Climatic Change (2016) 139:183–200
DOI 10.1007/s10584-016-1768-0

Can we learn from the past? Four hundred years of changes in adaptation to floods and droughts. Measuring the vulnerability in two Hispanic cities

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Received: 31 October 2015 / Accepted: 4 August 2016 / Published online: 27 August 2016
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Abstract In a context of increasingly severe weather disasters around the globe, planning strategies are critical. The study of vulnerability to climate risks reveals the failures of current social models to adapt to a changing environment due to heterogeneous cultural, economic, political and historical developments. Any discussion regarding vulnerability to climate risks requires knowing how societies have faced natural disasters in the past. We propose the *Perceptual Index for Changes in Climate Risk (PICCR)*. The PICCR is an index that groups several social indicators into four factors that summarize the evolution of both vulnerability and adaptation to floods and droughts. We compute the evolution of the PICCR and its main factor in two similar medium-sized Hispanic cities (Murcia in Spain and Mendoza in Argentina) from the 17th century to the present time. The results show that, over the last four centuries, hazard perception has improved, vulnerability remains high and adaptation strategies have improved, but not as much as current technology allows.

Electronic supplementary material The online version of this article (doi:10.1007/s10584-016-1768-0) contains supplementary material, which is available to authorized users.

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1 Introduction and historical analysis of natural disasters

Now that it is clear that rising greenhouse gas emissions change the hydrological cycle and the distribution of precipitation, the study of extreme weather events is crucial (IPCC 2012). The most immediate and critical consequences of such events are increased intensity of extreme precipitation (Schiermeier 2011; Min et al. 2011) and increased incidence of droughts. The Mediterranean's and the American Southern Cone's arid areas are especially prone to droughts (Prudhomme et al. 2014).

This environmental change, combined with people's and goods' growing exposure to natural hazards (Easterling et al. 2000), causes a disconnection between human groups and their environments. In turn, this disconnection increases climate impacts on societies (Barredo 2009). Historical studies of extreme events provide examples of societal adaptation to climate change over time (Alberola-Romá 2013). Such interpretation of the past contributes to an understanding of the relationship between society and the environment in both the present and future (Messerli et al. 2000). Historical studies also clarify the risks associated with this changing relationship (Dearing et al. 2006; McMichael 2012; Endfield 2012).

Knowing how societies have faced natural disasters in the past bounds the discussion of how comparatively vulnerable these societies are in the present (Juneja and Mauelshagen 2007). But here a question arises: how can we compare vulnerabilities at different times if we have sources and data of different origins? The answer lies in transforming qualitative information in historical texts into quantitative data.

In order to interpret this data, it is important to establish methodologies that allow us to analyse both natural and social factors in risk processes. Floods and droughts, the environmental risks that produce the highest casualties and economic losses around the world, should receive priority attention (WMO, CRED and UCL 2014).

Throughout history, climate variability has decisively influenced social, economic and demographic changes in societies worldwide (Weiss and Bradley 2001; Zhang et al. 2007; Hsiang and Burke 2014). However, the current approaches to study climate variability are flawed because social and environmental factors are not adequately differentiated within risk processes. Moreover, most causal relationships are made using environmental proxies—pollen, tree rings, sediment cores—which are shaky links without detailed analysis of the historical situation (Plunkett et al. 2013). Thus, at the risk of covering more limited time periods, it is necessary to give greater importance to the use of historical documentation as a climate proxy (Brázdil et al. 2005).

While recent uses of historical documentation have great potential, they lack a standardized method generalizable to different regions of the world and to different historical periods. Messerli et al. (2000) have made the most significant advances assessing changes in different communities' adaptation from the Middle Holocene to the present time. Endfield (2007 and 2012) has also made noteworthy progress in her studies of colonial Mexico. Xiao et al. (2015) take a longer view, examining social responses to climatic extremes in North China since the 15th century. DeMenocal (2001) takes the same approach to major droughts in the United States, Central America and Mesopotamia. Bankoff's (2003a) pioneering work analyses natural disasters in the Philippines from the mid-16th century until 1990.[1]

Risk processes are multidimensional and connected complex dynamic systems (Berkes and Folke 1998). Such systems integrate human and environmental variables to explain conditions

[1] Other regions where notable works have been conducted are Mesopotamia (Widell 2007), Europe (Pfister 1988; Pfister et al. 2002; Pfister and Brázdil 2006; and Zhang et al. 2011;), China (Wei et al. 2014), Germany (Mauelshagen 2009), the Sahel region (Meier 2007), South America (Aceituno et al. 2009 and Prieto and Rojas 2013), Spain (Gómez-Baggethun et al. 2012 and Barriendos et al. 2014).

of differential exposure and vulnerability in the face of natural hazards (Endfield 2007). The risk of a specific adverse natural event is determined additively by three factors (Cardona et al. 2012): (*i*) *natural hazard*: the possible occurrence of natural or human-induced physical events that may have adverse effects on exposed elements; (*ii*) *exposure of people and goods*: inventory of elements in an area in which hazard events may occur; (*iii*) *vulnerability*: the propensity of exposed elements to suffer adverse effects when impacted by hazard events. In this sense, it is necessary to be exposed to a natural hazard to be vulnerable, but not vice versa.

Among these three factors, vulnerability is the most difficult to measure. As Berkes and Folke (1998: 9) pointed out, "there is no single universally accepted way of formulating the linkages between human nature and systems" since both social and environmental issues are at stake.

The complex network of interconnections between social and environmental variables requires additional explanatory concepts, including resilience and adaptability. Folke (2006) defines resilience as a system's ability to absorb disturbance and then reorganize itself. Adaptation applied to human systems describes group or individual ability to draw on cultural repertoires to improve upon old and originate new environmental methods (O'Brien and Holland 1992). Different types of adaptation are manifestations of *adaptability* and represent ways of reducing vulnerability (Smit and Wandel 2006).

