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Learning from experience: a systematic review of assessments of vulnerability to drought

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Abstract In the last decades, there have been an increasing number of vulnerability studies undertaken in the frameworks of several schools of thought and disciplines. This spur of activity is linked to the growing awareness about the importance of shifting from a crisis-reactive approach to a proactive and preventive risk management approach to deal with natural disasters. The severity of the impacts that drought provokes worldwide has also contributed to raise awareness about the need to improve its management. In this context, drought vulnerability assessments are the first step in the identification of underlying causes that generate drought impacts. This paper presents a systematic review of past assessments of vulnerability to drought, to enhance the understanding of vulnerability and help orientating future research in this field. Results suggest that there are important geographical and thematic gaps to be filled in the assessment of drought vulnerability. Transparency in the design and validation of results should be improved, while the availability of relevant, reliable, and updated data is still a major constraint at all levels.

Keywords Drought · Vulnerability · Assessment · Systematic · Review

1 Introduction

Drought is a complex phenomenon and one of the least understood natural hazards (Swain and Swain 2011). Estimates of global economic losses caused by drought are higher than any other meteorological disaster (Wilhite 2000) and drought impacts affect directly or indirectly several sectors (social, economic, environmental) and large geographical areas.

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In 2013, several UN agencies[1] organized a high-level meeting on National Drought Policy (HMNDP) to provide decision makers with relevant recommendations and science-based actions to address key drought issues. The meeting conclusions expressed concern for the absence of drought preparedness and drought management policies in the majority of the countries, as the lack of national drought policy makes that "responses are generally reactive in terms of crisis management, and often untimely and poorly coordinated" (Sivakumar et al. 2014). Strategies for drought mitigation and preparedness are thus needed in order to reduce societal vulnerability, and drought vulnerability assessments are the first step in this direction (Knutson et al. 1998; Wilhelmi and Wilhite 2002; Zarafshani et al. 2012; Zhang et al. 2014). Drought vulnerability assessment can support decision-making processes (Sönmez et al. 2005; Pereira et al. 2014) through the identification of adequate mitigation actions (Wilhelmi and Wilhite 2002), the design of contingency plans (Sönmez et al. 2005), and the setup of early warning systems (Villholth et al. 2013; Naumann et al. 2013). In this context, several authors warn that more efforts are spent on studying and quantifying drought as a natural hazard than in exploring societal vulnerability to drought, despite the fact that the latter is the underlying cause of most of drought impacts (Downing and Bakker 2000 in Wilhelmi and Wilhite 2002; Shiau and Hsiao 2012; Kim et al. 2013).

According to Knutson et al. (1998) a vulnerability assessment provides a framework for identifying the root causes of drought impacts at social, economic, and environmental levels, linking drought mitigation with "true causes" of vulnerability that generate impacts. In other words, vulnerability assessments attempt to understand who is vulnerable to what, when, and why, and what can be done to reduce vulnerability (Gbetibouo and Ringler 2009). Since vulnerability is very context specific and location specific, its assessment should be multidimensional and should take into account socioeconomic and cultural aspects as well as physical ones (Sivakumar et al. 2014).

In the literature, there is a broad diversity of drought vulnerability assessments (DVAs) depending on the purposes, the scope, the conceptual framework, or the methodology used. For instance, there are descriptive studies that explore drought vulnerability and coping strategies (Abraham 2006; Derbile 2013); assessments focused on a specific socioeconomic sector (e.g., Thomas et al. 2013), or several ones (Karavitis et al. 2012; Assimacopoulos et al. 2014; De Stefano et al. 2015); studies that use ethnographic techniques (Adepetu and Berthe 2007; Keshavarz et al. 2013), modelling (Fraser et al. 2013; Flörke et al. 2011), fuzzy systems (Bhattacharya and Das 2007; Cheng and Tao 2010), or vulnerability curves (Lei and Luo 2011). There are also DVAs that study natural systems, human systems, or coupled human-environmental systems; that stress biophysical aspects or socioeconomic aspects or both; and that focus exclusively on responses or exclusively on drought hazard. Besides, DVAs are undertaken at different geographical (subnational to global) and temporal scales (past, current and future vulnerability). The diversity within drought vulnerability studies is extremely high, and there is a lack of common conceptual understanding of vulnerability, standardized methodology, and common vulnerability metrics. All this hampers comparisons of results obtained by different DVAs. Comparability of vulnerability levels, however, is frequently demanded by decision makers (Hinkel and Klein 2006; Wolf 2012), in order to identify hotspots of vulnerability where they should focus efforts to strengthen adaptive capacity (Cutter et al. 2003; Hinkel and Klein 2006; Eriksen and Kelly 2007; Sivakumar et al. 2014). DVAs also contribute to identify

[1] World Meteorological Organization (WMO), the Secretariat of the United Nations Convention to Combat Desertification (UNCCD) and the Food and Agriculture Organization of the United Nations(FAO), in collaboration with a number of partners.

the sources of risk inherent in the assessed system, and, for this reason, they are important elements for the development of drought risk management plans. Moreover, they can be used as a diagnostic tool to understand why some areas have suffered impacts in past events (Knutson et al. 1998), thus informing ex post evaluation of response to drought.

This paper presents a systematic literature review of existing applied assessments of vulnerability to drought, with the objective of identifying gaps and trends in this field. Thus, this work has the potential to support future research and practice related to the assessment of vulnerability to drought.

2 Methods

"A systematic literature review is a summary and assessment of the state of knowledge on a given topic area" (Ford and Pearce 2010). It systematizes the state of the art and is necessary to support practice and policy, as well as to identify gaps and new directions for further research efforts, policy, and methods (Petticrew and Roberts 2006; Ford and Pearce 2010; Johnson et al. 2011; Plummer et al. 2012). Systematic reviews allow overcoming potential author's bias and inconsistencies, manage and handle information overload, shed light into gaps, and inform policy makers by providing robust and reliable summaries of evidence (Petticrew and Roberts 2006).

