social science skills required (good understanding of the biophysical, climatic and economic systems necessary for modeling feedback effects between human activity and natural resources).
• *Types of data needed*: Biophysical data (soil physical and chemical data, erosion data for different crops, crop yield data on different soils, climatic data) and socio-economic data.
• *Data sources*: Previous scientific research (if available), FAO, the meteorological office, the statistics office.
• *Who collects the data*: Scientists, FAO, the meteorological office, the statistics office.
• *How is the data collected*: Biophysical data in the field through measurements, observations and experiments (managed by both researchers and farmers) over a certain period of time or from previous scientific studies and projects; socio-economic data from surveys.
• *Is data derived ex ante or ex post*: Data can be derived both ex ante and ex post in this approach.
• *Data quality*: Not standardized/assured to our knowledge.

3.6. Coupled hydrological-economic modeling

A coupled hydrologic–economic model consists of a hydrological model and an economic optimization model. It allows an analysis of the impacts of water allocation and use by different sectors under alternative policy scenarios. The model usually has three components: (1) economic factors, including the cost of water and the profits generated by its use, (2) hydrological factors, and (3) institutional factors that affect hydrologic and economic components. For the same reasons mentioned in Section 3.5, hydrological-economic models often have an explicit spatial structure. Hydrological-economic models serve as a particularly useful decision-support tool for local, regional, or national authorities and agricultural stakeholders. They are considered “bottom-up” approaches for the same reasons as biophysical-agroeconomic models. Examples of studies that applied such models for assessing drought costs are Booker (1995), Booker et al. (2005), and Ward et al. (2006).

Example:
Booker, J.F. (1995). Hydrologic and economic impacts of drought under alternative policy responses. Water Resources Bulletin, 31: 889-906.
• *Explanation*: An integrated hydrological-economic-institutional model for Colorado River basin has been developed in order to 1) estimate the economic damages of a hypothetical drought on consumptive and non-consumptive users of basin water resources under the existing rules and policy, and to 2) investigate potential benefits of eight alternative policy responses to drought.
• *Cost types addressed*: Direct costs, indirect costs, intangible costs.

• *Objective of the approach*: To estimate economic impacts of alternative water allocations, taking into account a set of institutional choices. Therefore, the approach is developed for assessing the economic impacts of policy responses to droughts. It provides important insights and policy recommendations for decision makers.

• *Impacted sectors*: Consumptive (agricultural and municipal) water use, hydropower production, recreation (flatwater boating, rafting, and fishing), damages of increased salinity levels in drinking and irrigation water.

• *Scale*: Colorado River Basin, USA; the study used requests for consumptive use for 32 basin locations, drought inflows to 14 locations and historic salt levels at 20 locations in the model; Time scale: long-term (simulation of a 38-year drought sequence), divided into 4 periods: baseline (years 1 to 9), early drought (years 10 to 16), critical drought (years 17 to 22), and recovery (years 23 to 38).

• *Parameters used for determining costs*: Annual water allocation, annual economic benefits of different water uses, average annual flow (based on reservoir water and salt levels, reservoir storage capacity, annual evaporation, salt inflows), average hydropower heads.

• *Results and result precision*: Percentage of changes in water available for consumptive uses, for hydropower production, losses from recreation water use, and from increased salinity concentrations is provided for four stages of a simulated 35-year drought. More rough results (either in terms of change in average annual flow or only qualitative analysis) are presented for eight alternative policy responses to drought.

• *Effort and resources required*: High (collecting and modeling detailed hydrological data with economic data under different water management policies).

• *Expected precision (validity)*: Good. The hydrological model most likely simulates hydrological impacts of drought rather precisely. Translating a percentage decrease in annual flow at different locations in the basin to a percentage loss of annual benefits under typical river conditions should provide good rough estimates of the damages, although they might not take into account the marginal values of water availability.

• *Is the method able to deal with the dynamics of risk?* Yes, to some extent. The approach is able to estimate the effects of hypothetical droughts under various hydrological and policy settings.

• *Skills required*: Excellent knowledge of hydrology and hydrology modeling skills.

• *Types of data needed*: Hydrologic data (e.g. reservoir water and salt levels, reservoir storage capacity, annual evaporation, average hydropower heads, water and salt inflows, water demand and water use); economic data (benefits derived from different water uses).

• *Data sources*: Previous scientific research (e.g. simulation models), water providing companies, water resource management/commission, the statistics office.

• *Who collects the data*: Scientists, experts in hydrology, water providing companies.

• *How is the data collected*: In the field, simulation modeling based on historical observations and predictions.

• *Is data derived ex ante or ex post*: Ex ante (simulation models).

• *Data quality*: Not standardized/assured to our knowledge.

3.7. Ricardian hedonic price modeling

Unlike the bottom-up approaches, the Ricardian hedonic price analysis represents a top-down approach as it directly measures the effect of climate on economic welfare. Building on the Ricardian model of land value, this approach links variations in land values across space with variations in climate. Land value is usually a good indicator of economic welfare because it reflects the present value of future streams of net revenue. Nevertheless, a disastrous event can lead to both positive and negative distortions of asset values, making such valuation more complex. For example, under normal conditions production capacity is not fully used and a disaster event can induce mobilization of an idle production capacity to compensate for foregone production from lost assets. In addition, workers can increase their working hours in unaffected businesses to help society cope with disaster consequences (and sometimes benefit from increased prices). As a consequence, unaffected capital can often increase production to compensate for output loss due to affected capital. The Ricardian approach can be considered as a form of hedonic price method, in which the price of a marketed good is related to its characteristics, or the services it provides. The hedonic price method is used in environmental economics and is predominantly applied to variations in housing prices that reflect the value of local environmental attributes. Ricardian hedonic price modeling uses the same principle with the aim of explaining variations in agricultural land prices by variations in climate conditions (temperature, rainfall).

Example:

Easterling, W., Mendelsohn, R. (2000). Estimating the economic impacts of drought on agriculture. In Wilhite, D.A. (ed.). Drought: A Global Assessment, 1: 256-68. London/New York: Routledge.

- *Explanation*: A multiple regression analysis for all agricultural counties in the United States is carried out in order to (1) understand how land values are affected by interannual climate variation (the average level of temperature and precipitation in each season) and then to (2) measure the economic repercussions of this variation in agricultural conditions.
- *Cost types addressed*: Direct costs (losses caused by the disruption of production processes).
- *Objective of the approach*: Estimating annual loss to US agriculture due to climate variation; later compared to the damages for farmers if better weather forecast would be available in order to evaluate climate predictions.
- *Impacted sectors*: Agriculture.
- *Scale*: United States; the model used data from all agricultural counties in the USA; Time scale: N/A.
- *Effort and resources required*: Medium (meteorological data such as temperature and precipitation is usually easily available; desk research might be sufficient).
- *Expected precision (validity)*: Reasonable. As climate is not the only factor that varies across space, the researcher has to control for variation due to other causes, such as soil characteristics, population density, altitude and latitude. However, not all variables can be perfectly measured and controlled for, which can bias or at least obscure the results. The same holds for the omitted variables. In addition, variations in land value can only explain damages in the agricultural sector, meaning that the approach cannot estimate any other costs of droughts apart from agricultural losses.
- *Parameters used for determining costs*: Land/farm values; precipitation and temperature over a certain period of time; land/farm characteristics (density, solar radiation, altitude, salinity, flooding, wetland, soil erosion, slope length, sand, clay, moisture capacity, permeability); income per capita.
- *Results and result precision*: Losses in agriculture (based on land value losses) due to climate variation in monetary value, one figure for the total loss of a sector.
- *Is the method able to deal with the dynamics of risk?* No.
- *Skills required*: Econometrics (multiple regression analysis).

• *Types of data needed*: Meteorological data (precipitation and temperature); land/farm values; land/farm characteristics (e.g. density, solar radiation, altitude, salinity, flooding, wetland, soil erosion, slope length, sand, clay, moisture capacity, permeability); economic data.
• *Data sources*: E.g. in the case of USA - National Climate Data Centre (meteorological data); US Census of Agriculture, National Resource Inventory and US Department of Agriculture surveys (farm characteristics); County and City Data Book (social, demographic, and economic data).
• *Who collects the data*: Experts of the field; administrative staff.
• *How is the data collected*: In the field; census; surveys.
• *Is data derived ex ante or ex post*: Ex post (based on the empirical historical data).
• *Data quality*: Apart from meteorological data, not standardized/assured to our knowledge.

3.8. Contingent valuation

Contingent valuation is a widely used method for estimating economic values for all kinds of ecosystem services and environmental goods which are not traded in the market and hence have no market price. Hence, it can be applied for estimating intangible costs of drought. Contingent valuation method is typically used to estimate the benefits (or costs) of a change in the level of provision (or in the level of quality) of a public good. It is also referred to as a stated preference method because it asks people in a survey to state how much they would be willing to pay for a (change in) specific environmental service. It is further possible to ask people what is the amount of compensation they would be willing to accept to give up an environmental service, although the first approach is more recommendable. A contingent valuation survey should include (1) a detailed description of a good being valued and the hypothetical change regarding the good, (2) questions about willingness to pay for a good being valued, and (3) questions about respondents' characteristics (age, income, education) and preferably also their preferences concerning the good. An advantage of contingent valuation (and other stated preference techniques, like choice experiments; see Section 3.9) over revealed preference techniques (like hedonic price, travel cost, Ricardian modeling methods and cost of illness approach) is that it can address hypothetical changes in policy, that is, policy changes which are considered but have not (yet) been implemented. The main disadvantage is that data generated by contingent valuation (and other stated preference techniques) are hypothetical, and because of this most economists tend to assign more credibility to revealed preference techniques which use data about actual, past choices by individuals in markets. The contingent valuation method has mainly been applied to estimate the value of avoiding water use restrictions or increasing the security of water supply (Bakarat and Chamberlin, Inc., 1994; Howe et al., 1994; Griffin and Mjelde, 2000; Koss and Khawaja, 2001). Pattanayak and Kramer (2001a) estimated the value of drought mitigation provided by tropical forest watersheds. More generally, contingent valuation can be used to assess the costs of drought damage, mitigation or adaptation. We provide an example of mitigation below.