According to Bankoff (2003b), those affected by natural disasters must review their current activities in light of the emerging situation. As a result, both loss and opportunity generated by disaster can catalyse socioeconomic reconfiguration. Specifically, disaster's differential effect on social groups generates change.

However, Pfister and Bradzil (2006) argue that understanding vulnerability requires insight into political, social and economic management of territory. In order to do this, we consider how natural risks are perceived throughout history. Along with this notion, we define *vulnerability* as the susceptibility of socio-environmental systems to damage caused by variation, change or alteration in the natural or social environment. Vulnerability is an example of the lack of adaptation to stress or change experienced by different social groups in their use of processes, land and natural resources. Adaptation, or lack thereof, is also influenced by how the population at-large and particular groups in power perceive environmental hazard. Notably, vulnerability is correlated with social, economic and cultural factors contemporary to catastrophe (Cutter et al. 2003). However, the causal relation is unclear and could go both ways (Tapsell et al. 2002). Hence, in order to have a precise and unbiased indicator, we measure vulnerability only with respect to those indicators that influence a natural hazard's severity.

This paper incorporates perception of risk alongside social and environmental factors in risk processes. To this end, we propose the *Perceptual Index for Changes in Climate Risk (PICCR)*, which groups various indicators into four factors to analyse the evolution of vulnerability and adaptation to floods and droughts from the 17th century until the present time. The aim of the PICCR is threefold: 1) to enable comparative study across space; 2) in identifying historical changes in systems of human-nature relationship, reveals "paths of vulnerability" in human society (Messerli et al. 2000); and 3) to, identify recurrent errors in the management of droughts and floods.

2 Hispanic medium-sized cities

We apply the PICCR over the last four centuries in two spaces within the Hispanic world: the city of Murcia, Spain in the Segura River basin and the city of Mendoza, Argentina in the Mendoza River watershed.

We choose these two cities based on their shared imperial past and climatic similarities. These two cities were once ruled by the Spanish crown and thus have analogous documents. The predominantly semi-arid climate and warm temperature in each city led to similar environmental conditions with the common denominator of a very high historical risk of - and vulnerability to- droughts and floods. The availability of water, rather than temperature, is the main climate determinant for life in semi-arid regions around the globe (DeMenocal 2001), and by extension, also in these cities.

The climate of Murcia is characterized by meagre precipitation (slightly above 300 mm) with eight dry months, a marked summer drought and high inter- and intra-annual irregularity. In addition, annual average temperatures are high (around 18 °C). The *Guadalentín* River is considered the most dangerous river in Spain due to its great irregularity (Benito et al. 2010). Upstream of Murcia the *Guadalentín* River joins the Segura River. These features determine the danger of droughts and floods.

The city of Mendoza has a continental mild climate, with an average temperature of 16 °C. Rainfall is highly variable and averages around 200 mm per year, with a minimum in winter and a maximum in summer. The metropolitan area of Mendoza is crisscrossed by steep alluvial courses from the foothills of the Andes mountain range. The Mendoza River carries snowmelt from the mountains, the level of which determines the danger of flooding in the area.

The average water availability in the Mendoza River basin is 1600 cubic metres per inhabitant and year, much lower than the world average (7400) and below the threshold considered critical by the FAO (1700). Anyhow, the value is far above the 872.62 cubic meters per capita and year available on average to the inhabitants of the Segura River basin (Gil-Guirado 2013). Until recently, the city of Mendoza had a smaller total population, a lower population density and a greater availability of irrigable land per capita, than the city of Murcia. Even though the population density of Mendoza has greatly increased ever since the end of the 19th century, irrigable land per capita is still more available than in Murcia.[2]

3 Data and sources

The PICCR primarily uses administrative data. Given the role played by public institutions in spatial planning, management and governance, these documents, mainly Municipal Records (Chapter Act Book) from Mendoza and Murcia, represent the best approach to consider climatic vicissitudes (Barriendos 1999; Metcalfe et al. 2002; Pfister et al. 2002). Such documents focus on the effect atmospheric agents had on society. Therefore, extreme weather events, which resulted in catastrophes, were always treated exhaustively (Alberola-Romá 2014). In addition, the notebooks and letters written by adventurers, scientists, writers and other chroniclers have considerable value. These documents provide an accurate picture of the environmental and climate reality (Prieto and García-Herrera 2009). From the second half of the 19th century onwards, newspapers became an important source of data providing detailed information on environmental events that affected society. Nevertheless, newspapers are subject to selection bias and subjective analysis.[3]

[2] See Online Resource 1 for details.
[3] See Online Resource 2 for details.

4 Methodology

The proposed method involves collection of implied elements and verification of the parts of the system that have been affected. We analyse the evolution of four key factors in risk processes: *perception of the agents responsible for the impact, natural hazard perception, vulnerability and strategy of adaptation and resilience*.

The PICCR, analyses the available historical information subsequent to the occurrence of the disaster. In this way, the information refers to the impacts of the event, how it is perceived and the strategies used to manage and overcome the event.

Before applying this method, we narrow the extreme climatic events under study using specific criteria. Following the historical climate reconstruction of Gil-Guirado (2013) in each city, we choose a catastrophic drought and flood in each century studied. We select each drought and flood taking into account the proximity in time between the two cities, so that the temporal context does not differ (See Fig. 1).

In our study, a flood begins when water rises and ends when documentary sources go without news of the phenomenon for three months (the season's length). A drought begins when historical sources explicitly attribute a lack of water to a lack of rain and ends when at least three months—the length of a season—elapse without news about it. Governments have often characterized natural disasters as "acts of God", a label which immediately encourages the public to forget what just happened (Steinberg 2006).

