ENVIRONMENTAL SCIENCE & POLICY 14 (2011) 794–803

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/envsci

Towards an inter-disciplinary research agenda on climate change, water and security in Southern Europe and neighboring countries

Ralf Ludwig [a,*], *Roberto Roson* [b,c], *Christos Zografos* [d], *Giorgios Kallis* [d]

[a] *Ludwig-Maximilians-Universitaet Muenchen, Department of Geography (LMU), Munich, Germany*
[b] *Ca'Foscari University, Venice, Italy*
[c] *Centro Euro-Mediterraneo per i Cambiamenti Climatici (CMCC) & IEFE, Bocconi University, Milan, Italy*
[d] *Universitat Autònoma de Barcelona, Institute of Environmental Science and Technology (UAB-ICTA), Spain*

ARTICLE INFO

Published on line 4 May 2011

Keywords:
Climate change
Water
Human security
Conflict
Mediterranean
CLIWASEC

ABSTRACT

The Mediterranean and neighboring countries are already experiencing a broad range of natural and man-made threats to water security. According to climate projections, the region is at risk due to its pronounced susceptibility to changes in the hydrological budget and extremes. Such changes are expected to have strong impacts on the management of water resources and on key strategic sectors of regional economies. Related developments have an increased capacity to exacerbate tensions, and even intra- and inter-state conflict among social, political, ecological and economic actors. Thus, effective adaptation and prevention policy measures call for multi-disciplinary analysis and action.

This review paper presents the current state-of-the-art on research related to climate change impacts upon water resources and security from an ecological, economic and social angle. It provides perspectives for current and upcoming research needs and describes the challenges and potential of integrating and clustering multi-disciplinary research interests in complex and interwoven human-environment systems and its contribution to the upcoming 5th assessment report of the IPCC.

1. Introduction

The latest reports of the intergovernmental panel on climate change (IPCC, 2007) reveal substantial evidence in historical and recent observations that the Mediterranean and neighboring regions are especially vulnerable to the impacts of climate change. Numerous climate projections, stemming from ensembles of global and regional climate models (Blenkinsop and Fowler, 2007; van der Linden and Mitchell, 2009), agree on severe changes in the climate forcing which are likely to exacerbate subsequent ecological, economic and social impacts. Many of these causal connections are closely linked to the general expectation that water availability will decline in the already water-stressed basins of Africa, the Mediterranean region and the Near East (Bates et al., 2008), even though considerable regional variances must be expected.

Consequently, climate change impacts on water resources are raising concerns regarding their possible management and security implications. Decreasing access to water resources and other related factors could be a cause or a 'multiplier' of tensions within and between countries. Whether security threats arise from climate impacts or options for cooperation

* *Corresponding author.*
E-mail address: r.ludwig@lmu.de (R. Ludwig).
1462-9011/$ – see front matter
doi:10.1016/j.envsci.2011.04.003

evolve does not depend only on the severity of the impacts themselves, but on social, economic, and institutional vulnerabilities or resilience as well as factors that influence local, national and international relations. Multidisciplinary research is needed to tackle the multi-facet complexity of climate change impacts on water resources in the Mediterranean and neighboring countries.

2. State of the art in research on climate change impact on water resources and security in Southern Europe and neighboring countries

This review of existing literature on water security with regard to climate change in the Mediterranean and neighboring regions is focused on three perspectives: (i) hydro-climatic change and eco-hydrological factors in relation to hazards such as floods or droughts, (ii) the economics of water, including the economics of virtual water trade and (iii) the social and political factors and conditions under which water hazards trigger conflict and/or threaten human security.

2.1. *Hydro-climatic aspects of water security*

Many studies over the past decade concurrently describe that Europe's sensitivity to climate change is characterized by a distinct north–south gradient, indicating most severe affects in Southern Europe (EEA, 2004) and the Mediterranean, as the already hot and semi-arid climate is expected to continuously become even warmer and drier (IPCC, 2007). This development will impose additional pressure on the vulnerability of freshwater resources and their management (Vörösmarty et al., 2000) and is likely to expand the spatial and temporal extent of water stress symptoms and phenomena (Alcamo et al., 2003).