Example:

Pattanayak, S.K., Kramer, R.A. (2001a). Pricing ecological services: Willingness to pay for drought mitigation from watershed protection in eastern Indonesia. Water Resources Research, 37: 771-78.

• *Explanation*: A survey conducted in eastern Indonesia (500 face-to-face interviews with local farmers) to estimate the economic value of an ecosystem service of drought mitigation provided by tropical forest watersheds in Ruteng Park protected area to local agrarian communities. The mean (median) annual stated WTP through an annual fee is USD $2.79 ($1.64) per household, which aggregates to a total annual value of USD $27.000.

• *Cost types addressed*: Intangible costs - loss of local farmers' welfare (well-being) due to decreased agricultural production.

• *Objective of the approach*: The survey is part of a larger project on the economic analysis of protected areas. The study intends to provide signals to watershed managers and policy makers regarding the economic magnitude and spatial distribution of the local economic value of watershed protection.

• *Impacted sectors*: Agriculture (services provided by protected watershed primarily contribute as inputs to agricultural production).

• *Scale*: Ruteng Park, Indonesia; survey on the household level; Time scale: N/A.

• *Effort and resources required*: High (design and administration of a survey).

• *Expected precision*: Reasonable. Applying the CV method to an ecological service in a developing country setting includes a high risk of commodity and context misspecification despite a good practice in survey design and administration. The authors themselves point out that because of the imprecision in their economic data, indices of ecological attributes, and household opinions they do not recommend using the estimates to predict precise values of drought mitigation services. However, in other contexts the approach may provide rather reasonable estimates.

• *Validity*: The main problem in assessing the validity of the WTP estimates is the absence of actual values against which to compare the results. However, validity of the WTP can be tested by comparing the result with those from other valuation studies using other methods, the findings of cross-study analyses (e.g. meta-analyses or benefits transfer exercises), or simulated markets. Such comparisons often showed that CVM is likely to slightly overestimate the actual value due to its hypothetical nature. Validity can also be evaluated by examining consistency of CVM estimates with theoretical expectations derived from economic theory. For example, when the price of a good increases, consumption of that good should fall. Moreover, a positive relationship between stated values and the respondent's disposable income is expected.

• *Is the method able to deal with the dynamics of risk?* Yes.

• *Skills required*: Empirical methods of social science - focus groups (optionally), questionnaire design and econometric analysis, particularly regarding the WTP questions.

• *Types of data needed*: Stated willingness to pay about the good/service being valued; individual or household characteristics (demographic and socio-economic data) and preferences, environmental conditions.

• *Data sources*: Questionnaire; statistics/meteorological office (environmental conditions).

• *Who collects the data*: Scientists; the statistics/meteorological office (environmental conditions).

• *How is the data collected*: Survey; in the field (environmental conditions).

• *Is data derived ex ante or ex post*: Data is usually derived ex ante, based on a hypothetical scenario regarding the good/service being valued, which is described in the questionnaire and followed by WTP questions.

• *Data quality*: A guidance document published by NOAA – National Oceanic and Atmospheric Administration (1993) "Report of the NOAA Panel on Contingent Valuation", Federal Register, Vol. 58, no. 10, US, 4601-4614 sets out recommendations concerning the design and implementation of the CV survey as well as result analysis and reporting.

3.9. Choice experiments

Choice experiments (CE) are, along with the contingent valuation method (CVM), important tools for valuing non-market goods, i.e. intangible costs of drought. They are a newer approach and offer several advantages over CVM. For example, respondents are more familiar – through participating on an almost daily basis in market transactions – with making a choice for a good that has a range of characteristics of which price is one, rather than stating a price they would be willing to pay for that good. Moreover, CE enables estimating the value of the individual attributes that make up an environmental good, and they avoid some of the biases associated with CVM. In a choice experiment, individuals are given a hypothetical setting and asked to choose their preferred alternative among several alternatives in a choice set, and they are usually requested to perform a sequence of such choices. Each alternative is described by a number of attributes or characteristics. A monetary value is included as one of the attributes, which enables estimation of the willingness to pay. CE is, however, generally more difficult to execute than CVM, especially if the number of attributes is large. Like contingent valuation, it suffers from hypothetical bias and its precision depends mainly on the design of the experiment, which involves the definition of attributes and their levels, the context of the experiment, and questionnaire development. The choice sets selected for an experiment further have an important impact on the results. In addition, the questions in a CE study are often conceptually difficult to handle for respondents and require considerable cognitive efforts. As a result, responses may be biased (McFadden et al., 2005). Despite its advantages over CVM, there seems to be only one CE application related to drought cost estimation (Hensher et al., 2005 and Hensher et al., 2006). Like CVM, CE can be used to assess the costs of drought damage, mitigation or adaptation. The example below is about adaptation costs.

Example:

Hensher, D., Shore, N., Train, K. (2006). Water supply security and willingness to pay to avoid drought restrictions. The Economic Record, 82: 56-66.

• *Explanation*: Stated choice experiments were applied in Canberra, Australia in order to estimate households' and businesses' willingness to pay (WTP) to avoid drought water restrictions. A total of 211 residential respondents and 205 business respondents completed the choice experiments. Respondents seem to be unwilling to pay to avoid low-level restrictions that are not in place every day, and all year. They are willing to adjust their watering schedules or tolerate high-level restrictions for limited periods each year, compared with paying higher water bills. Household are on average willing to pay AUD $239 to move from a situation with continuous restrictions on level 3 (medium restriction measures) or above every day all year every year to a situation with virtually no risk of restrictions. An average WTP of business customers for the same change in conditions equals AUD $1.104 and the median is AUD $239.

• *Cost types addressed*: Intangible costs (social welfare loss due to restrictions on water supply).

- *Objective of the approach*: The study was commissioned by the region's water service provider in response to a request by the Independent Competition and Regulatory Commission for information on customers' valuation of service attributes in order to assess whether the existing service levels provided by the water company were appropriate.
- *Impacted sectors*: Water supply service.
- *Scale*: Canberra, Australia; survey on the household level (residential respondents) and company level (business respondents); Time scale: the method is able to estimate short, mid, and long-term effects (long-term effects refer to a period of 20-30 years).
- *Effort and resources required*: High (focus groups and survey).
- *Expected precision (validity)*: Good. Most of analyses of CE validity (although there are relatively few) show results in favor of external validity of the choice experiments method.
- *Is the method able to deal with the dynamics of risk?* Yes. It is, for example, able to estimate the approximate costs of water supply restrictions due to drought based on various simulated water restriction levels and frequencies.
- *Skills required*: Social science skills (focus groups; questionnaire design, especially concerning choice experiments; econometric analysis).
- *Types of data needed*: Water users' preferences of service options with different attributes and varying prices; demographic and socio-economic data.
- *Data sources*: Questionnaire involving choice experiments; the statistics office.
- *Who collects the data*: Scientists.
- *How is the data collected*: Survey.
- *Is data derived ex ante or ex post*: Ex ante (estimations are based on different hypothetical combination of frequency, duration, and intensity of drought/water restrictions at varying prices).
- *Data quality*: Choice experiment is a standardized method. Survey and experimental design is performed according to established practices and are crucial for assuring data quality. Furthermore, the econometric analysis of choice data should follow well-established rules.

3.10. Life satisfaction analysis

Life satisfaction (also referred to as happiness or subjective well-being) research is emerging as an important approach within many disciplines, such as psychology, sociology, economics, and medicine. Asking people to assess their current level of happiness has become a regular feature of public surveys. These data can then be used jointly with data on per capita income, other socio-economic indicators, and environmental conditions, for example, to examine how self-reported well-being varies with prosperity, life stages, life styles and environmental quality. Econometric modeling such as techniques of regression analysis are applied to analyze subjective well-being data. So far there seems to be only one study that relates life satisfaction data with rainfall data for Australia. Nevertheless, we do not see obstacles for a more widespread use of this approach in estimating intangible costs of droughts.

Example:

Carroll, N., Frijters, P., Shields, M.A. (2009). Quantifying the costs of drought: new evidence from life satisfaction data. Journal of Population Economics, 22: 445-61.