In the range of drought and flood events, PICCR categorizes agricultural and socio-economic droughts and flash floods caused by high-intensity rainfall. The method adapts "content analysis" to historical climatology. "Content analysis" is a research technique used to identify the meaning of full written accounts, taking into consideration the historical, social and cultural context in which documents were drafted (Prieto et al. 2005). The procedure is based on the analysis of contemporary texts that explicitly refer to the catastrophe, its impact and consequences. These references can be classified dichotomously (presence = 1, absence = 0) on various indicators that refer to any of the four factors analysed.[4] Finally, the total number of occurrences of each indicator is recorded and assigned a percentage value relative to the total factor accounted for. A single document may refer to indicators that belong to different factors. On average, each classified document yields 8.4 indicators for floods and 7.1 for droughts (Fig. 1).

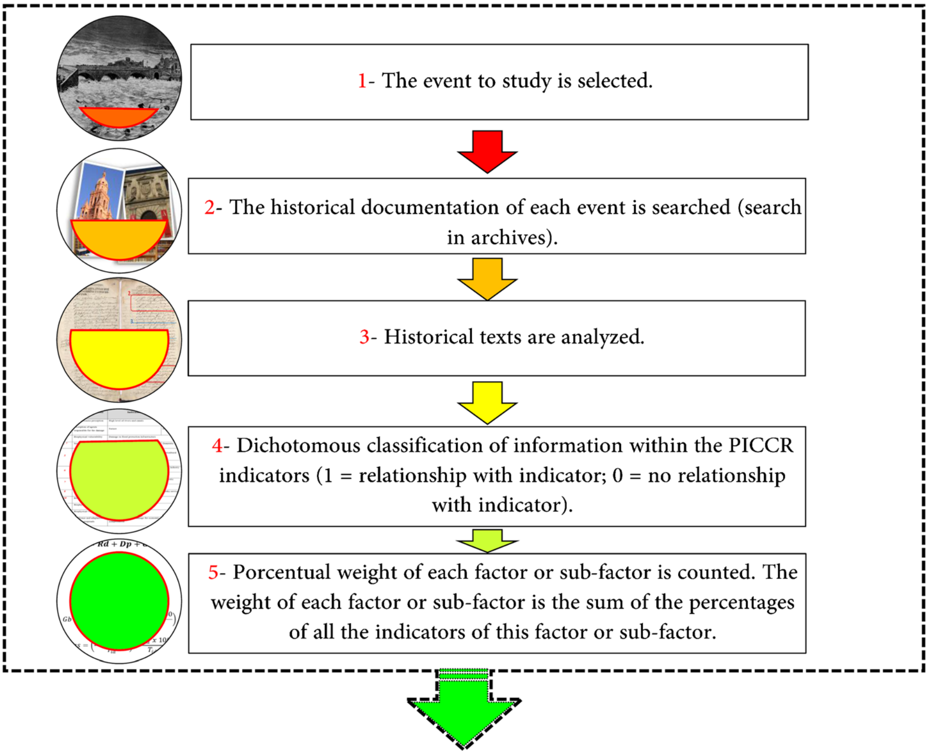
Most indicators have been used in other studies and vulnerability analysis models (Pfister 1988; Messerli et al. 2000; Brooks et al. 2005; Endfield 2007). Other indicators are new, arising from the need to make a model applicable across different time periods and spaces. Overall, the PICCR groups 123 indicators grouped into four factors (Table 1 panel A).

The expression for the PICCR is as follows

$$PICCR = (Dp + Gv + Ras)$$

Where Dp is the factor Dangerousness perception (henceforth Dangerousness), Gp is the factor Global vulnerability, Ras is the factor Resilience and adaptation strategy. Notice that the PICCR is different than Rd, i.e., is the factor Perception of agents responsible for the damage (henceforth Perception).

[4] See Online Resource 3 for a detailed example.



Murcia						Mendoza					
Floods			Droughts			Floods			Droughts		
Date	Doc	Id	Date	Doc	Id	Date	Doc	Id	Date	Doc	Id
October 14, 1651	129	8.7	From 1625 to 1632	175	5.9	April 11, 1662	14	6.3	From 1626 to 1631	21	6.7
September 6, 1733	42	10.7	From 1747 to 1751	96	6.3	Floods from 1758 to 1782[1]	28	9.8	From 1737 to 1747	42	7.4
October 14, 1879	186	9.0	From 1846 to 1850	182	5.9	January 8, 1895	41	7.6	From 1861 to 1871	28	7.1
September 28, 2012	17	9.4	From 2004 to 2007	848	9.4	February 8, 2005	30	5.6	From 1996 to 1999	90	7.9

Fig. 1 Stages in work process of the PICCR and extreme events analysed in the study areas. Steps 1 and 2 correspond to archival research. Step 3 is the transcription and pre-classification of the information collected in step 2. Step 4 is the phase in which the qualitative information moves to quantitative information. Step 5 is when the numerical information is processed to move it to the PICCR. The table indicates the general data obtained after application of PICCR. The table indicates the dates (column Date) of floods and droughts studied in each city. The Doc column reports the number of historical documents classified at each event. The column Id reports the average of indicators of the PICCR, in which each document was classified. [1]The lack of data in Mendoza determines that for the flooding in the 18th century, several consecutive events are considered in an integrated way in order to have a greater amount of information

4.1 Perception

Contemporary sources sometimes assign responsibility for environmental catastrophes to particular social groups. This perception factor provides information about ideological, cultural, educational and political vulnerability—taken together, the socio-political context (Wilches-Chaux 1993).

We begin with the hypothesis that before the emergence of rationalist ideas, superhuman entities, like nature and divinity, would be more frequently identified as responsible for climate events. This situation changed gradually, with the emergence of rationalism and the extension of class conflicts, right up to the present time. Over this period, references to human guilt became more frequent (Steinberg 2006).