In recent years, there have been several efforts to synthesize investigations and assessments in different domains, such as global environmental and climate change (e.g., Rudel 2008; Ford and Pearce 2010; Thompson et al. 2010; Hofmann et al. 2011) or vulnerability and risk assessments (e.g., Plummer et al. 2012; or Sohrabizadeh et al. 2014), but none of these addresses specifically vulnerability to drought.

A systematic literature review usually follows three steps (Hofmann et al. 2011). Firstly, a search protocol must be designed through the establishment of inclusion and exclusion criteria for the selection of the studies to be reviewed (Rudel 2008; Hofmann et al. 2011; Plummer et al. 2012); then the information from the selected studies is classified or coded (Rudel 2008; Hofmann et al. 2011); and finally, the information is analyzed following specific criteria and using statistical, descriptive, or qualitative methods.

These steps were followed to study the existing applied assessments of vulnerability to drought that have been documented in the scientific literature until April 2015.

2.1 Search protocol

Table 1 summarizes the criteria used for the selection of items to be analyzed. We focused specifically on DVAs that quantify vulnerability and present vulnerability values in a graphic or numerical way. Furthermore, we prioritised studies focused on human systems, excluding those exploring only natural systems (e.g., vulnerability to drought of flora and fauna).

Table 2 presents the outcomes of the application of the search protocol to diverse databases of scientific literature (ProQuest, Springer Link, Science Direct, Willey Online and Google Scholar). To undertake the search, we worked under the assumption that relevant items should include in the abstract the words "DROUGHT + VULNERABILITY + ASSESSMENT". To complement the search, and not limit it to peer review journals, we also followed the CEE protocol[2] for internet searches, fully reviewing the first

[2] Collaboration for Environmental Evidence (CEE) is a specialized library of systematic reviews.

Table 1 Criteria for items selection

Inclusion criteria	Exclusion criteria
English literature	All non-English literature
Drought vulnerability assessment	Assessment of the vulnerability of water resources, climate variability, or climate change (broadly) vulnerability assessment Drought hazard assessment or drought risk assessment not measuring vulnerability
Human systems and/or coupled human–environment systems	DVAs focused exclusively on natural system (forest, fishes, aquatic ecosystem, etc.) DVAs focused exclusively on functioning of water supply systems DVAs focused only on agriculture productivity
Applied assessment with a quantification of vulnerability	Theoretical framework and ethnographic or qualitative studies that do not include vulnerability quantification

Table 2 Search outcomes

Dataset	Search Parameters	Outcome
ProQuest	1st search: Drought AND vulnerability AND assessment ALL (except full text) 2nd search: + drought (title)	1st search 334 items found 21 included 2nd Search: 71 items found 16 Duplicated 3 Included 52 Excluded
Springer link	1st search: Drought AND vulnerability AND assessment 2nd search: + drought (title)	6431 items found 2nd search: 298 items found 36 Included 262 Excluded
Science direct	1st search: Drought AND vulnerability AND assessment + ABSTRACT TITLE KEYWORDS	50 Items found 8 Duplicated 2 Included 40 Excluded
Willey online	1st search: Drought AND vulnerability AND assessment + ABSTRACT	27 Items found: 1 Included 26 Excluded
Google scholar	1st search "Drought vulnerability assessment"	121 Items found: 35 Duplicated 88 Excluded

50 items presented in Google, and exploring the following 50 for relevance. We explored also the references of selected studies to identify further relevant investigations. To narrow the search and identify relevant studies, in those search motors that allowed it, the search was restricted using specific words as search parameters (see Table 2). We conducted the searches along a 4-month period (April–July, 2014) and repeated the exploration in October 2014 and April 2015.

During the search, we found some DVAs that were presented in more than one publication. Thus, we decided that our unit of analysis (item) should be each DVA and not the single papers. Following the document screening, approximately 190 items were selected for systematic review (see Supplementary Material). After a full-text exploration of those items and the application of the inclusion criteria described above, 46 DVAs were retained for the systematic review.

After the identification of the items to be analyzed, we proceeded to code them to explore methodological and conceptual aspects of the DVAs, and also for basic inferential statistics. The analysis was focused on the following aspects: location and scale of DVAs, to identify possible gaps and scale implications; conceptual frameworks most frequently used within DVAs; dimensions and subdimensions of vulnerability factors included in DVA's, to explore comprehensiveness and identify possible patterns. On the methodological side, we explored three steps in the assessment process: identification and selection of factors, weighing of factors and components, and validation of results. And finally, we examined the intended uses and users stated in the DVAs.

3 Results and discussion

3.1 Geographical distribution and spatial scope

Trends in the number of vulnerability studies published during the last decade (Fig. 1) mirror the growing interest for vulnerability assessments in the international community, especially within the disaster risk reduction (DRR) and climate change adaptation (CCA) schools.

Diversity in terms of scale, as well as geographical location, is high (Table 3). The majority of the assessments identified focus on Asia, mostly at subnational level in China, India, and Iran, while South and Central America and Northern Africa are the regions where fewer assessments have been found (Table 3 and Table 1 in Supplementary material). Initially, this gap was attributed to the linguistic criterion applied in the search, since these are mostly Spanish- and French-speaking regions, respectively. However, a test search applying the protocol with Spanish terms ("evaluación or análisis + vulnerabilidad + sequía") returned a very low number of items, thus suggesting that, at least for Latin America, the scarcity of DVAs found cannot be attributed to our search protocol. Also the absence of DVAs in Australia is somehow surprising and requires further research, in order to understand the reasons behind this gap.