- *Explanation*: A fixed-effects model for Australia matching rainfall data with individual life satisfaction (a sample of 15.561 adults) was used to estimate (1) the total cost of the 2002 drought, (2) the costs of drought among residents in rural and urban areas, and (3) the potential costs of a doubling in the frequency of spring droughts, as predicted by the Australian Commonwealth Scientific and Industrial Research Organization. The total cost of dry spring across Australia in 2002 was equivalent to the lowering of national income by AUD $5.4 billion. The loss in life satisfaction for residents of rural areas was equivalent to a fall in average annual household income of AUD $18.000 or around 35%, while no evidence of a loss of life satisfaction from drought was found for urban communities. A doubling of spring drought episodes would lead to the equivalent loss in life satisfaction of AUD $7.4 billion per year, or just over 1% of Australia's GDP.
- *Cost types addressed*: Intangible costs (psychological costs of drought that may be associated with a drop in expected future income or other factors related to very low rainfall).
- *Objective of the approach*: Taking into account psychological costs of drought, apart from its economic costs.
- *Impacted sectors*: Households (social welfare).
- *Scale*: Australia; methodological data correspond to the postcode level, life satisfaction and demographic data used are at the individual level; Time scale: mid-term effects (period 2001-2004, including a particularly severe drought in 2002).
- *Effort and resources required*: High if own data have to be generated through questionnaires; Medium if life satisfaction and other required data is available.
- *Expected precision (validity)*: Reasonable. Generally, in order to have a precise estimate by using information on life satisfaction it is of crucial importance that respondents are able to express accurately their degree of satisfaction and that all respondents interpret the satisfaction scale equivalently. Data used in this study is the “Australian Unity Wellbeing Index”, which is being collected quarterly and is expected to be reliable. Coefficients from the model are then applied to calculate the income-equivalence changes due to a fall in self-reported life satisfaction, which is a crucial step for determining precision of the approach and depends primarily on the quality of the model. Data available for this study does not allow distinguishing between farmers and non-farmers or others directly connected to agricultural production, which means that it cannot determine the precise transmission mechanisms of drought on life satisfaction, even though it might provide a correct average effect. However, life satisfaction analysis has seen very few applications in a drought context. For this reason, its precision in this research area is difficult to judge.
- *Is the method able to deal with the dynamics of risk?* Possibly yes, although it has not been done yet (this would possibly require asking about happiness under hypothetical, future conditions, such as associated with climate change and policy; it is not clear if this would be seen as acceptable by the research community, as current studies have been limited to current or past happiness). For example, this study has estimated potential costs of a predicted doubling in the frequency of droughts applying the equivalent loss in life satisfaction. However, more information would be needed on the various ways in which individuals could adapt to a greater drought frequency to be more certain about the costs of changes in future climate risks.
- *Skills required*: Empirical methods of social science (econometric modeling if data is available, otherwise also questionnaire design).

• *Reliability*: Depends largely on the quality of the data used. The authors have conducted a series of robustness checks using several different definitions of drought and found that the results are quite robust.
• *Types of data needed*: Meteorological data (e.g. rainfall and temperature); individual life satisfaction and demographic data.
• *Data sources*: The meteorological office; existing scientific research/surveys on life satisfaction, wellbeing or quality of life.
• *Who collects the data*: The meteorological office; scientists.
• *How is the data collected*: Meteorological data in the field (at weather stations which are measuring rainfall and temperature); life satisfaction and demographic data by (telephone) interviews.
• *Is data derived ex ante or ex post*: Ex post (empirical historical observations of both meteorological and life satisfaction data).
• *Data quality*: Good; the meteorological data is likely to be standardized; the life satisfaction data is based on a widely-used scale measure of well-being (Australian Unity Wellbeing Index).

3.11. Benefit or value transfer

Conducting valuation methods require a survey, which can be costly and time-consuming. Hence, the benefit transfer method was developed for situations in which the funds and/or time available for data collection are constrained. With this method, monetary environmental values estimated at one site (study site) are spatially and/or temporally transferred to another (policy) site. The study site(s) refers to the place(s) where the original study/ies took place, while the policy site is a new site where information is needed about the monetary value of similar benefits. The transfer can be done by simply applying a benefit estimate obtained from a similar study to the current case study (benefit estimate transfer), by inserting characteristics of the current case study into the econometric model instead of the characteristics used in the original study (benefit function transfer), and by constructing a dataset based on a larger number of previous studies and regressing environmental benefit measures against study characteristics (meta-analysis). The latter approach has the advantage that it can extend the number of variables in the primary studies with moderator variables which differ in value between the primary studies in the meta-analysis (but not within each primary study). Examples are aggregate variables like GDP/capita, population size or surface area. These moderator variables can then help to better predict for the policy site. Brouwer (2000) provides an overview of the environmental value transfer approach, discusses its potential role in cost-benefit analysis as a decision-support tool and develops guidelines for its proper application. He argues that this method often results in substantial transfer errors, which could be diminished if one would follow strict guidelines for quantitative adjustment mechanisms, especially taking into account differences in the very nature of the values elicited (such as, the diversity of motivations underpinning valuations or the historical-cultural and policy context in which they are elicited).

Example:

Martin-Ortega J. and A. Markandya (2009), “The costs of drought: the exceptional 2007-2008 case of Barcelona”, BC3 Working Paper Series 2009:09.

• *Explanation*: This study is part of the 7th EU Framework Program Project XEROCHORE: An Exercise to Assess Research Needs and Policy Choices in Areas of Drought, a support action to the European Union aimed at contributing to the design of a road map towards a European Drought Policy by identifying research gaps. The information on which this study is based comes from different available sources and is analyzed and interpreted in the context of the socio-economic costs of drought in Europe. Direct, indirect and intangible costs of the 2007-2008 droughts in Barcelona are being valued. In this context, a benefit transfer approach has been applied, based on public's willingness to pay for the estimation of the environmental costs of the drought event, through a value transfer exercise. The value estimates of the droughts' environmental costs in this case were transferred from a choice experiment that was applied by the AquaMoney project in the Serpis river basin (Jucar river basin district) in Spain. The research came up with the aggregate estimates of environmental costs of the drought in Barcelona of 127.89 - 207.61 million € per year and of costs due to restrictions of water supply in households of 594.19 million € per year. This adds up to the total non-market costs due to drought of 722.09 – 801.81 million € per year. Summing up direct, indirect, and non-market costs, the total estimated cost of drought event in Catalonia was 1,661 billion € on a yearly basis.[1]

• *Cost types addressed*: Intangible costs (welfare losses due to the worsening of the environmental quality and water supply restrictions for households).

• *Objective of the approach*: The aim of this study is to contribute to further research on the estimation of the costs of drought (especially at the European level) that needs to be embedded into the assessment of the costs of adaptation to climate changes.

• *Impacted sectors*: The non-market welfare losses occurred as a consequence of the drought, including: a) those related to the decrease of the ecological status of the river basin due to the lowering of water flows (reduction of the provisioning of ecosystem services) and b) those related to the social welfare losses due to the restrictions of water supply in the households for secondary uses (outdoor use, use of washing machines, etc.).

• *Scale*: Region of Catalonia in Spain; Time scale: 20 months, from April 2007 to January 2009.

• *Effort and resources required*: Medium as no surveys are needed, but high if done using meta-analysis of primary studies (coding primary studies is difficult, requires experience and expert judgment, and is very laborious).

• *Expected precision (validity)*: Reasonable.

• *Is the method able to deal with the dynamics of risk?* Yes, to a limited extent. It primarily depends on the range of primary study/ies. If cost-assessment of future risks using benefit transfer means that one can remain in the range spanned by primary studies the results will be more reliable (a kind of interpolation) than when one has to move outside this range (a kind of extrapolation).

• *Skills required*: Social science skills (familiarity with environmental valuation techniques).

• *Types of data needed*: Values of the same environmental good or service conducted by previous studies in a similar context.

• *Data sources*: Previous studies using valuation techniques for the same environmental good or service.

• *Who collects the data*: Scientists.

• *How is the data collected*: Reviewing the existing studies.

[1] Note that the estimates correspond to a one-year period, although the drought lasted for 20 months. Hence, the total costs of drought are actually much higher.

- *Is data derived ex ante or ex post*: Depends on the original valuation study from which the data is taken.
- *Data quality*: Depends primarily on the quality of the original survey and its econometric analysis. If the original study is conducted properly, data quality should be rather good.

Table 3 presents a comparative overview of some key characteristics of different methods for assessing drought costs.

Table 3. Overview of the main characteristics of drought cost assessment methods

	Characteristics / Method	**Type of method**	**Complementarity between methods**	**Type of drought cost addressed**	**Expected precision**	**Ability to incorporate future climate change risks**	**Is data derived ex ante or ex post?**	**Types of data needed**	**Data sources**	**Effort and resources required**
1.	**Market prices, production function, avoided costs, replacement or repair costs**	Market valuation techniques	Market valuation methods are often substitutes for one another	Direct and indirect	Good	Yes	Ex post	Prices and quantities of goods and services sold and bought in markets; production function (output and parameters of production factors); avoided cost (difference between actual cost and potential cost without improvements); cost of replacing or repairing a good or service	Markets for a good or service; private companies; statistics office; government agencies; researcher's estimates	Medium
2.	**Assessing effects on GDP and agricultural production**	No clear category	Can use results of methods 5, 6 & 7 as inputs	Direct and indirect (very limited) costs	Poor	Unclear	Ex post	Share of agriculture in GDP and fall in agricultural GDP due to drought	Statistics office	Low
3.	**Input-output analysis**	Systems approach	Substitute for method 4	Especially useful for indirect costs	Good (depending, among others, on sector disaggregation)	Yes	Both	Input-output tables	Statistics office	Medium
4.	**Computable general equilibrium analysis**	Systems approach based on a market(s) model	Substitute for method 3. Can use results of methods 5, 6 & 7 as inputs	Especially useful for indirect costs	Good (depending, among others, on disaggregation level)	Yes	Both	Input-output tables, matrices of trade, taxes, input factors, stock changes, various elasticities, etc.	Statistics office; researcher's estimates; estimates from the literature	High
5.	**Biophysical-agro-economic modeling**	Integration of physical and economic models	Substitute for methods 6 & 7	Direct and (some) indirect costs	Good	Yes	Both	Biophysical (soil, erosion, crop yield, climatic) and socio-economic data	Previous research; FAO; meteorological office; statistics office	High
6.	**Coupled hydrological-economic modeling**	Integration of physical and economic models	Substitute for methods 5 & 7	Direct, (some) indirect and (some) intangible costs	Good	Yes	Ex ante	Hydrologic and economic data	Previous research; water providing companies; water resource management; statistics office	High
7.	**Ricardian hedonic price modeling**	Revealed preference method	Substitute for methods 5 & 6	Direct costs	Reasonable	No	Ex post	Meteorological data, land/farm values and characteristics. economic data	Meteorological office; census or survey; statistics office	Medium
8.	**Contingent valuation**	Stated preference method	Substitute for methods 9 & 10	Intangible costs	Reasonable	Yes	Ex ante	Stated willingness to pay, demographic and socio-economic data, preferences, environmental conditions	Questionnaire; statistics office; meteorological office	High