These indicators are summarized into four general causes: environmental, divinity, anthropogenic and indefinite (Table 1 panel B).

The Perception expression is as follows

$$Rd = \frac{Rd_{id}\ x\ 100}{T_{id}-(Dp_{id} + Gv_{id} + Ras_{id})}$$

Where Rd is the factor Perception, Rd_{id} is the sum of all documentary references classified as indicators of Perception. T_{id} is the sum of all documentary references classified as indicators for an event in question. Dp_{id} is the sum of all documentary references classified as indicators of Dangerousness. Gv_{id} is the sum of all documentary references classified as indicators of Global vulnerability. Ras_{id} is the sum of all documentary references classified as indicators of Resilience and adaptation strategy.

4.2 Dangerousness

These indicators measure how contemporaries examined the role of natural factors as triggers. This determination is of special importance. The more successful the perception of the natural hazard, the better protected the population during the catastrophe (Dake 1992). Even though dangerousness is a measure of a hazard's severity, the indexes used here only include information about those natural factors *perceived* as dangerous. We interpret natural risks as a social construction. Hence, the intensity of an event affects risk only when a society is not adapted to the range of those events (García-Acosta 2005).

In total ten variables are computed in this subgroup (Table 1 panel C).

$$Dp = \frac{Dp_{id}\ x\ 100}{T_{id}-Rd_{id}}$$

Where Dp is the factor Dangerousness, Dp_{id} is the sum of all documentary references classified as indicators of Dangerousness. T_{id} is the sum of all documentary references classified as indicators for an event in question. Rd_{id} is the sum of all documentary references classified as indicators of Perception.

4.3 Global vulnerability

We decompose global vulnerability into two large sub-factors: social vulnerability and biophysical vulnerability. The global vulnerability factor is the sum of both (Wilches-Chaux 1993).

According to Cutter et al. (2003), social vulnerability is the result of social inequalities. Hence, social actors affected by disaster directly report directly its differential impact. Not all the analysed documents inform us about the stakeholders affected by an event. Therefore, more often an indicator refers to a social actor, the greater the measured social vulnerability. The PICCR summarizes social vulnerability indicators into seven types of land use (see Online Resource Table 5): domestic, industrial, agricultural, cattle industry, trade, tourism, public services.

Biophysical vulnerability refers to territorial damage both natural and anthropogenic. There is a physical component associated with the nature of the disaster risk, and a biological or social component associated with the properties of the affected system (Brooks 2003). In all, the PICCR distinguishes 22 indicators in this sub-factor (Table 1 panels D_1 and D_2).

$$Gv = \left(\frac{Sv_{id}\ x\ 100}{T_{id} - Rd_{id}}\right) + \left(\frac{Bv_{id}\ x\ 100}{T_{id} - Rd_{id}}\right)$$

Where Gv is the factor Global vulnerability, Sv_{id} is the sum of all documentary references classified as indicators of Social vulnerability, Bv_{id} is the sum of all documentary references classified as indicators of Biophysical vulnerability. T_{id} is the sum of all documentary references classified as indicators for an event in question. Rd_{id} is the sum of all documentary references classified as indicators of Perception.

4.4 Resilience and adaptation strategy

The indicators considered in this factor refer to the strategies used to overcome an existing disaster as well as to mitigate vulnerability in preparation for future disasters (Adger et al. 2005; Folke 2006). We split twenty-two indicators between the sub-factors "proposals" and "implemented measures." The sum of these two sub-factors produces a strategy of resilience and adaptation. The indicators are summarized into six general indicators that refer to the type of measures taken (Table 1 panel E).

$$Ras = \left(\frac{Pa_{id}\ x\ 100}{T_{id} - Rd_{id}}\right) + \left(\frac{Ma_{id}\ x\ 100}{T_{id} - Rd_{id}}\right)$$

Where Ras is the factor Resilience and adaptation strategy, Pa_{id} is the sum of all documentary references classified as indicators of Resilience and adaptation proposals, Ma_{id} is the sum of all documentary references classified as indicators of Resilience and adaptation implemented measures. T_{id} is the sum of all documentary references classified as indicators for an event in question. Rd_{id} is the sum of all documentary references classified as indicators of Perception.[5]

5 Results

5.1 Evolution of perception of guilty agents

Over the last four centuries, the perception of who was liable for flooding changed. The most significant change was the increasing importance of human affairs, especially from the 19^{th} century onwards. During the 17^{th} century, humans were blamed 9.5 % of the time in Murcia and 0 % in Mendoza. In contrast, during the 21^{st} century human attribution dramatically increased to 55.6 % in Murcia and 53.6 % in Mendoza.

Since the 17^{th} century, references to human responsibility for drought significantly multiply, especially in Murcia (from 25.9 to 67.2 %), while attributions to religious factors diminish. However, this city suffered years of excessive politicization as a result of the political discourse

[5] For detailed results see Online Resource 5 to 9.