It is interesting to compare the spatial distribution of DVAs (Fig. 2) with the magnitude of the impacts of drought registered in EM-DAT.[3] Table 4 shows the 15 countries most affected by droughts in terms of people affected, total economic damage, and number of drought events since 1990. Countries with high drought impacts such as China, USA, or Brazil present at least one DVA, while in others such as Mozambique, Ethiopia, Thailand, or Honduras, no DVAs were found.

3.2 Types of conceptual frameworks

The review has shown that there is a significant diversity in the understanding and definition of vulnerability (see Table 4 Supplementary Material), confirming that the lack of

[3] http://www.emdat.be/database.

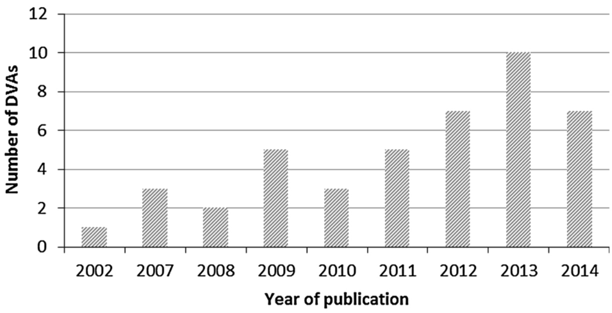

Fig. 1 Evolution over time of DVA publications (*source*: own elaboration)

Table 3 Location and scale of the reviewed DVAs

Location	Subnational	National	Regional	Continental	Global	Total
Africa	3	1	1	1		6
Asia	21	3				24
Europe	2	4	1	2		9
Mediterranean			1			1
North America	3					3
South America	1					1
World					2	2
Total	30	8	3	3	2	46

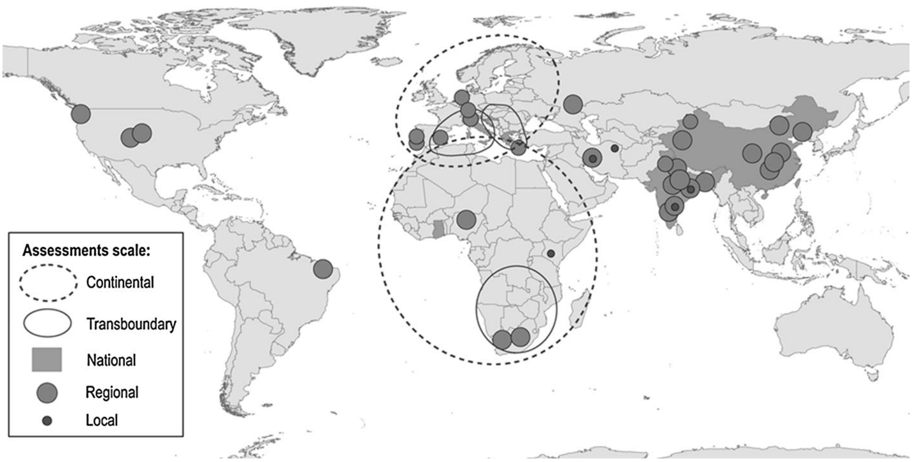

Fig. 2 Location of the reviewed DVAs

consensus among scholars regarding the definition, frames, and methods for measuring vulnerability continues to be an unresolved issue (Preston et al. 2011; Costa and Kropp 2013).

Table 4 Drought impacts and losses around the world (1990–2014)

Country	Total people affected (millions)	Country	Total damage ('000$)	Country	Drought events
China P Rep	415.27	**United States**	39,135,000	**China P Rep**	26
India	351.18	**China P Rep**	25,110,415	**United States**	11
Kenya	46.15	**Spain**	7,700,000	**Brazil**	10
Ethiopia	39.49	**Brazil**	7,532,000	Mozambique	9
Iran Islam Rep	37.00	Australia	3,973,000	Ethiopia	9
Thailand	29.98	**Iran Islam Rep**	3,300,000	**Kenya**	9
Malawi	20.15	Russia	2,540,000	Thailand	8
Niger	19.12	**India**	2,041,122	Honduras	8
Sudan	18.86	**Italy**	1,990,000	Bolivia	7
Zimbabwe	17.02	Ukraine	1,690,000	Namibia	6
South Africa	15.30	Mexico	1,610,000	Zimbabwe	6
Brazil	12.06	**Portugal**	1,348,136	Uganda	6
Somalia	11.70	**South Africa**	1,000,000	Malawi	6
Tanzania Uni Rep	10.65	**Greece**	1,000,000	**Niger**	6
Australia	7.00	Yugoslavia	1,000,000	Sudan	6

EM-DATA (2014) (Drought events 1990–2014. In bold locations with DVAs)

Most of the definitions of vulnerability used in the reviewed DVAs originate from the following definitions by the climate change adaptation (CCA) and the disaster reduction risk (DRR) schools:

- CCA school: The degree to which a system is susceptible to, or unable to cope with, adverse effects of drought. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2001, 2007), used by, e.g., Chandrasekar et al. (2009), Antwi-Agyei et al. (2012), Deems (2010), and Flörke et al. (2011), De Stefano et al. (2015).
- DDR school: The characteristics of a person or group in terms of their capacity to anticipate, resist, cope with, and recover from the impact of natural or man-made hazards (UN/ISDR 2009) used by, e.g., Iglesias et al. (2007), Adepetu and Berthe (2007), Cheng and Tao (2010), Zarafshani et al. (2012), Safavi et al. (2014), and Naumann et al. (2013).

According to Romieu et al. (2010), both schools have different goals, as DRR aims at highlighting means for risk reduction in shocks, while CCA looks for the most efficient way to adapt to shocks derived from climate change. Hence, DDR considers vulnerability as one step within the process of a risk assessment, whereas CCA considers vulnerability assessment as the expected outcome of the analysis.[4] These differences are reflected in their patterns of conceptualization and operationalization of vulnerability.