9.	**Choice experiments**	Stated preference method	Substitute for methods 8 & 10	Intangible costs	Good (although difficult to execute well)	Yes	Ex ante	Goods/services with different attributes and prices, demographic and socio-economic data	Questionnaire; statistics office	High
10.	**Life satisfaction analysis**	A sort of stated preference method (eliciting subjective well-being)	Substitute for methods 8 & 9	Intangible costs	Reasonable (little experience so far and therefore also difficult to judge)	Possibly yes, but hypothetical situations not addressed yet with this method	Ex post	Meteorological data, individual life satisfaction and demographic data	Meteorological office; surveys on life satisfaction, wellbeing or quality of life	High if data have to be generated through questionnaires; Medium if data already exists
11.	**Benefit or value transfer**	An aggregation or transfer of previous primary studies	Substitute for stated or revealed preference methods 7, 8 & 9, and possibly also 10	Intangible costs	Reasonable (depends partly on availability of good similar previous studies)	Yes, to a limited extent (depending on the range of primary studies)	Depends on the original study	Values of a similar environmental good or service obtained by previous studies in a similar context	Previous studies using valuation techniques for the same environmental good or service	Medium (High if done using meta-analysis of primary studies)

4. Drought mitigation and adaptation policies[2]

4.1. Risk assessment of droughts

We are not aware of the existence of official guidelines for the assessment of drought risks (including its costs and benefits). However, there are data and information systems that can help policy- and decision-makers to assess the risks of droughts, including early warning systems.

Several metrics have been developed to assess severity of drought, although no universal measures can be adopted since drought is a relative concept and depends on the local climate characteristics and socio-environmental conditions. The indices are mainly based on precipitation, soil moisture, and hydrological data (streamflow, groundwater, reservoir or lake levels). An overview of the commonly used indicators of drought is offered in Kallis (2008), Hayes (2006), Redmond (2000), and Heim (2000). In line with the earlier noted diversity of drought definitions, it is not possible to come up with a single, universal drought metric because it is problem, context and user specific. This explains why one can find precipitation-based, hydrological and water supply drought indicators. Precipitation indicators have the advantage of not being influenced by human or environmental factors. The main precipitation indicators include days of rain, percent of average rainfall (runoff or streamflow), and Standard Precipitation Index. Other commonly used indicators are Vegetation Condition Index, total water deficit, and days of water supply remaining. Probably the most widely used drought indicator is Palmer Drought Severity Index, which combines data on rainfall, temperature, evapotranspiration, soil moisture, and runoff.

Most countries are monitoring rainfall, reservoir levels and volume, flow data, and quantity and quality of both surface and groundwater. Safety levels of hydrological drought are usually based on the reservoir levels. To illustrate, for Spain these include pre-alert stage, exceptional status 1 (when reservoir levels drop to 40%), exceptional status 2 (reservoir levels at 23%), and emergency stage (reservoir levels at 20% or below), as reported in Martin-Ortega and Markandya (2009). Desalinization capacity can also serve as an indicator of resilience to hydrological drought.

Rainfall data is usually collected by meteorological services. In Catalonia, the rest of the above-mentioned data is collected mainly by the Catalan Water Agency, with the exception of hydrological data and the state of reservoirs in the Ebro River Basin, which is provided by the Hydrographical Confederation of the Ebro.

On a European scale, a European Drought Observatory with the aim of drought forecasting, assessment and monitoring is currently being developed by the Joint Research Centre's Action DESERT edo.jrc.ec.europa.eu/php/index.php?action=view&id=36 and EuroGEOSS www.eurogeoss.eu/default.aspx.

In the United States the U.S. Drought Monitor, www.drought.unl.edu/dm/monitor.html, and National Integrated Drought Information System, www.drought.gov/portal/server.pt/community/drought_gov/202, have developed an early warning

[2] Even though the terms mitigation and adaptation to climate change are often used jointly, they denote different issues. Mitigation can be defined as a risk reduction, while adaptation refers to the adjustments made to a given risk. The former conists of actions taken ex ante, while the latter can include both ext ante and ex post measures. IPCC (2001a) provides its own definitions of mitigation and adaptation to climate change. Differences and similarities between these two terms are discussed in Section 18 of IPCC (2007b) . A third notion that is frequently used when referring to climate change is coping. Sometimes it is used in the context of coping capacity or coping mechanism/strategies and sometimes the term is used as a synonim for adaptation.

system based on integrated drought monitoring and forecasting to provide accurate, timely, and integrated information. The U.S. Drought Monitor (see Figure 2) provides a weekly overview of where in the United States drought is emerging, lingering, subsiding or forecast. The map uses a new classification system to show drought intensity and type, similar to the schemes currently in use for hurricanes and tornadoes. The map combines key indices of rainfall and drought to produce the final drought intensity rating. Since drought often affects various activities differently, the map indicates whether drought is affecting agriculture, fire danger, or water supplies.

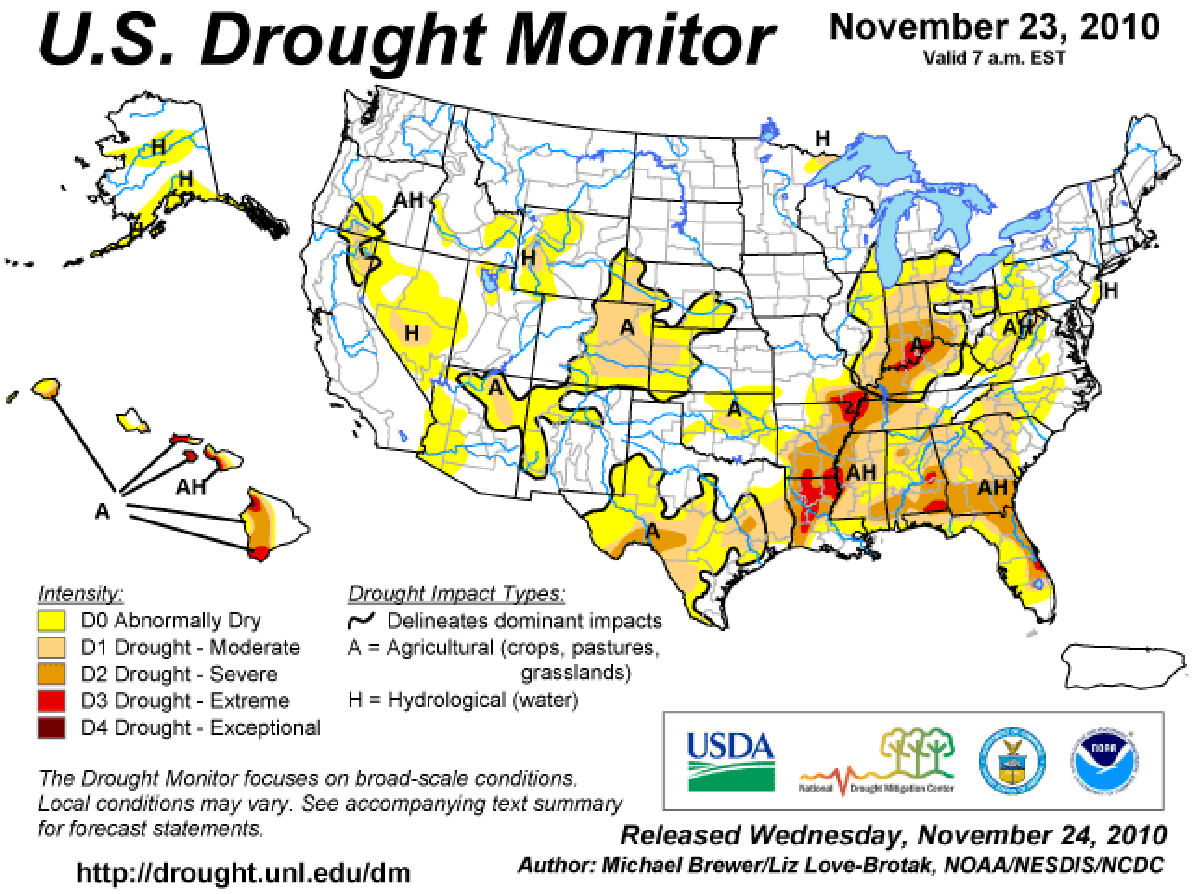

Figure 2. The U.S. Drought Monitor for the week of November 24th, 2010.