Table 1 Factor, sub-factors and indicators of PICCR

A	Factor, sub-factors and number of indicators of the PICCR				
	Factor		F_{id}	D_{id}	T_{id}
	1. Perception of agents responsible for the damage		27	27	27
	2. Natural hazard perception		7	6	10
	3. Global vulnerability	Social Vulnerability	20	20	20
		Biophysical vulnerability	19	17	22
	4. Resilience and adaptation strategy	Proposal	22	22	22
		Measures	22	22	22
	TOTAL:		117	114	123
B	Indicators for perception of agents responsible for the damage factor				
	General causes	Causing agents			
	Environmental	Nature			
	Divinity	Divinity			
	Anthropogenic	Rural Population	Landowners		
		Urban Population	Speculators and economic interests		
		Technicians	Poor population		
		Land Use Managers	Rich population		
		Water supply deficiencies or defence system	Outsiders		
		Water Managers	Nobility		
		Inspectors and forces of order	Priests		
		Little land owners	National Government		
		Farmers	Provincial government		
		Ranchers	Local Government		
		Dealer	Politicians without distinction		
		Factory worker and manufacturers	Indigenous communities		
	Indefinite	No distinction			
C	Indicators for dangerousness perception factor				
	Torrential rains[1]	Lack of snow in rivers source [2]			
	Materials dragged for the flood[1]	Lack of rain[2]			
	Hail[1]	Low level of rivers, canals and reservoirs[2]			
	High level of rivers and canals[1]	Typology of lithology			
	Topography and slope[1]	Typology and volume vegetation			
D_1	Indicators for social vulnerability factor				
	Land use affected	Social actors affected			
	Domestic	No social distinction	Poor	Outsiders	
		Children	Rich	Nobility	
		Elderly	Rural population	Indigenous communities	
		Women	Urban Population		
	Industrial	Factory worker and manufacturers			
	Agricultural	Landowners	Cottager	Little land owners	
	Cattle industry	Ranchers			
	Trade	Dealer			
	Tourism	Tourists and tour agents			
	Public services	Priests	Army and forces of law and order		
D_2	Indicators for biophysical vulnerability factor				
	Stagnation and siltation of land	Damage to agriculture			
	Damage in flood protection infrastructure[1]	Damage to livestock			

Table 1 (continued)

	Damage in irrigation infrastructure	Wildfires[2]
	Damage in transport communications	Environmental pollution problems[2]
	Faults in energy systems	Overexploitation of aquifers[2]
	Changing in the course of rivers	Food security problems
	Shortage of supplies of domestic water	Increased of social conflict
	Shortage of supplies of irrigation water	Worsening in general economic conditions
	Deaths and injuries[1]	Worsening in population health status
	Flooding of homes and buildings[1]	Socio-demographic impact
	Loss of tangible goods[1]	Financial problems
E	Indicators for resilience and adaptation strategy factor	
	General indicators	Proposals or Measures to be implemented
	Measures for reduction of biophysical vulnerability	Increase and improvement of water supply for populations
		Programs to bring water to new populations
		Improved flood defence system
		Improvements in irrigation system
	Measures for reducing social vulnerability	Application of better adapted materials and building techniques
		Improvement of quality of life, health and housing for disadvantaged sectors
		Hygienic measures
	Measures for reducing exposure	Creation of new habitable spaces in safer places
		Territorial land use regulation
		Management measures (model of water distribution; turn in water supply, etc.)
		Administrative changes and new laws in planning
		Expropriation of highly exposed lands
	Economic measures	Evaluation of disasters damage for economic compensation
		Facilities of access to loans
		Economic Incentives
		Aid to agriculture
		Aid to other affected sectors
	Measures for prevention and evasion of natural hazard	Budget provisions for emergency cases
		Educational programs to raise awareness of the dangerousness
		Improvement of Warning systems
		Optimization and adaptation measures to adjust water demand to water offer
	Unspecified change proposal	Unspecified solution request

In panel A, the first column shows the PICCR factors and sub-factors that include the Global vulnerability, the Resilience and the adaptation strategy factors. The F_{id} column reports the number of indicators of each factor for the floods. D_{id} column reports the number of indicators of each factor for the drought. The sum of the columns F_{id} and D_{id} could be lower than T_{id}, since many indicators are common in floods and droughts

Panel B show all indicators of PICCR for perception of agents responsible for the damage factor. These indicators are summarized into four general causes

Panel C show all indicators of PICCR for dangerousness perception factor

Panels D_1 and D_2 show all indicators of PICCR for social vulnerability and biophysical vulnerability sub-factor respectively. The sum of both factors is the global vulnerability. The indicators of panel D_1 are summarized into seven types of land use

Panel E show all indicators of PICCR for resilience and adaptation strategy factor. These indicators are summarized into six general indicators

Indicators are binary variables (presence = 1; absence = 0)

Factors and sub-factors are discrete variables, constructed by adding up the relevant indicators

[1] Specific indicators of floods

[2] Specific indicators of droughts

of water resources, which led to clashes between various sectors (agricultural against urban development, progressive against conservative political parties, etc.) (Albiac et al. 2007). This situation jeopardized social peace. In Mendoza, by contrast, environmental causes have gained increasing prominence (from 21.4 to 50.9 %), spreading the misconception that the problems caused by droughts are unavoidable.

5.2 Evolution of the impact and perception of extreme climate events

The ways in which the populations of Murcia and Mendoza confronted and overcame droughts and floods have improved over the last four centuries. Between the 17th and 21st centuries, conditions have gone from comparatively negative to positive or very positive in both cities. The biggest changes have occurred in Murcia in relation to floods and in Mendoza in relation to drought. There are currently too few measures to improve flooding resilience in Mendoza while drought adaptation measures to droughts are scarce. Alternatively, social vulnerability is still too high and there is a poor perception of the dangerousness of drought in Murcia.

Despite having fallen, global vulnerability to floods remains high in the studied areas, especially in Mendoza. In Murcia, the change started in the 18th century, due to improvements in infrastructure, and to adaptation proposals and policies. In Mendoza, major changes occurred between the 19th and 21st centuries (see Fig. 2). However, social vulnerability remains high because defence systems are still lacking. Moreover, the social model has not prevented continuing fatalities, which affect an increasing number of social actors.

The increase in consideration of hazard indicates a better understanding of the environment and natural conditions. These improvements became possible due to a more proactive strategy of adaptation, one still more evident in proposals rather than implemented measures, though.

The frameworks for drought and flood risks are significantly different. Drought impacts a range of social sectors beyond just territorial infrastructure or exposed assets.