Within the reviewed DVAs, 16 assessments adopted the IPCC (2001) definition of vulnerability. Table 5 presents a selection of these DVAs to show that each DVA has a

[4] Some risk assessment studies (e.g., Blauhut et al. 2015) combine data about past drought impacts with hazard measurement in order to assess drought risk. This is a quite new approach that, contrary to traditional risk assessments, does not include a vulnerability assessment sensu stricto.

Table 5 Selection of DVAs following the IPCC (2001) model

Study	Equation	Exposure	Sensitivity	Adaptive capacity
Antwi-Agyei et al. (2012) (national)	$V = (E + S - AC)$	Long-term growing season rainfall/yearly growing season rainfall	Crop yield sensitivity index = expected yield/actual yield	Human capital (literacy rate (%), financial capital (poverty rates (%)
Assimacopoulos et al. (2014) (subnational)	$V = (E + S - AC)$	Number of drought events, drought duration, drought intensity, water exploitation index	Ground water level, water quality, population density, (demand coverage urban and agriculture), % irrigated land, Share of agricultural GDP, crop pattern/diversity, tourism intensity	Access to information, willingness to change, conflicts, existence of drought management policies, actors and institutions (jurisdictions, availability to resources), access to (water saving) technology, access to alternative water sources, infrastructure
Bhattacharya and Das (2007) (subnational)	$V = f(E, S, AC)$	Probability of drought, labor in agriculture, rural population, share of irrigated/unirrigated land?	Socioeconomic factors (income per capita, Gini coefficient); technology (fertilizer per Ha, tractor per Ha); activity (share of fruit/vegetable, share of oilseed)	Human capacity (literacy and education expenditure), governance (share of tax revenue) coping options (labor in households (HHs) industries)
Deems (2010) (national)	$V = \frac{(E+S+AC)}{3}$	Precipitation (average annual precipitation) Drought (SPI)	Water resources (GW, government irrigation scheme, irrigated area) land resources (slope, soil)	Human capital (population); social capital (services, institution, social participation); financial capital (farm holders, workforce, unemployed, €/agricultural holdings); Physical capital (agricultural area, livestock, crop and livestock diversity)
De Stefano et al. (2015) (regional)	$V = (E + S - AC)$	Drought characteristics	Water use, water stress, water body status, population, Socioeconomic relevance (by sector)	Law enforcement, drought management tools, public participation, drought awareness, education, innovation capacity, water resources development, availability and distribution of economic resources, financial capacity for drought recovery
Fontaine and Steinemann (2009) (subnational)	$V = (I - AC)$ $I = (E + S)$	Drought frequency, severity, magnitude, duration, spatial extent	Susceptibility of a water user	Ability of a water user to manage or reduce adverse effects of a drought, through actions taken before, during, or after the drought

Table 5 continued

Study	Equation	Exposure	Sensitivity	Adaptive capacity
Liu et al. (2013) (subnational)	$V = \frac{(E+S)}{AC}$	Temporal and spatial changes of annual precipitation	Precipitation variances; temperature variances; vegetation coverage deviation; average elevation	Population-economic production factor (cultivated land area, ratio of agriculture and industry output, population density), income-information access factor (savings deposit and access to information), skills and total productivity factor (technologists and income)
Pereira et al. (2011, 2014) (subnational)	$V = \frac{EI+SI+(1-ACI)}{3}$	Aridity index	Agricultural employment (%), smallholder farm's production system (%); level of smallholder farming's income dependence on vegetal and livestock production (%), % of rain-fed smallholder farms; HHs with access to water supply (%)	HHs legally owned by farmer (%), HHs receiving technical assistance (%) HHs whose heads can read and write (%) HHs whose heads are engaged in associations or unions (%) HHs with access to electric energy supply (%)
Wu et al. (2013) (subnational)	$VI = SI + ACI$	Not included	Amount of water resources per unit, irrigation water use rate, sown area rate of farm crops, population density	GDP, Net income of residents in rural area, rate of irrigation area to cultivation area, rate of GW resources, Effective utilization coefficient of irrigated water use, land reclamation rate, rate of regular secondary schools
Yuan et al. (2013) (subnational)	$V = f(E, S, AC)$	Share of cultivated fields, share of paddy fields and population density	Share of rural population, water consumption per agriculture value added and water consumption per industry VA	Per capita GDP, fixed assets for drought mitigation, emergency irrigation, water supply and rate of effective irrigation area

specific context and scope, but they all conceptualize their assessment components (exposure, sensitivity and adaptive capacity) in a similar manner, e.g., most of them include drought characteristics in exposure, and diverse capitals (social, economic, institutional, etc.) in adaptive capacity. At the same time, it can be noticed that the combination of components to produce a measure of vulnerability varies and that the boundaries between the components are not clearly defined, as variations of the same factor are used to characterize different components (e.g., rural population or the percentage of arable land under irrigation).

Among the reviewed DVAs, 11 assess vulnerability as part of a risk assessment study. These studies apply the formula proposed by the Pressure and Release Model (Blaikie et al. 1994):

$$R = H \times V$$

where risk (R) is considered to be a function of hazard (H) and vulnerability (V).

Most of these studies build a composite index to measure drought vulnerability but use different conceptualizations. Some of them group factors in renewable natural capital, economic capacity, human and civic resources, institutional capacity and infrastructure and technology (Naumann et al. (2013) or in socioeconomic and physical factors (Shahid and Behrawan, 2008); Jordaan (2012) assesses social, economic, and environmental vulnerabilities separately, whereas Kim et al. (2013) or Kipterer and Mundia (2014) combine diverse individual factors, without grouping them. The dimensions and subdimensions used in these DVAs to assess vulnerability can be found in Table 7.