Source: The U.S. Drought Monitor, drought.unl.edu/dm/monitor.html

Legend: Drought Intensity Categories

D0 - Abnormally Dry

Used for areas showing dryness but not yet subject to drought, or for areas recovering from drought. Possible impacts of (a) going into drought: short-term dryness slowing planting, growth of crops or pastures, (b) coming out of drought: some lingering water deficits; pastures or crops not fully recovered.

D1 - Moderate Drought

Possible impacts: some damage to crops, pastures; streams, reservoirs, or wells low, some water shortages developing or imminent; voluntary water-use restrictions requested.

D2 - Severe Drought

Possible impacts: crop or pasture losses likely; water shortages common; water restrictions imposed.

D3 - Extreme Drought

Possible impacts: major crop/pasture losses; widespread water shortages or restrictions.

D4 - Exceptional Drought

Possible impacts: exceptional and widespread crop/pasture losses; shortages of water in reservoirs, streams, and wells creating water emergencies.

Drought or Dryness Types

A ... Agricultural (crops, pasture, grasslands)

H ... Hydrological (water)

Drought intensity categories are based on five key indicators (see Table 4) and numerous supplementary indicators. The accompanying drought severity classification table shows the ranges for each indicator for each dryness level. Because the ranges of the various indicators often do not coincide, the final drought category tends to be based on what the majority of the indicators show.

Table 4. Drought Severity Classification used by the U.S. Drought Monitor

Drought Severity Classification						
		RANGES				
Category	**Description**	**Palmer Drought Index**	**CPC Soil Moisture Model (Percentiles)**	**USGS Weekly Streamflow (Percentiles)**	**Standardized Precipitation Index (SPI)**	**Objective Short and Long-term Drought Indicator Blends (Percentiles)**
D0	Abnormally Dry	-1.0 to -1.9	21-30	21-30	-0.5 to -0.7	21-30
D1	Moderate Drought	-2.0 to -2.9	11-20	11-20	-0.8 to -1.2	11-20
D2	Severe Drought	-3.0 to -3.9	6-10	6-10	-1.3 to -1.5	6-10
D3	Extreme Drought	-4.0 to -4.9	3-5	3-5	-1.6 to -1.9	3-5
D4	Exceptional Drought	-5.0 or less	0-2	0-2	-2.0 or less	0-2

Source: The U.S. Drought Monitor, www.drought.unl.edu/dm/classify.htm

4.2. Climate change and droughts

Future climate change will strongly affect drought-related events and impacts. For this reason, in this section we provide an overview of the studies which predict climate change and its impact on droughts.

The IPCC assessments from 2001 and 2007 discuss expected future climate changes which are relevant to droughts. First, there is high confidence that precipitation variability and associated drought risk will increase in many areas (IPCC, 2007b). Moreover, there is a very high confidence about the world regions that will experience increasingly drier conditions. Runoff in the Mediterranean, southern Africa, western United States/northern Mexico, and north-eastern Brazil will decrease 10% to 30% by the end of the century (IPCC, 2007b). Freshwater availability in coastal areas that depend on groundwater or estuary water will decrease, which will increase the likelihood of water supply shortages. The IPCC's (2001b) climate change scenarios suggest significant summer drying across many parts of Europe, particularly in the Mediterranean basin, with increased number of hot days. It also predicts lower rainfall in some areas in spring and autumn, higher variability in winter rainfall, an increase in the average summer temperature between 2 and 6˚C, and more intense evaporation. Based on the combination of factors, the IPCC (2001b) concludes that over the next 100 years Europe is likely to suffer more frequent meteorological droughts, especially in the south.

The European Commission (2009) recognizes in the White Paper on climate change adaptation that climate change will cause significant changes in the quality and availability of water resources, affecting many sectors including food production. Namely, more than 80% of the agricultural land is rain-fed, while the rest also depends on available water resources for irrigation. This White Paper further states that limited water availability already poses a problem in many parts of Europe and that it is likely to deteriorate in the future due to climate change. Europe’s high water stress areas are expected to increase from 19% today to 35% of total area by 2070. This in turn could cause large scale migration.

The UK’s Met Office Hadley centre projects a doubling of global increase in land area under drought by 2100, or 25% by 2030 (Dlugolecki, 2007). Based on this information, Dlugolecki (2007) estimates losses due to climate change in 2030 according to hazards and regions, and scales them to the GDP change by that date. Hazard typology used in this report include storms, floods and other, which comprise wild-fire, drought and heat- and cold-wave events. For Europe, he predicts that water stress will increase from 19 to 35% of land area in 70 years, giving an increase of (25/70)x(35/19) by 2030. Applying this figure to half of the losses results with a loss increase of 33%. Accordingly, the projected annual losses in Europe due to 'other' extreme events, including droughts, are estimated at 4.31 billion USD (in 2006 values) in 2030.

OTA (1993) reports the result of Global Climate Models, which indicate that global precipitation could increase 7–15%. Meanwhile, global evapotranspiration could increase 5–10%. Thus, the combined impacts of increased temperature, precipitation, and evapotranspiration will affect snowmelt, runoff, and soil moisture conditions. The models generally show that precipitation will increase at high latitudes and decrease at low and mid-latitudes. Therefore, in mid-continent regions, evapotranspiration will be greater than precipitation so that these areas may suffer from more severe, longer-lasting droughts. In addition, the increased temperatures alone will cause the water in the oceans to expand, causing an estimated sea level rise of 20 cm (8 in) by 2030 (OTA, 1993).

Whetton et al. (1993) assess the implications of climate change for drought occurrence in Australia. This is undertaken using an off-line soil water balance model driven by observed time series of rainfall and potential evaporation to determine the sensitivity of the soil water regime to changes in rainfall and temperature, and hence potential evaporation. Potential impacts are assessed at nine sites, representing a range of climate regimes and possible climate futures, by linking this sensitivity analysis with scenarios of regional climate change. The latter are derived from five general circulation models which perform an enhanced greenhouse experiment (doubled concentration of CO_2 in the atmosphere). The results indicate that significant drying may be limited to the south of Australia. However, because the direction of change in terms of the soil water regime is uncertain at all sites and for all seasons, there is no basis for statements about how drought potential may change. A more recent study on Australia (IPCC, 2007b) shows that a tendency for decreased annual rainfall is likely for most of southern and sub-tropical Australia, while a tendency for increases is more likely in Tasmania, central Northern

Territory and northern NSW. Projected changes in rainfall and evaporation have been applied to water-balance models, indicating that reduced soil moisture and runoff are very likely for most of Australia (IPCC, 2007a). Up to 20% more droughts (defined as the 1-in-10 year soil moisture deficit from 1974 to 2003) are simulated over most of Australia by 2030 and up to 80% more droughts by 2070 in south-western Australia (Mpelasoka et al., 2007).

The study of Sheffield and Wood (2008) uses soil moisture data for three different future climate scenarios. Under the future projections, the models show decreases in soil moisture globally for all scenarios with a corresponding doubling of the spatial extent of severe soil moisture deficits and frequency of short-term (4–6-month duration) droughts from the mid-twentieth to the end of the twenty-first century. Long-term droughts become three times more common. Regionally, the Mediterranean, west African, central Asian and central American regions show large increases most notably for long-term frequencies as do mid-latitude North American regions but with larger variation between scenarios.

Le Houérou (1996) provides a review of historical fluctuations and trends in rainfall and temperature in desert, arid, semi-arid and dry sub-humid lands of the world, analyses the impacts of possible warming, and discusses mitigation strategies through improved land-use and management practices.

4.3. Drought prevention, mitigation and adaptation measures

Two main types of government responses to drought can be distinguished: pre-impact interventions for drought impact reduction and post-impact government interventions. The former set of measures represents risk management because the undertaken measures are proactive, being aimed at mitigating the future effects of drought, increasing coping capacity and building resilience. The examples of such measures include development of an early warning system, preparedness plans, increased water supply, demand reduction (such as water conservation programs), and crop insurance. The latter, post-impact government interventions, exhibit crisis management. Namely, such programs are reactive since measures are implemented after a drought occurs and focus on treating the symptoms, but not the causes of the natural hazard. These include drought relief funds, low-interest loans, transportation subsidies for livestock and livestock feed, provision of food, water transport, and drilling wells for irrigation and public water supplies (Wilhite, 2000). The latter drought management approach has been criticized by scientists, government officials, and many relief recipients as inefficient, ineffective and untimely (Wilhite, 1993). In addition, the provision of emergency relief has been criticized as being a disincentive to the sustainable use of natural resources because it does not foster self-reliance (Bruwer, 1993; White et al., 1993). Such measures can actually increase vulnerability to droughts as well as other natural hazards. For this reason, it is more recommendable to put an emphasis on proactive mitigation programs aimed at reducing vulnerability to and thus the future impacts of droughts. In addition, cost-benefit analysis of risk and crisis management (measures) in the context of droughts may be useful.

The following list presents an overview of the most commonly used measures for drought prevention, mitigation and adaptation. The first six measures are considered proactive as they reduce risks or enhance preparedness, while the last three measures are reactive since they are implemented in response to drought.