As for global vulnerability, a gradual reduction occurred beginning in the 18th century. This reduction was due to increased active adaptation and resilience measures based on public works, especially in Murcia.

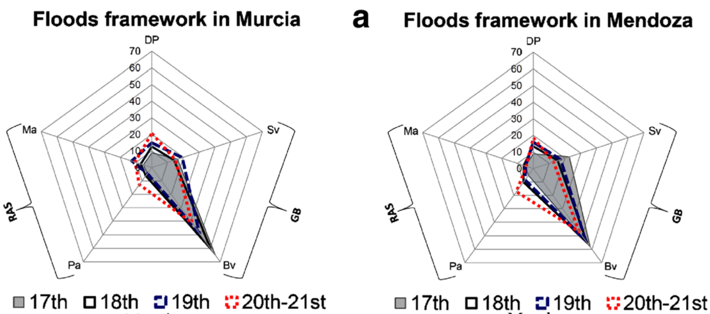
However, drought adaptation strategies often are politicized, leading to a distorted perception of danger. In any case, larger advances occurred in drought than in flood prevention.

In Mendoza, secular infrastructure deficiencies have not been resolved at the same pace than increases in exposure. Therefore, biophysical vulnerability has hardly been modified while social vulnerability has not been modified, as in Murcia (Fig. 2).

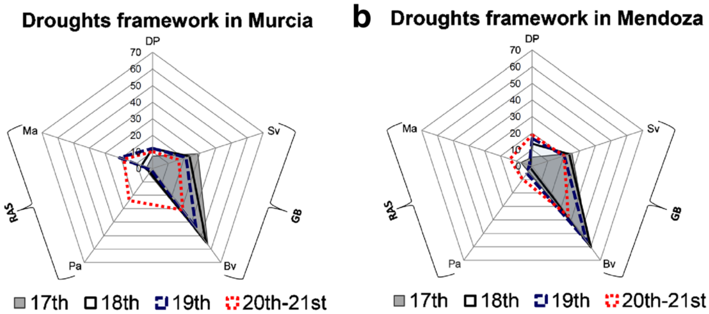
5.3 Changes in vulnerability before extreme climate events

In both floods and droughts, the most vulnerable social groups are city inhabitants. However, there are some differences between the two cities. While social inequalities in Mendoza lead to increased damage to the poor and the young, in Murcia these references are scarce.

During floods, there are important contrasts between study areas. In Mendoza, most agricultural specialization makes farmers, landowners, labourers and farmers bear the growing impact. In Murcia, economic diversification and quality defence systems reduce these groups' vulnerability. However, traders are more vulnerable because of their greater exposure within turban areas.



Factor		Murcia: October 14, 1651	Murcia: September 6, 1733	Murcia: October 14, 1879	Murcia: September 28, 2012	Mendoza: April 11, 1662	Mendoza: From 1758 to 1782	Mendoza: January 8, 1895	Mendoza: February 8, 2005
DP		8,90%	12,62%	14,90%	20,57%	8,86%	13,36%	15,90%	18,59%
GV	*Sv*	16,24%	14,11%	19,27%	14,89%	22,78%	15,38%	17,31%	12,82%
	Bv	64,97%	60,15%	48,61%	41,13%	58,23%	55,06%	53,36%	46,79%
RAS	*Pa*	4,60%	6,19%	4,50%	12,77%	5,06%	10,12%	8,48%	17,31%
	Ma	5,28%	6,93%	12,72%	10,64%	5,06%	6,07%	4,95%	4,49%



Factor		Murcia: 1625-1632	Murcia: 1747- 1751	Murcia: 1846-1850	Murcia: 2004-2007	Mendoza: 1626-1631	Mendoza: 1737-1747	Mendoza: 18611871	Mendoza: 1996-1999
DP		7,46%	12,13%	12,13%	10,18%	5,51%	13,64%	16,77%	18,91%
GV	*Sv*	28,67%	23,46%	21,20%	16,68%	25,20%	23,48%	20,36%	20,23%
	Bv	56,64%	54,87%	44,59%	31,10%	58,27%	60,23%	55,69%	36,98%
RAS	*Pa*	3,73%	2,78%	1,09%	23,97%	3,94%	1,52%	5,39%	9,78%
	Ma	3,50%	6,76%	20,98%	18,08%	7,09%	1,14%	1,80%	14,10%

Fig. 2 Changes in floods (**a**) and droughts (**b**) frameworks factors. Each plot corresponds to a different century. DP is the factor Dangerousness perception. GV is the factor Global vulnerability. Sv is the sub-factor Social vulnerability. Bv is the sub-factor Biophysical vulnerability. RAS is the factor Resilience and adaptation strategy. Pa is the sub-factor Resilience and adaptation proposals. Ma is the sub-factor Resilience and adaptation implemented measures. In tables different colours are depending on this value within the first, second, third or fourth quartile (see Online Resource Table 8). *Green colour* shows conditions comparatively positive, yellow conditions comparatively neutral, orange conditions comparatively negative, red conditions comparatively very negative

During droughts, when water supplies are underfunded, inelastic urban demand makes farmers increasingly vulnerable, especially in Murcia (Fig. 3 panel A). Water shortages also affect urban groups, such as traders and tourists. The resulting confrontation between new uses and traditional agricultural uses mostly impacts the latter.

Biophysical vulnerability differs for droughts and floods, primarily due to less significant agricultural and livestock damage as floods more directly affect exposed population centres. In Murcia, flood defences and irrigation protect against water damage, while in Mendoza such infrastructure is weak. At the same time, the more modern the infrastructure, the more communications and energy systems there are to be damaged.

Examining direct effects on society reveals a more complex picture. While the number of deaths has been reduced, technical achievements make it possible to lower this number even further. As with droughts, food security has been achieved in the case of floods. In Mendoza, socio-economic divides have contributed to continuing health problems. By comparison, in Murcia, credit dependence has created secular financial problems.