3.3 Scope of the vulnerability factors

Several vulnerability scholars argue that vulnerability has a multifaceted and multidimensional nature (Turner et al. 2003; Vogel and O'Brien 2004; Birkmann 2006; Birkmann and Wisner 2006; Hufschmidt 2011), and that no single measure can fully capture its complexity (Luers et al. 2003; Gbetiobouo and Ringler 2009). Therefore, vulnerability assessments should be integrative and comprehensive and incorporate different dimensions (social, economic, physical, environmental, and institutional).

To analyze the comprehensiveness of the approaches, we have grouped vulnerability factors in two main dimensions—biophysical and socioeconomic (Preston et al. 2011)—and eleven subdimensions (Table 6). Six DVAs that did not describe vulnerability factors explicitly were not considered in this part of the analysis.

Table 6 shows the number of reviewed DVAs that include each type of subdimension, and the most frequently used vulnerability factor within each subdimension. The most commonly used subdimension (70 % of the DVAs) describes sociocultural characteristics of the assessed system, while the least common one is the one characterizing water uses (27 %).

The number of DVAs that include water resources or water uses within vulnerability factors is quite low (19 and 11, respectively). This is in contrast to reality, where availability of water resources and how it is employed are key elements within drought mitigation and prevention policies. Even though several scholars consider water scarcity to be a key driver of drought impacts (Wilhite et al. 2007; Ganapuram et al. 2013), only few assessments (Flörke et al. 2011; Shiau and Hsiao 2012; Assimacopoulos et al. 2014; De Stefano et al. 2015) include water stress among their vulnerability factors. Some studies (Deems 2010; Sreedhar et al. 2012; Fraser et al. 2013) acknowledge the relevance of

Table 6 Subdimensions and most frequent factors

	Subdimension	DVAs No	DVAs %	Most frequently included factors (# of DVAs)
Biophysical dimensions	Drought characteristics (‘*Drought*’)	17	41	SPI (3), NDVI (4)
	Climatic components: rainfall, evapotranspiration, temperature (‘*Climate*’)	20	49	Average annual precipitation (9)
	Soil characteristics and topographic factors (‘*Soil*’)	20	49	Soil water-holding capacity (10)
	Water resources (SW and GW, storage, runoff, etc.) (‘*Water resource*’)	19	46	Status groundwater (12) and surface water (10)
Socioeconomic dimensions	Water uses (DWS, industrial, agricultural, etc.) (‘*Water uses*’)	11	27	Agricultural water use (9)
	Land use (‘*Land use*’)	17	41	Agricultural land uses (9)
	Sociocultural (demography, education, health, gender, drought awareness, etc.) (‘*Sociocultural*’)	29	71	Population (24) and education (16)
	Economic and financial resources (labor, income, consumption, equity, productivity, investments, savings, assets, insurance, etc.) (‘*Econ financ*’)	28	68	Economic resources (20), agricultural income (17), employment (9)
	Institutional, policy and governance (social networks, taxes, governmental programs, participation, etc.) (‘*Instit*’)	14	34	Government presence or programs (9)
	Technical, technological and infrastructural (irrigation, tillage, improved seeds, fertilizers, access to services (electricity, safe water, communications, etc.) (‘*Techn infrastr*)	28	68	Irrigation (23)
	Others (‘*Others*’)	4	10	Impacts (2)

In cursive and between parentheses are the abbreviated names used in Table 7

including information about the available water resources (e.g., availability of groundwater, water balance, and water quality) but eventually cannot take them into account in the assessment due to lack of data.

Very few DVAs (Villholth et al. 2011, 2013; De Stefano et al. 2015; Murthy et al. 2015) include environmental aspects, such as water body status and water quality. This is surprising for two reasons. First, because, in a context of high anthropogenic pressure, the environment is highly vulnerable to drought. And second, because a low quantitative or qualitative status of water bodies decreases the capacity of response of water supply systems and thus exacerbates the vulnerability to drought of the whole socioeconomic system (WWAP 2014; Kossida et al. 2012; Van Vliet and Zwolsman 2008; Strosser et al. 2012). Interestingly, only four studies include gender as a factor (Adepetu and Berthe 2007; Shahid and Behrawan 2008; Cheng and Tao 2010; Zhang et al. 2014).

The majority of the studies reviewed include biophysical as well as socioeconomic factors (Table 7). The number of factors used in each DVA ranges from 3 to 33. Only very few cases [Cheng and Tao (2010), Zarafshani et al. (2012), Khoshnodifar et al. (2012)] explore drought vulnerability from a merely socioeconomic perspective, excluding factors of the biophysical dimensions. On the contrary, Moring et al. (2012), Perčec Tadić et al.

Table 7 Drought vulnerability assessments: dimensions, sub-dimensions and factors

	Biophysical dimensions				Socioeconomic dimensions							Total
	Drought	Climate	Soil	Water resource	Water uses	Land use	Sociocultural	Econ financ	Instit	Techn infrastr	Others	
Adepetu and Berthe (2007)						1	3	9	1			14
Antwi-Agyei et al. (2012)		1					1	2				4
Assimacopoulos et al. (2014)	4			2	2		2	2	4	6		22
Bhattacharya and Das (2007)	1						3	7	1	3		15
Chandrasekar et al. (2009)	4	2	4	1			2	1		2		16
Cheng and Tao (2010)							7	7	2	1		17
De Stefano et al. (2015)	1			2	1		4	3	2	2		15
Deems (2010)	1	1	2	1			4	8	1	1		19
Fraser et al. (2013)		2					1	4		2		9
Ganapuram et al. (2013)		2			3							5
Huang et al. (2014)		1	2	1		2	1	3		5		15
Iglesias et al. (2007)		1			2		3	6		4	1	17
Jain et al. (2015)	2		5			1	1				1	10
Jiang et al. (2012)		2	1				1	3		2		9
Jordaan (2012)			2	3		1	1	8	2			17
Karavitis et al. (2011)	2			1	1					1	1	6
Kim et al. (2013)					3		1	2		1		7
Kipterer and Mundia (2014)							1	2				3
Kumar (2008)		2	2	4		1	1	2		1		13
Liu et al. (2013)	1	3	1				2	4		2		13
Xin et al. (2011)	1		2							1		4
Móring et al. (2012)		2	2	1		1				1		7
Murthy et al. (2015)	1	2	1	1								5