- Developing and improving drought prediction, monitoring and early warning systems - continuous observation of rainfall levels and comparisons with current usage levels, improving data collection and availability
- Augmenting water supply and developing new water supply infrastructure – rehabilitating reservoirs, dams and transfers, desalination, lowering water pressure of the water supply system, conservation demand management, leakage control, wastewater reclamation, improved supply efficiency, water recycling and reuse
- Water demand reduction or conservation programs – establishing drought stage triggers and defining the measures to be implemented during each stage (e.g. rationing, use of lower-quality water, water transfers), putting the right price tag on water
- Improving land-use by agriculture – e.g. crop diversification and crop rotation can allow farmers to plan less water-dependent crops in drier years
- Raising public awareness and education programs – keeping the public aware of the severity of the situation through mass media campaigns; distribution of pamphlets to individuals, businesses and municipalities on water conservation techniques; school education programs
- Developing drought contingency plans – establishing a response framework including a drought risk management and mitigation plan
- Emergency response programs – defining alert procedures, developing drought relief and technical assistance programs, establishing funds for recovery programs
- Rainwater storage - collection of rainwater from roofs
- Weather control – seeding clouds with chemicals to induce rainfall

Workshop participants pointed out that more attention should be given to developing measures that ensure (the recovery of) good environmental conditions (e.g. wetlands, aquifers) and more flexible water concession systems (such as exchanging centers and assignment contracts in Spain, which enable buying water rights from the agricultural sector for urban uses). In addition, establishing an insurance system against droughts and increasing water recycling were considered potentially important mitigation measures.

Insurance against droughts

Insurance against droughts also represents a proactive and desirable measure for drought adaptation. However, in most countries worldwide, there are no insurance policies against damage resulting from drought. Although a crop insurance against adverse weather conditions exists, crop losses as a result of heat waves and drought are still largely uncovered by insurance in the European Union, implying that these costs are born by the agricultural sector. According to Dlugolecki (2007), the problem is that the traditional crop insurance is not commercially viable anywhere. Farmers understand their risks so well that only high-risk ones insure (anti-selection), and the costs of monitoring crops at field level is high. Hence, a pure private market insurance may be difficult to establish due to problems with covariate risks, affordable insurance, moral hazard, and ambiguity of risk, as in the case of floods (Freeman and Kunreuther, 2003). An involvement of the government in providing reinsurance capital is likely to be a necessary condition to implement flood insurance (Botzen, 2010). The same holds for droughts. However, there are few pilot programs, limited to the USA, several African countries, and India.

In the USA a three-year pilot program involves rangeland insurance, which is currently available in nine states: Oklahoma, Colorado, North Dakota, South Dakota, Pennsylvania, South

Carolina, Idaho, Oregon and Texas. There are 16 private insurance companies which offer voluntary rangeland insurance to ranchers in case they don't get enough rain.

The World Food Programme (WFP) signed a contract in March 2006 with Axa Re for a payout of 7 million USD in the event of a severe drought in the subsequent year to Ethiopian farmers. Insurers were prepared to take on the risks because advances in technology meant it was easier to predict factors like rainfall. The premium for one year is 930,000 USD and has been met by a small group of donors, including the United States, together with the Ethiopian government (Dlugolecki, 2007).

In 2007 Swiss Re (a private re-insurance company) launched derivative contracts protecting three village clusters situated in Sauri (Kenya), Tiby (Mali), and Koraro (Ethiopia). Under the agreement Swiss Re would provide up to 2 million USD of financial protection in the case of extreme drought. The contracts protect smallholder farmers against drought-related livelihood shocks such as food shortages and famines.

In addition, since 2003, rainfall insurance policy was launched in rural India and offered to smallholder farmers. Since then, there have been many improvements. A key development was the partnership between BASIX, an Indian micro-finance institution, The World Bank’s Commodity Risk Management Group, and private insurers. The pilot insurances in 2003 and 2004 were on a small scale and a major expansion took place in 2005. The product was then no longer crop-specific, but focused on district as the risk factor. Over 7,000 policies were sold, and other insurance companies and agents followed suit. However, the growth may be limited by the availability of weather data. Insurance for non-farming activities could also take off. The premium rates are not low, at between 5 and 12% of the sum insured, but experience shows that insurers will not participate unless the scheme is viable, and clients are willing to pay if the claim settlement process is fast and fair. The insurer identified three barriers: better weather data will reduce basis risk for clients and encourage improved reinsurance rates; automatic reinsurance is needed to permit greater flexibility in writing new contracts and portfolios; and the government should revise its subsidy policy for yield-insurance products, as the current policy undermines the weather insurance market (Dlugolecki, 2007).

It might be also worth mentioning that Munich Re (another private re-insurance company) has proposed a crop insurance system called SystemAgro, which would secure farmers regardless of the exposure they face and would be based on a public private partnership. This insurance system would take into account a predicted increase in extreme weather conditions due to climate change, including droughts. The proposal can be found at http://www.munichre.com/app_pages/www/@res/pdf/reinsurance/business/non-life/systemagro/sustainable_crop_insurance_en.pdf.

4.4. Costs of drought prevention, mitigation and adaptation measures

Costs related to monitoring and early warning systems mainly include research and development, engineering, investment and maintenance costs. These types of (direct) costs usually relate to physical impacts that are associated with market prices, which makes their assessment rather easy and straightforward. Land-use planning often involves costs because it can distort land market values, in two ways - when authorities do not acquire land at its equilibrium market price, and when sudden shortages in the supply of land are created which disrupt a well-functioning market. Construction of new infrastructure for increasing water supply not only goes along with direct market costs, but also can have detrimental impacts on social welfare due to their impacts on land fragmentation and aesthetics. As a counterpart, they are also a potential source of benefits by allowing for additional recreational activities or tourism. All these non-market costs and benefits can be captured by both stated and revealed preference techniques, as explained in Section 3.

It is generally agreed that mitigation and preparedness are key to reducing future drought risks. However, government officials are often reluctant to allocate money and resources to mitigation because of limited information on the costs and benefits of drought mitigation programmes (Ding et al., 2010). There are very few studies that try to assess the costs of drought prevention, mitigation or adaptation measures. Some of them include Michelsen and Young (1993), Woo (1994), Fisher et al. (1995), Pattanayak and Kramer (2001a; 2001b), Morton et al. (2005), and Grafton and Ward (2008).

It is considered useful to compare the costs of drought mitigation and adaptation measures with both the costs of drought prevention and the costs of potential or historical drought. The former should also include transaction costs of enforcing a new policy. This kind of analysis can shed light on the existing practices (e.g. in agriculture) and their cost-effectiveness. For example, it might prove to be less costly to invest into an irrigation system than to subsidize farmers or offer them a drought relief programme. The US Federal Emergency Management Agency (FEMA) estimated that the country will save at least two dollars on future disaster costs from every dollar spent on mitigation (Natural Hazards Observer, 1996).

4.5. Drought legislation in the EU

Even though there is still no European Drought Policy, the European Commission (2007b) adopted a “Communication on Water scarcity & droughts” in 2007. Moreover, Member States had to prepare the River Management Plans and some of them also developed Drought Management Plans based on national requirements. The Water Framework Directive (WFD) is the most relevant existing European policy related to droughts issues. It emphasizes river basin integrated water resource management and string involvement of stakeholders.

Apart from this, a Support Action project XEROCHORE is aimed at assisting in the development of a European Drought Policy in accordance with the EU-Water Framework Directive, http://www.feem-project.net/xerochore/. This illustrates that drought policy is not yet very much developed, especially in comparison with other hazard types. A book of Correia (1998) is a result of a research project EUROWATER, which aimed at contributing to a better understanding of the institutional framework of water management in Europe. The analysis covers a limited set of countries, namely France, Germany, the Netherlands, Portugal and the United Kingdom.

All this provides a good basis for European drought mitigation, but there is still much more left to be done. For example, the report of European’s Network of Freshwater Research Organisations EurAqua (2004) suggests that at European scale the EU lags behind other industrialized countries with respect to drought policies and planning, for three reasons. The first one is the lack of the European Drought Policy. Secondly, it indicates that the WFD supports more sustainable water abstraction regimes, but some of its provisions are not fully consistent with good drought mitigation practices. It also noted that in some respects the WFD treats droughts as a crisis which triggers exemptions, rather than a risk to be managed and mitigated. The third reason is that drought receives scant attention in many areas of European policy. Namely, it is argued in the report that in agricultural policy, drought is rarely mentioned despite haying major direct impacts. In fact, the Common Agricultural Policy supports water intensive practices in regions with high water stress and vulnerability to future droughts. The European forest policy, energy policies, transport policy, or tourism policy do not mention droughts or their impacts within these specific areas, even though they are likely to be affected by droughts. It is therefore necessary not only to have a European drought policy in the near future, but also to incorporate drought-specific issues in a wider set of European policies.