One of the symptoms of modernity is that higher flood exposure levels, together with the increasing monetary value of goods exposed, impacts housing stock and contributes to social unrest. Higher current territorial pressure has caused increasing pollution and overexploitation of aquifers during droughts.

The composition of biophysical vulnerability is similar for droughts and floods but significant developmental differences distinguish the impact in Murcia and Mendoza. In both areas, agricultural and livestock problems have been and remain the main territorial condition. Murcia, but not Mendoza, has seen some improvement on this front.

At the same time, in Murcia social conflicts due to increased pressure on territory have emerged, increasing both demand for, and politicization of, drought management (Fig. 3 panel B).

5.4 Changes in resilience and adaptation strategy

During the 17th century in Mendoza, proposals to address floods focused on reducing exposure, while in Murcia the focus was on economic measures and proposals to reduce biophysical vulnerability.

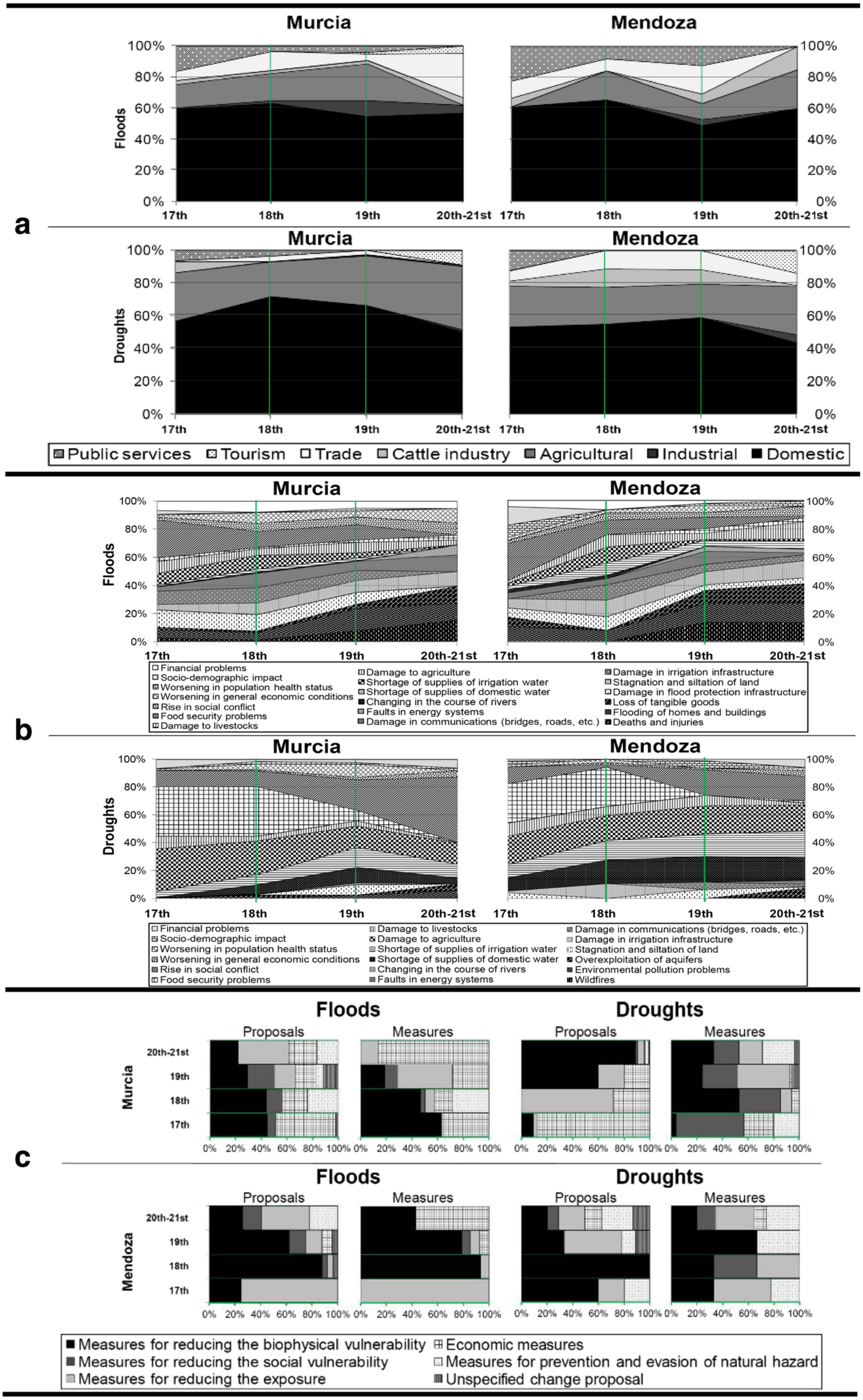
In the 18th century, in Mendoza, the strategies focused on measures and proposals to reduce biophysical vulnerability, while in Murcia, the focus was on avoiding natural hazard. In both cities, the leading measure remains the improvement of irrigation and defence infrastructure.

19th century floods were especially catastrophic, giving rise to a quantitative and qualitative leap in adaptation measures. The population was more aware that increased exposure and mismanagement were partly responsible for the impacts. However, in Mendoza, the type of measures and proposals did not vary much from the last century. In Murcia, the changes were very positive: increased economic measures reduced exposure. The flooding adaptation strategy in Murcia during the 19th century seems the most balanced of the last four centuries. However, this strategy has not held up to the present, since economic measures have been increased in both cities, leaving aside other types of actions (Fig. 3 panel C).

The adaptation strategy differs significantly between droughts and floods. In the 17th century, the city of Mendoza's recent founding motivated adaptation measures. For this reason, the measures and proposals to reduce the biophysical vulnerability were very important in Mendoza.