Table 7 continued

	Biophysical dimensions				Socioeconomic dimensions							Total
	Drought	Climate	Soil	Water resource	Water uses	Land use	Sociocultural	Econ financ	Instit	Techn infrastr	Others	
Naumann et al. (2013)		1			2	1	6	4	2	5		21
Pandey et al. (2010)		1	1	2	1	2						7
Perčec Tadić et al. (2014)		2	2			1						5
Pereira et al. (2011, 2014)	1						1	5	1	3		11
Safavi et al. (2014)		3	2	3		1						9
Salvati et al. (2009)	1	4	5			2	2					14
Shahid and Behrawan (2008)			1				2	3		1		7
Shiau and Hsiao (2012)				3	3							6
Simelton et al. (2009)	1					4	3	8		3		19
Sookhtanlo et al. (2013)							7	9	2	9		27
Sreedhar et al. (2012)		1	3			1						5
Swain and Swain (2011)	2	1	2	1		2	3	5	1	2		19
Villholth et al. (2011, 2013)	1	3	1	1			2	2	1	2		13
Wilhelmi and Wilhite (2002)	1		1			1				1		4
Wu et al. (2013)				2	1	1	2	3		2		11
Yuan et al. (2013)				1	2	2	2	2		2		11
Zarafshani et al. (2012)				1			5	11	3	7	6	33
Zhang et al. (2014)	1							5	2		1	9

(2014) and Safavi et al. (2014) include factors belonging mostly to the biophysical dimensions.

Forty-two percent of the reviewed DVAs include less than five subdimensions. The subdimensions and factors most frequently used within DVAs are sociocultural factors and economic and financial resources (both used in 69 % of the reviewed studies); followed by technical, technological, and infrastructural resources (67 %); and climatic components (49 %). Among vulnerability factors, the most used ones are population and irrigation (both 58 %), and economic resources (50 %).

The inclusion of a high number of subdimensions can be interpreted as an attempt to have a comprehensive approach, as they consider different perspectives. None of the selected DVAs includes factors of all subdimensions, although DVAs by Swain and Swain (2011), Deems (2010) and Villholth et al. (2013) include most of them. In this context, a high number of factors can help to improve the understanding of a specific subdimension, but it does not necessarily reflect a comprehensive approach. For instance, Sookhtanlo et al. (2013) use 27 factors but only consider five subdimensions.

3.4 Geographical and temporal scales

The majority of the studies reviewed (65 %) were carried out at subnational level, mainly in a particular region, state, or river basin. According to several authors (Cutter et al. 2009; Fekete et al. 2010; Preston et al. 2011), the subnational scale favors the inclusion of more detailed information and the use of participatory approaches and qualitative techniques, which allows a contextualization of drought vulnerability and could lead to a better identification of intervention tools for reducing vulnerability locally (Cutter et al. 2009). At the same time, very context-specific assessments are not suitable for comparison across regions to identify hotspots and, e.g., guide the allocation of funds, which is often demanded by policy and decision makers at national, regional, or international level. The trade-off between scope and depth of analysis, however, seems inevitable, as spatially broader assessments are usually compelled to simplify their methodological approach due to constraints in data availability, and to consider only issues that are relevant across the whole region assessed.

Interestingly, these differences in depth and scope do not reflect on the number of subdimensions and factors included in the assessment at different geographical scales, as the average mean of factors among subnational assessments is 13 factors against 11 in assessments of national, regional, or global scales. Some of the reviewed DVAs at larger scales (Villholth et al. 2011, 2013; Naumann et al. 2013 and De Stefano et al. 2015) attempt to apprehend multidimensionality of drought vulnerability by including an even higher number of factors (13, 21, and 15, respectively) from different subdimensions (8, 9, and 7, respectively).

Several studies (e.g., Wilhelmi and Wilhite 2002; Naumann et al. 2013; De Stefano et al. 2015) acknowledge that the reliability and accuracy of data represent a significant challenge for the elaboration of policy-relevant DVAs and stress the need to invest in systematic data collection at different scales. This underscores the importance for DVAs to discuss data constraints, as they should be taken into account the interpretation of the DVA results.

In terms of data used, Adger (2006) and Cardona et al. (2012) highlight the importance of complementing quantitative measures with narratives of stakeholders in order to better capture the complexity of vulnerability, and thus enhance the assessment. According to Cardona et al. (2012), the diversity of tangible and intangible features of vulnerability in complex systems, cannot be grasped and assessed using the same methodology. Besides,

Table 8 Scale and type of data

Scale	Type of data				Scale
	Mixed	Qualitative	Quantitative	Total	%
Subnational	5	5	20	30	65
National	1		7	8	17
Regional			3	3	7
Continental	1		2	3	7
Global			2	2	4
Total	7	5	34	46	100

Adepetu and Berthe (2007) argue that ethnographic methods can provide valuable information that might improve further capacity-building measures to reduce vulnerability, especially in contexts where "long-standing cultural and economic differences among multiple ethnic groups produce different adaptation strategies to natural disasters" (p. xi).