4.6. Cooperation in coping with droughts

Cooperation at various scales is needed as water flows, hydrological systems and drought problems are not limited to local, regional or political boundaries. Hence, cooperation between different countries, agencies, and stakeholders is important in coping effectively with droughts. Cooperative actions will be much more effective if agreed upon before any crisis. There is a lot of reporting on specific regional or national drought planning initiatives, but very little on the operation and effectiveness of existing plans. Only a few studies show that drought planning is not as effective when detached from other development and environment decision-making processes, which is unfortunately often the case (Kallis, 2008). Cooperation mechanisms for drought risk reduction between countries include the following international organizations:

- European Drought Centre, http://www.geo.uio.no/edc/, is a virtual centre of European drought research and drought management organizations to promote collaboration and capacity building between scientists and the user community. The long term objective of the centre is to enhance European co-operation in order to mitigate the impacts of droughts on society, economy and the environment.
- UNCCD (United Nations Convention to Combat Desertification) entered into force in 1996 and 183 countries were parties by 2009. The convention is fostering international cooperation through the collection, analysis and exchange of information, research, technology transfer, capacity and awareness building, and providing financial assistance, especially from developed to the affected countries. In addition, country parties affected by desertification in Africa, Asia, Latin America, Caribbean and Northern Mediterranean have to prepare national action programmes and cooperate at the regional and sub-regional levels.
- WMO (World Meteorological Organization) established a Disaster Risk Reduction Programme with the aim of observing, detecting, monitoring, predicting and early warning of weather, climate and water-related hazards. It was founded in 2003 and has 188 members.
- NEMEDCA is a Network on drought management whose main objective is the international cooperation on drought management plans in the Near East, Mediterranean and Central Asia. It is supported by the International Center for Agricultural Research in the Dry Areas (ICARDA), the Food and Agriculture Organization of the United Nations (FAO) and the International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM).
- CILSS - Comité Inter-Etate pour la Lutte contre la Sécheresse au Sahel (Permanent Inter-State Committee for Drought Control in the Sahel).
- IGADD. The Intergovernmental Authority on Development (IGAD) in Eastern Africa was created in 1996 to supersede the Intergovernmental Authority on Drought and Development (IGADD) which was founded in 1986 by six countries in the Horn of Africa - Djibouti, Ethiopia, Kenya, Somalia, Sudan and Uganda. The State of Eritrea became the seventh member after attaining independence in 1993.

- SADC – South African Development Community. Among many other fields of cooperation, this organization covers the area of environment and land management. It has established drought monitoring centre for South African countries.

Apart from these, cooperation between countries to deal with drought issues can also be established through (existing) international river basin commissions, e.g. for the Mekong River see Hundertmark (2008).

5. Recommendations and knowledge gaps

5.1. Recommendations and best practices regarding methods for cost assessment of droughts

5.1.1. Direct costs

Which are good practice approaches and why?

In our opinion, the most suitable methods for assessing direct tangible costs of droughts include market valuation techniques, namely market prices, production function, avoided costs, replacement or repair costs. They can be applied to any economic sectors, are relatively easy to apply and yield rather precise estimates. Computable general equilibrium (CGE) analysis and the input-output analysis can also serve for estimating direct costs, although they are more demanding than the market valuation techniques and are more frequently applied to estimate indirect and direct costs jointly rather than direct costs alone. Biophysical-agroeconomic modeling is a quite complex method and provides an in-depth analysis of agricultural markets, but its drawback is that it is limited to the agricultural sector. The same holds for Ricardian hedonic price modeling, which focuses on agriculture. Nevertheless, usually the largest share of the direct costs caused by droughts is experienced in the agricultural sector. In such cases, these approaches represent a good practice. Coupled hydrological-economic modeling is limited to assessing drought costs which are directly related to water use. The different methods could hence function in a complementary way, where the biophysical-agroeconomic and Ricardian hedonic price modeling approaches would provide more detail and possibly an input to CGE analysis, meaning that the first two focus more on direct and the latter on indirect costs.

What are the disadvantages of approaches for estimating direct drought costs?

In our opinion, the approach that assesses the costs of droughts by observing a decline in GDP and agricultural production in a drought year is not a very clear method. In particular, the assumptions underlying this approach are not well explained, i.e. they remain implicit. This means that it is difficult if not impossible to say something specific about the advantages or disadvantages of this approach. It may in fact be based on different methods, including simple extrapolation based on past correlations, macroeconomic or CGE modeling, a very simple conceptual model (like the study of Benson and Clay, 1998, discussed in Section 3.2), or even "intuitive guestimation". In the first and last cases, when explaining a change in GDP and in agricultural production only by drought, relevant factors and complex interactions within the economy are likely omitted, in which case this approach provides an unreliable estimate of drought costs. On the other hand, if based on a good model, this approach can yield solid estimates. In any case, without providing sufficient details about the particular method used, results of studies in this vein should be treated with care.

5.1.2. Indirect costs

Which are good practice approaches and why?

Of all the approaches for assessing indirect costs of droughts presented in this report, we consider computable general equilibrium (CGE) analysis as the most complete method because it takes all sectors and markets of the economy into account. This approach actually may use some direct impacts as an input for estimating indirect costs. Thus, it is particularly useful for estimating indirect costs. Its development and application to drought issues requires possibly adaptation for, i.e. particular attention given to, sectors that directly feel the impacts of a drought, such as agriculture, forestry and health. General-purpose CGE models may be unsuitable to assess the costs of drought without such adaptation. As indirect costs might as well be estimated using a less demanding approach, a tradeoff between the advantages and the effort required to apply this method should be carefully considered. For example, the input-output analysis is simpler, although somewhat less precise as it does not take into account the substitution effects of production factors, market effects (price elasticities), and demand-supply interactions. It also enables assessment of economy-wide effects and is expected to yield rather good estimates of the order of magnitude of indirect effects. Both types of approaches will be more precise and reliable if resource-based (water-using) sectors like agriculture, hydro-electricity, water transport and (drinking) water provision are well demarcated and disaggregated, and the interactions of these activities with the other activities are accurately captured in the I/O table. Other approaches are not as complete because they are limited to specific aspects of droughts, and are hence only able to assess part of the drought costs. For example, biophysical-agroeconomic modeling focuses on the agricultural sector, while coupled hydrological-economic modeling deals with costs which are directly related to water use. Some of these methods could hence be considered as complementary, with CGE analysis offering the most comprehensive approach in estimating indirect costs of droughts.

What are the disadvantages of approaches for estimating indirect drought costs?

As said in Section 3.2, assessing indirect costs of droughts by observing a change in GDP and agricultural production of a country can be used only for indicative purposes, but is unlikely to provide a reliable cost estimate. Regarding the other methods for estimating indirect drought costs, such as secondary effects on the production of various economic sectors and on the employment, their main disadvantage is that all of them demand a lot of data and good formal (and applied) modeling skills.

5.1.3. Intangible costs

Which are good practice approaches and why?

A choice between the methods for estimating intangible costs of droughts is less clear. Contingent valuation (CV) and choice experiments (CE) can be used as alternative, substitute methods for eliciting individuals' willingness to pay and are expected to arrive to similar estimates. Recently, CE has become more popular due to several advantages over CV. These include less bias because of more similarity to real market situations (notably, price as one of many attributes of a good), the ease of estimating values of single attributes of an environmental resource, avoidance of part-whole bias problem since different levels of the good can be easily built into the experimental design, and avoidance of yea-saying in the case of double-bounded dichotomous choice in CV. However, there are also some drawbacks to CE. The technique is much more demanding for respondents to answer, preferences may be inconsistent in the experiment, the design of a CE is a non-trivial task, and its incentive properties are unclear.

Life satisfaction analysis can be regarded as a substitute approach to both CV and CE. Nevertheless, CV and CE are often used for calculating hypothetical or future changes, while life satisfaction analysis has not yet been applied to a hypothetical situation – only to current or historical situations. However, there seems to be no fundamental obstacle against using life satisfaction analysis in a hypothetical setting as well (even though it is not sure to receive an enthusiastic response from the happiness research community). This approach thus resembles stated preference methods in the sense that happiness scores have to be stated by respondents, while it shares with revealed preference methods a focus on actual, realized (policy) changes.

What are the disadvantages of approaches for estimating intangible drought costs?

We do not consider any of the approaches presented for estimating the intangible costs of droughts as an example of a bad practice.

5.2. Recommendations and best practices with respect to drought mitigation and adaptation policies

An important measure pointed out by policy makers is the recovery of good environmental conditions (e.g. recovery of wetlands and aquifers), which enables resilience of the system to droughts. This implies that environmental policy plays a substantial role in the mitigation of droughts. Another recommended approach for drought mitigation is the establishment of exchanging centers and assignment contracts for water use rights. These two market options were recently introduced in Spain inspired by the Water Bank experiences in the US. Through exchanging centers the water authorities can make takeover bids of concession rights to water in order to reallocate them or to recover a sustainable rate of use. So, in the case of anticipated or increasing water shortages water authorities can buy concession rights on water for irrigation from farmers and reallocate it to urban users. In this way, agriculture can serve as a buffer when a drought occurs, absorbing a great part of the drought risk. Nevertheless, in order for such centers to operate efficiently it is necessary to estimate correctly the sacrificed profits, including environmental and opportunity costs. Also, it is important to do this well in advance of a drought, as otherwise the negotiating power of the government is small. Stakeholders have also mentioned that it is desirable to establish good drought mitigation through insurance (primarily crop insurance), because it is otherwise too expensive to guarantee water supply or compensate for the losses cause by droughts. They further see a substantial potential in water recycling and reuse. Here, there should be a shift in paradigm, meaning that different water qualities would be provided for different uses. In general, it is of crucial importance to have a legal framework that is strong enough to ensure the implementation of relevant, required mitigation and adaptation measures.