In the 18th century, proposals to reduce biophysical vulnerability, as well as measures to reduce social vulnerability, gained importance in Mendoza. In Murcia, there was an important change, as both measures to reduce social vulnerability, in addition to proposals to reduce social vulnerability increased.

In the 19th century the most important changes were: the increase in proposals for reducing exposure and measures to reduce biophysical vulnerability in Mendoza; and the increase in proposals for reducing biophysical vulnerability in Murcia. In the latter city, the adaptation strategy improved considerably, since there was a balance in the type of implementation measures.


a
Murcia
Mendoza
Floods
Droughts
0%
20%
40%
60%
80%
100%
17th
18th
19th
20th-21st
Public services
Tourism
Trade
Cattle industry
Agricultural
Industrial
Domestic
b
Financial problems
Socio-demographic impact
Worsening in population health status
Worsening in general economic conditions
Rise in social conflict
Food security problems
Damage to livestocks
Damage to agriculture
Shortage of supplies of irrigation water
Shortage of supplies of domestic water
Changing in the course of rivers
Faults in energy systems
Damage in communications (bridges, roads, etc.)
Damage in irrigation infrastructure
Stagnation and siltation of land
Damage in flood protection infrastructure
Loss of tangible goods
Flooding of homes and buildings
Deaths and injuries
Overexploitation of aquifers
Environmental pollution problems
Wildfires
c
Proposals
Measures
Measures for reducing the biophysical vulnerability
Measures for reducing the social vulnerability
Measures for reducing the exposure
Economic measures
Measures for prevention and evasion of natural hazard
Unspecified change proposal

◀**Fig. 3** Changes in social vulnerability (**a**), changes in biophysical vulnerability (**b**) and changes in resilience and adaptation strategy (**c**) during the last four centuries, due to: floods and droughts. In **a** and **b**, each column shows the data from a different century. Changes are shown inside the social vulnerability factor as percentage changes in each of the seven land uses affected. Changes are shown as percentage changes in each indicator for which the biophysical vulnerability factor (19 for floods and 18 for droughts) integrates. In **c**, each row shows the data from a different century. Changes are shown as percentage changes in each of the six general indicators for which the resilience and adaptation strategy factor is integrated, differentiating between proposals and measures

Currently, few changes with respect to previous centuries have occurred in the type of proposals in Mendoza. However, in this city, the measures are balanced and have thus improved. By contrast, in Murcia, politicization of discourse around water increased proposals to reduce biophysical vulnerability by increasing the supply of water, although the measures have improved in a sensitive manner given the increased efforts to avoid the natural hazard (Fig. 3 panel C).

6 Discussion and conclusions

After applying the PICCR, we confirmed the existence of three phases in the society-nature relationship first differentiated by Messerli et al. (2000). Here we outline the corresponding implications for the type of impact and response: (i) preindustrial agrarian societies from the 17th until the mid-18th century were characterized by passivity toward environmental vicissitudes due to the lack of technical resources and the religious tendency to blame God or sins of man; (ii) industrial agrarian societies from the mid-19th until the mid-20th century, particularly more agrarian societies, were characterized by the use of enlightened ideas and technological advances to facilitate intervention in the environment as people increasingly blamed nature and human acts for environmental danger; and (iii) current societies from the second half of the 20th century onwards, in which the globalized economy has disproportionately increased exposure to danger through the impact of droughts and floods—now thought to be caused by nature—in agriculture, trade, transport and tourism. Today, technology provides a false sense of security.

On a positive note, our results show an emergent 4th stage response: danger avoidance. In this sense, there has been an increase in adaptation proposals that advocate for exposure reduction in exposure as the best defence against danger.

However, the current situation shows several troubling issues. First, droughts have been politicized in Murcia—taking water from other basins is the most common adaptation proposal—which has increased social conflicts. Second, after the materialization of a natural disaster, residents have chosen to pay for damaged exposed goods (houses, road, and infrastructures), rather than to pay the cost of changing the model to prevent future damages. In this sense, and as Mauelshagen (2006: S83) points out: "severe crisis is regarded as the outcome of state failure."

Aligning with Messerli et al. (2000), we observed that, during droughts, the conditions of modernity have competing implications for drought management. The result is increased environmental problems and overexploitation of water resources. It is evident that the analysis of historical vulnerability is essential to understand recurrent errors and learn from our past (Juneja and Mauelshagen 2007).

As Susman et al. (1983) noted more than thirty years ago, it is necessary to pay priority attention to the evolution of the vulnerability of societies and the relationship between each social class and the natural hazard. The PICCR proves that any social class could feel safe from natural hazards.

The possibility of comparing vulnerability throughout time and space is determined by the definition of vulnerability. We define vulnerability as the increased probability of a given social system's failure. This failure is due to the defective application of the social model. Our vulnerability analysis demonstrates the problems associated with trying to apply linear and static social models in a changing and non-linear environment.

In any case, the study of vulnerability in different geographical areas and in different historical periods reveals the difficulty of studying complex adaptive social-ecological systems at-large (Holland 1995). The obstacles are even greater if we consider relations within these systems, particularly those biased by powerful interests. Such dynamics are difficult to quantify through an indicator. This is the main limitation of PICCR.

Future research should focus on how each sub-factor contributes to the management of floods and droughts. Additionally, the use of journalistic sources that are continuous and contemporary to the event under study could improve the method's applicability. By using such sources, the PICCR could be applied worldwide, in a variable time range from the 19th century to the present.

Acknowledgments We acknowledge financial support from the Economic Growth Center at Yale University and the Séneca Foundation (Agencia de Ciencia y Tecnología de la Región de Murcia). The authors thank two anonymous referees for useful comments and discussions. The authors also want to thank Kelly Goodman for editorial help.

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