As it can be observed in Table 8, qualitative data are used only in 11 DVAs (24 %), mostly corresponding to subnational scales, with the exception of Deems (2010), who assessed vulnerability to drought in Cyprus at national level. The majority of DVAs use data compiled from secondary sources such as official census and governmental or international statistics datasets. There are very few studies that collect or produce their own data ad hoc for the assessment, such as Fontaine and Steinemann (2009).

Within the studies that use qualitative or mixed methods, data are gathered mostly through surveys (Jordaan 2012; Zarafshani et al. 2012; Khoshnodifar et al. 2012; Sookhtanlo et al. 2013), interviews (Alcamo et al. 2008; Fontaine and Steinemann; 2009; Khoshnodifar et al. 2012; Sookhtanlo et al. 2013; Jordaan 2012; Assimacopoulos et al. 2014), stakeholder meetings (Jordaan 2012; Assimacopoulos et al. 2014), and visits in loco (Adepetu and Berthe 2007; Jordaan 2012). The use of qualitative methods is not limited to data gathering, as it occurs also in other steps of the vulnerability assessment processes, such as the identification and weighting of vulnerability factors (Adepetu and Berthe 2007; Khoshnodifar et al. 2012; Sookhtanlo et al. 2013); the design of the assessment process (CWCB 2010); or the validation of results (Deems 2010).

3.5 Transparency of design and validation of results

Vulnerability assessments necessarily involve a certain level of subjectivity. Several authors (Luers et al. 2003; Vincent 2004; Eriksen and Kelly 2007) highlight the need for improving transparency along the process, by making the assumptions as well as the decisions adopted for the assessment explicit. Wiréhn et al. (2015) also prove how methodological choices influence the final results of the DVA and stress that "methods and underlying factors must be visible." Transparency increases the robustness of the assessments (Eriksen and Kelly 2007) and contributes to comparability across studies. To examine transparency, we have focused on two key methodological aspects of the design and operationalization of the DVAs: the selection of vulnerability factors and, where several factors are aggregated, the process used to weight their relative importance.

The review of DVAs shows that only 57 % of the studies actually describe their process of selection of vulnerability factors. Usually, it is based on previous studies and specialized literature, and adjusted on data availability. Some studies limit it to data availability (Liu et al. 2013; Antwi-Agyei et al. 2012; Kim et al. 2013; Naumann et al. 2013), while others specifically refer to expert knowledge (Wilhelmi and Wilhite 2002; Shahid and Behrawan 2008; Cheng and Tao 2010; Khoshnodifar et al. 2012; Sookhtanlo et al. 2013; Yuan et al. 2013; Assimacopoulos et al. 2014). Others involve stakeholders in the selection process (Adepetu and Berthe 2007). Moreover, 56 % of the studies describe the hypothesized relationship between factors and vulnerability; 13 % provide brief explanations; while the remaining 31 % do not explicitly describe the logic underlying the factors' selection.

Applied weighing schemes can be categorized into three groups: (a) arbitrary choice of equal weights; (b) statistical methods; and (c) expert judgment (Gbetibouo and Ringler 2009; Deems 2010). In the review, we found that only 28 DVAs (61 % of the total) mention and describe the weighing scheme applied. Almost half of these (12) use statistical methods such as principal component analysis, while eight consult experts and/or stakeholders for weighing the indicators. Iglesias et al. (2007) present two scenarios, one with equal weights, and another with weights based on expert opinion, so as to support an explicit theoretical assumption.

Finally, an important step within the research process is the validation of results. As Eriksen and Kelly (2007) explain, this process increases the credibility of the set of measures and contributes to improve the understanding of vulnerability. Also Fekete et al. (2010) stress the importance of the validation process using an independent dataset. Nonetheless, only a third of the reviewed studies attempt to validate their results, or explicitly mention that they attempted to do so. The most common method employed (Table 9) is to correlate vulnerability results to past disasters data (Vincent 2004; Brooks et al. 2005).

Seven studies validate the assessment by comparing their results with previous impacts of past drought events using data from media (Alcamo et al. 2008), from international data bases such EM-DAT (Naumann et al. 2013), or their own register, such as the impact archive developed by the DMCSEE project (Karavitis et al. 2012). Villholth et al. (2011, 2013) explain that, due to lack of data, they could undertake only a partial validation of results. Other studies (Deems 2010; Pandey et al. 2010; Jordaan 2012; Safavi et al. 2014) validate their findings with field surveys, through community meetings, interviews, or visit in loco. This method is more feasible in assessments with a narrow geographical scope, where proximity makes data gathering easier. And finally, some of the studies consult experts or specialist literature to validate their results with expert opinion (Fontaine and Steinemann 2009; Chandrasekar et al. 2009; Flörke et al. 2011; Zarafshani et al. 2012).

The validation of DVA results is hampered by several factors. First, vulnerability is frequently conceptualized and measured as a potential state, and thus no dataset of observed variables can fully reflect and measure it. Despite this important difference, however, past impact data are often used as a proxy for vulnerability. This leads to a second important constraint, linked to the fact that drought impacts are difficult to quantify (Mishra and Singh 2010) and that the vast majority of countries and regions lack comprehensive and systematic drought impact databases. Although there are recent regional and global initiatives to create impacts inventories (e.g., EM-DAT, North America Impact

Table 9 Validation process

Validation process	DVA	%
Experts and/or specialist literature	6	13
Field surveys	5	11
Partial validation due to lack of past event data	1	2
Impacts recorded during past drought events	7	15
Not mentioned validation process	27	59
	46	100

Reporter, European Drought Impact Inventory), these are still far from complete, especially in terms of evaluation of economic losses and indirect impacts. And finally, even when impact data are available, the reporting methods heavily influence issues such as the count or the magnitude of the reported impacts, thus making those parameters highly imperfect indicators to validate vulnerability assessments.