Most of the approaches for reducing drought risks and impacts represent good practices. These include improving drought prediction, monitoring and early warning systems, water demand reduction and conservation programs (e.g. though rationing or water pricing policy), improving crop water use through crop selection and diversification, raising public awareness, and developing drought contingency and emergency response plans. These are all complementary measures, so each one helps in reducing different risk types and are important at different stages of drought evolution. Hence, it is recommendable to use a combination (set) of measures instead of focusing on one of them. Combining different measures ensures better risk distribution and has a synergetic value. Furthermore, drought mitigation and adaptation measures should be based on modularity, i.e. they should be adapted to the particular region or territory, implying that there is no unique solution or recommendation that would be valid everywhere. For this reason, it is recommendable to conduct a vulnerability assessment, which tends to discover where the roots of vulnerabilities are so that mitigation and adaptation policies can be designed to cope with these.

When choosing between different policy options, multi-criteria analysis can serve as useful decision-making tool because it allows analyzing the impacts of alternative policies. Rossi et al. (2005) used this method for selecting the preferable mix of drought mitigation measures related to a water supply system in eastern Sicily, Italy. They first applied a simulation model to evaluate the effects of several drought mitigation alternatives consisting of a mix of long- and short-term measures. Next, multi-criteria analysis was applied to rank different alternatives on the basis of economic, environmental, and social criteria, taking into account preferences of the various stakeholders involved. Their results confirm the applicability of multi-criteria analysis for a transparent comparison of drought mitigation measures and its relevance as a support tool for the decision making process.

Augmenting water supply and developing new water supply infrastructure are important measures for ensuring sufficient water supply. Desalination, for instance, increases flexibility of water supply and can be seen as an insurance strategy against water supply shortages. Water transfer is another option, although in Catalonia the plan of transferring water from the Ebro River was finally rejected because it was considered that it would not work well in drought years, However, such measures might lead to reverse effects of increased water consumption and a diminished public awareness of a water scarcity problem. Weather control, i.e. cloud seeding with the aim of enhancing precipitation might be the most controversial of all drought risk-reduction approaches. Unlike the rest of approaches, it does not provide an incentive for a change in attitude or undertaking efforts for drought preparedness. More importantly perhaps, its effectiveness and safety (unintended effects) are not very clear.

With respect to the reduction of water demand, it would be recommendable to reconsider some of the existing (unsustainable) practices of water use or at least to set stricter standards for their water consumption, particularly in arid areas. Examples include numerous golf courses, swimming pools and aqua parks for tourism purposes in Mediterranean regions and intensive agriculture based on irrigation, such as in Almeria, Spain. In addition, it is important to determine priorities of water uses for periods of water shortages. In Cyprus, for instance, water availability for tourism has priority over that for agriculture during the summer months. Again, multi-criteria can be useful for these purposes.

In general, drought policy should be based on good planning. It is strongly recommendable that planners conduct a cost-benefit analysis in which damage costs of a (potential) drought are compared to the costs of mitigation and adaptation measures. When planning for a drought, one should define the goals to be achieved during a drought period. For example, guaranteeing water supply at 100% during a drought is possible, but comes at a certain cost. This means that there is a tradeoff between the level of water security and the corresponding costs and that the desirable levels should be decided upon beforehand.

A distinction should be made between short and long-term measures. Drought mitigation and adaptation policies should be set for a longer term (at least 20 years in the future) than they are at the moment. In this way, impacts of infrequent drought events are taken into account, and additionally one can incorporate the projected impacts of climate change more easily. Otherwise, no effects of climate change are 'observable' within the time frame of a plan and thus there is no incentive to invest in its prevention, mitigation or adaptation. For example, the plan for Catalonia embraces the period until 2015, but until then no serious climate change effects are expected and hence no investment is planned. Surveillance by the European Commission is considered as an effective measure in ensuring implementation of relevant plans and legislation.

In addition, it is considered important to ensure participation of local communities in decision-making and water planning, since access to water represents a basic human right and should thus not be driven by market rules. In this way, a feeling of co-responsibility may also develop, as everyone bears part of the responsibility for mitigating drought impacts, that is, not only the government. For example, the social impacts of droughts partly depend on people's tolerance, i.e. capacity to live with less water during a drought period and to change their habits.

Workshop participants identified the following criteria as the most important ones when deciding about the implementation of a drought policy: reliability, efficiency, environmental quality, equity, and risk distribution. The timing of a policy is yet another relevant factor to be taken into consideration (e.g. when to switch from supply- to demand-side policy measures). It was further noted that water planning and policies have similarities with planning and policies in transport and energy, which suggests that useful lessons may be learned from those policy areas.

5.3. Knowledge gaps

In general, there seems to be a consensus within the drought expert community on the lack of information on, and studies dealing with, the impacts of droughts, the economic assessment of drought damages, and cost estimation of drought mitigation and adaptation measures. This suggests the need for more research on these themes, particularly as some end users pointed out that economic information is crucial for good policy making.

More specifically, for assessing the costs of droughts, identified user needs include data on the opportunity costs of water, on water productivity in different sectors, on the intensity of water production of different crop types in agriculture, on damage due to drought on different crop types, on the economic value of ecosystem services, and on damage caused by subsidence of buildings. Workshop participants also reported the need for data on water consumption in agriculture, soil parameters (e.g. water-storage capacity of soil), indicators of economic damage, and establishing thresholds for different parameters and indicators. Further identified problems regarding available data for estimating drought costs comprise too general data and indicators provided by meteorological offices, agricultural or other agencies (e.g. they often use averages) while there is need for more specific and precise data at the regional or local level (e.g. crop yield estimates); international data is often not additional but merely reflects already gathered or aggregated national data; dispersion of data among various departments and institutions; lack of data comaparability between and within different departments, institutions, regions and countries; different data gathered by different agencies; and the fact that data is not always publicly available or free of charge. There is an impression by the end users that data availability and quality is inferior for eastern European countries. Finally, once the data is available, the major obstacle for cost assessment of droughts is the advanced level of expertise needed and the interdisciplinary character of the knowledge required for its execution (hydrology, agriculture, forestry, economics, etc.). Moreover, different methods and associated expertise are needed for estimating different types of drought costs, adding to the complexity of estimating the costs of droughts.

Better acquaintance with the costs would enable a more optimal pricing of water. Otherwise, if prices are not set appropriately, someone is bearing the costs unjustifiably, which could be either certain private agents or the government (and indirectly tax payers). In Barcelona there are three different pricing blocks based on water consumption. The price of the third block is approximately three times that of the first one. However, the prices are not determined on the basis of a thorough economic analysis; the price of the first block was set at the level that covers the costs of water provision, while the other blocks serve as a fines for higher than average water consumption. More insight into relevant costs could increase the optimization of water resources and their pricing. In order to achieve this, setting appropriate thresholds is quite important. It is also recommendable to enable block pricing thresholds to vary during drought periods. This means that water pricing schemes could include a 'scarcity' component, which would enable flexible reaction to hydro-meteorological conditions, with a predetermined cap agreed beforehand (Xerochore project, 2010).

It is often difficult to distinguish whether the costs of a drought are stemming from drought severity (i.e. bad weather conditions) or bad management practice (in agriculture, for instance). Hence, there is a need to investigate this issue further. Moreover, potential food shortage problems due to droughts and related mitigation and adaptation policies do not seem to have received much attention in the literature so far. There is also a need for a comprehensive cost-benefit analysis of various drought mitigation and adaptation policies.

A significant knowledge gap identified concerns the distribution of drought costs (and to a lesser extent benefits) among different economic sectors and social actors. UN (2011) indicates that social and economic impacts of droughts disproportionally fall upon poor rural households. Therefore, apart from the level of the costs of droughts themselves, it is equally (if not more) important to understand how these costs are distributed within society in order to ensure both effective and equitable drought policies – in terms of emergency, mitigation and adaptation measures.

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Appendix: Previous and current European projects related to drought

AquaMoney (Assessment of environmental and resource costs and benefits in the European Water Framework Directive), http://www.aquamoney.ecologic-events.de

AquaStress (Mitigation of Water Stress through new Approaches to Integrating Management, Technical, Economic and Institutional Instruments), http://www.aquastress.net

ARIDE (Assessment of the Regional Impacts of Droughts in Europe), http://www.hydrology.uni-freiburg.de/forsch/aride

ASTHyDA (Analysis, Synthesis and Transfer of Knowledge and Tools on Hydrological Drought Assessment through a European Network), http://www.geo.uio.no/english/research/projects/old/asthyda

AVEC (Integrated Assessment of Vulnerable Ecosystems under Global Change), http://www.pik-potsdam.de/avec

DESERT (Desertification, Land Degradation, and Drought – Monitoring, Mitigation, and Early Warning), http://desert.jrc.ec.europa.eu/action/php/index.php?action=view&id=-1

EuroGEOSS (European environment Earth observation system supporting INSPIRE Directive 2007/2/EC and compatible with the Global Earth Observation System of Systems in the areas of Drought, Forestry and Biodiversity), http://www.eurogeoss.eu

EUROWATER, http://www.aprh.pt/congressoagua98/files/com/ew4.pdf

MEDDMAN (Integrated water resources management, development and comparison of common transnational methodologies to combat drought in the MEDOCC regions), http://www.meddman.org

MEDROPLAN (Mediterranean Drought Preparedness and Mitigation Planning), http://www.iamz.ciheam.org/medroplan

WATCH (Water and Global Change), http://www.eu-watch.org/

XEROCHORE SA (An Exercise to Assess Research Needs and Policy Choices in Areas of Drought), http://www.feem-project.net/xerochore