The mean temperature in the central-west Mediterranean for the 20th century shows an increase of about 0.8 °C/100 year. Model simulations for Europe mostly agree on a strong increase of temperature for the 21st century, yet with regional and seasonal differences. It is projected that the increase of temperature rise in Southern Europe and the Mediterranean is expected to be higher in summer, with regional studies for the Iberian Peninsula hinterland indicating 5–7 °C higher in summer and 3–4 °C in winter. While temperatures on the coast are projected to increase by some 2 °C less than the hinterland, the number of days with extreme high temperatures would rise considerably, raising the number of days per year surpassing the heat index threshold by up to more than 50 all along the coastal rim of the Mediterranean (Diffenbaugh et al., 2007).

Hertig and Jacobeit (2008) assessed Mediterranean temperature changes in the 21st century from a multi-model analysis based on B2 emission scenarios to assess Mediterranean temperature changes in the 21st century. The results show a temperature increase for the whole Mediterranean area for all months of the year in the period 2071–2100 as compared to 1990–1999. The assessed temperature rise varies depending on region and season, but overall substantial temperature changes of partly more than 4 °C by the end of this century have to be anticipated under enhanced greenhouse warming conditions.

The Mediterranean is often referred to as the region most prone to severe climate induced changes on the hydrological cycle. Rising temperatures will cause the hydrological cycle to intensify and for most European regions, the frequency and intensity of extreme precipitation events and thus flood risks, particularly flash floods, is projected to increase. However, in terms of mean annual precipitation, a significant decrease in annual precipitation is expected (Norrant and Douguédroit, 2006) with strong seasonal and regional patterns (Gallego et al., 2006). While the general trend of an amplified decrease of precipitation during summer months is concurrently presented in nearly all studies, there is strong uncertainty about the projected magnitude of change, varying between more than 20% (IPCC, 2007) up to 70% (Räisänen et al., 2004) by the end of the 21st century. Consequently, annual runoff is projected to decrease for the whole region in the same time with up to 50% as compared to the reference period (Milly and Dunne, 2005). A crucial component of expected change is attributed to a shift in seasonal timing of water availability, especially if snowfall is involved in the water cycle. A gradual transition in winter precipitation from snow to rainfall (Kundzewicz et al., 2008) along with an earlier snow melt gives reason to an early onset of low flows (Stahl et al., 2008) and longer persisting water stress conditions, which increase the potential for tension in arid or semi-arid regions.

Until the 2050s, computed groundwater recharge decreases dramatically by more than 70% along the south rim of the Mediterranean Sea in comparison to the reference climate normal 1961–1990 (IPCC, 2007). While results from recent multi-model ensemble evaluations, conducted e.g. in the ENSEMBLES project (van der Linden and Mitchell, 2009), confirm the large spread in the projected changes of the water cycle, the climate variability (Lionello et al., 2006) and the extreme events (EEA, 2004), the agreement between models in projections of regional precipitation change with summer Mediterranean drying indicates a robust result with little uncertainty for the time horizon 2021–2050 (van der Linden and Mitchell, 2009). Overall, based on regional mean precipitation change, mean surface air temperature change, and change in precipitation and temperature interannual variability, Giorgi (2006) identifies the Mediterranean as a primary hotspot for responsiveness to climate change, using the comparative regional Climate change index (RCCI).

An immediate response to atmospheric warming is already measured and further expected from Mediterranean sea level rise (Tsimplis et al., 2008), which is attributed to a number of different sources, e.g. changes in atmospheric pressure, changes in currents and salinity, mainly thermal expansion and, to a small extent, additional water sources from land (melting snow and glaciers) (Marcos et al., 2009). Rising sea levels, and adjunct coastal erosion and flooding, impose a remarkable threat to water resources and security, especially near important coastal aquifers, which are endangered by salt water intrusion and thus enduring contamination. This is particularly true where the effects of eustatic sea level rise mix with strong near-coastal subsidence due to anthropogenic activity, such as in the Nile Delta, where extensive withdrawal of groundwater (and other resources), diminishing river sedimentation and natural isostatic causes give reason to expect pronounced and harmful impacts on coastal and deltaic water resources (Sherif and Singh, 1999) and the population (El-Raey et al., 1999).