3.6 Users and uses of the results of vulnerability assessments

The majority of the reviewed studies state that policy makers or decision makers, disaster reduction or water managers, other stakeholders (e.g., farmers) or the scientific community are the intended users of their results. Nevertheless, only one-third of the DVAs involve prospective final users in some of the steps of the assessment process, even though that inclusion could enhance relevance and adequacy of assessments, relating them to the "real world" (Tscherning et al. 2012). Tscherning et al. (2012) observed similar trends in their systematic review of DPSIR framework studies. This suggests the difficulties that still exist in creating a good communication between science and policy, and points to the need to further invest in bridging that gap.

The majority of the reviewed assessments present final results through maps of vulnerability (72 %), while 18 % present scores and 10 % spider diagrams. This is in line with the fact that mapping undoubtedly is an appropriate method to communicate complex spatial and temporal information (WHO 2014). Vulnerability mapping can help decision makers to visualize the hazard and communicate it to potentially affected stakeholders such as agricultural producers (Wilhelmi and Wilhite 2002). Ganapuram et al. (2013), for example, expressly chose an intuitive range of color for mapping, to reach illiterate farmers. Nevertheless, practitioners and stakeholders should be cautious with the use of maps since mapping can also be a misleading instrument, as they can lead to premature decisions, under the assumption that "once a map is available, sufficient information is at hand for effective decision making" (Preston et al. 2011).

Only a third of the assessments reviewed expressly link their results with recommendations for drought mitigation, prevention or adaptation strategies. According to Costa and Kropp (2013), scientists frequently use DVAs to understand general principles of a system and what can be learned from observed situations, while stakeholders expect concrete solutions regarding what to do to cope with specific threats. Considerations such as Pereira's et al. (2014) of building a vulnerability assessment tool that is "simple, easy to use for decision makers while at the same time being sufficiently representative of reality" are not frequent within DVAs. This could due to the fact that DVAs are a way of combining and presenting data to systematically characterize vulnerability, pointing to areas where there is a concomitance of factors that can exacerbate vulnerability. However, the formulation of specific recommendations and solutions requires an in-depth understanding of a range of dynamics that influence decision-making processes and that are too complex and diverse to be taken into account in a DVA.

4 Conclusions

The assessment of vulnerability to drought is a very complex task. The diversity of scope, approach, focus, methodology, and measurement criteria used within assessments hampers a common understanding of vulnerability to drought. In this paper, we have undertaken a systematic literature review of existing applied assessments of vulnerability to drought, with the objective of identifying gaps and trends in this field, and contributing to future research and practice related to the assessment of vulnerability to drought. The review has identified and analysed 46 drought vulnerability assessments from different perspectives: location and scale of DVAs; type and characteristics of the most commonly used conceptual frameworks; processes used in the identification and selection of assessment factors; weighting and validation methods; and intended uses and users of the DVAs.

The review has shown that the assessment of vulnerability to drought is not a widespread practice. The spatial distribution of existing DVAs suggests the need to increase assessment efforts in general, but especially in Central and South America and in North African countries. This has been remarked also by Belal et al. (2014), who recommend the development of national drought policies and preparedness plans based on drought risk assessments in drought-prone countries, in order to effectively shift from a reactive approach to a proactive and preventive risk management approach. In this context, drought vulnerability at different scales (subnational to global) are both necessary and complementary, since local studies might help to design more adequate mitigation tools, whereas larger-scale DVAs offer an overview of broader trends of vulnerability as required by policy makers.

The DVA's design and implementation are strongly influenced by the context, the focus, and objective of the study and data availability. Thus, while it is possible to formulate some recommendations about the design and implementation of DVAs, the specific content of the assessment will have to reflect the specific needs of each DVA.

Vulnerability is multidimensional and multifaceted, so assessments should attempt to increase comprehensiveness and use different types of data to get new and more integrated insights into drought vulnerability. The review found that 42% of the reviewed DVAs include less than five subdimensions and only one-fifth use qualitative or mixed data. The subdimensions and factors most frequently used within DVAs are sociocultural factors and economic and financial resources, followed by technical, technological, and infrastructural resources, and climatic components. This diversity of approaches shows that there is no consensus on the number and type of factors and dimensions to be considered in a DVA. However, the intrinsically multidimensional nature of any DVA makes it advisable to include at least the analysis of the needs (of the assessed system) that could be threatened by drought and the physical and institutional capacity to address them.

Knowing the most commonly used vulnerability factors is a starting point in the construction of common drought vulnerability datasets. This is particularly relevant in view of the fact that that several DVAs acknowledge the difficulties faced in the inclusion of several relevant factors due to constraints in data availability. Thus, the improvement in DVAs clearly requires the improvement in data gathering, mostly by national and local authorities. In particular, the improvement in data on drought impacts, as well as on water uses, water balance, and water status, is an urgent task in order that these aspects be more accurately appraised within DVAs.

At methodological level, several authors recommend the explicit inclusion of the underlying assumptions used during the whole process, especially those employed in the construction of the conceptual model used to assess drought vulnerability, as well as those employed in the selection and weighing of indicators. This is crucial in order to ensure transparency and increase comparability. Regrettably, there is still a significant number of DVAs that do not make the selection of factors or the hypothesized relation of factors with vulnerability explicit. Moreover, the final step of validation that can make results more robust and sound and enhance their durability, is undertaken only by a third of the studies reviewed, mainly due to lack of data and methodological constraints. Steps toward data gathering of past drought impact data such as the European Drought Impact Inventory (Stahl et al., under review) could contribute to overcome this handicap and ease validation process.

Drought as a natural hazard can be very destructive, but its slow onset and development provides a major opportunity to prevent and mitigate its impacts. The understanding and appraise of drought vulnerability is key to develop adequate drought management strategies, and thus its practice should be promoted and enhanced.

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