It is further expected that water quality will deteriorate due to higher water temperatures and changes in extremes, including floods and droughts. These developments are projected to have possible negative impacts on ecosystems and human health, as well as water system reliability and operating costs. Besides this, changes in water quantity and quality due to climate change are expected to affect food availability, water access and utilisation, especially in arid and semi-arid areas, as well as the operation of water infrastructure, such as irrigation systems, which are of growing importance to sustain the regions agricultural productivity. Döll (2002) and Donevska and Dodeva (2002) report that the Mediterranean is among the regions where the highest increase in irrigation water demand is projected. Growing competition for available water resources is triggered by both climate change, i.e. diminishing water availability, and increasing water withdrawals and is likely to enlarge the area of severe water stress, particularly in southern France and Italy, Spain, Portugal, and Greece (Schröter et al., 2005).

Along with a generally changing frequency of low flow conditions (Hisdal et al., 2001), an increased frequency for long-duration droughts has been identified for southern European catchments, however with a yet uncertain magnitude (Blenkinsop and Fowler, 2007). Due to growing concerns over land degradation, further stressed by poor agricultural practice, and desertification, much research has been undertaken with a regional focus on the Mediterranean (Lana et al., 2009; Estrela et al., 2000) and the assessment of drought risk (Lehner et al., 2006). Weiß et al. (2007) examined the combined influences of climate and water consumptions on future drought frequencies around the Mediterranean. The results show strong increases in drought frequencies over all of Southern Europe for the A2 scenario.

2.2. *Economic aspects of water security*

During the second half of the 20th century, water demand in the Mediterranean has increased twofold, reaching 280 km^3/year (UNEP, 2006). Much of the demand comes from agricultural activities (45% in the North, 82% in South and East), but other industries also contribute significantly (most notably, tourism) and more competition for water resources can be easily foreseen in the near future. On the supply side, many countries are already affected by over-exploitation of renewable water resources (often generating salt-water intrusion) and exploitation of non-renewable resources (including the so-called ''fossil water'').

Much could be done through improved water management, proper water pricing and international cooperation. It is estimated (UNEP, 2006) that improved water demand management would make it possible to save 25% of water demand. Additional measures, such as the use of return water from agricultural drainage, the reuse of treated wastewater for irrigation, freshwater production through desalination of seawater or brackish water, may prove to be effective. Water pricing is also an important issue (OECD, 2009), although introducing water pricing is not easy and it would significantly affect the structure of regional economies and trade flows (Berrittella et al., 2008).

Market functioning, competition and trade, can also significantly help in allocating water resources more efficiently. In particular, international trade can be interpreted as an indirect exchange of primary resources, including water. To highlight the contribution of trade in alleviating water scarcity problems, Allan (1993) introduced the concept of ''virtual water'', that is, the implicit content of water in the production of goods and services, whereas ''virtual water trade'' refers to the implied exchange of water through conventional trade (Hoekstra, 2003). A large and flourishing literature on virtual water, as well as on the related concept of water ''footprint'', is now available (for a critical review, see Yang and Zehnder, 2007, and for a popularization of the concept, National Geographic, 2010).

Roson and Sartori (2010) present an analysis of virtual water trade in the Mediterranean, carried out through simulation experiments with a computable general equilibrium (CGE) model of the world economy. They show that most Mediterranean countries are *net* importers of virtual water through trade in agricultural products. The regions mostly dependent on virtual water imports are Cyprus, Italy, Albania and Egypt. The rest of Europe and Middle-East/North Africa are also significantly dependent on imports. Other countries, which are known to have limited water resources (e.g. Spain, Morocco, Tunisia, Turkey) turn out to virtually import little water, or even to export it. This result suggests that water resources in these countries may be under-priced and over-exploited. In other words, water is kept ''artificially abundant'' and water-intensive industries have a significant role in the productive structure of these economies.

A future reduction of water availability in the Mediterranean could have negative consequences in terms of national income and welfare. Less water means lower agricultural productivity, and lower competitiveness in international markets. Roson and Sartori (2010) found that, on average, a reduction of 1% in agricultural productivity is associated with additional *net* virtual water imports, estimated to be 1277 Mm^3 of water in Spain, 1158 in Italy, 547 in Egypt, 437 in Turkey, 326 in Morocco, 226 in Greece, 145 in Tunisia.

The macroeconomic loss due to future water scarcity depends on the assumed reduction of water resources (which is estimated on the basis of climatologic and hydrologic scenarios, as well as on specific hypotheses about water management), but also depends on the share of agricultural activities in the economy. Preliminary results from Roson and Sartori (2010) indicate that the welfare impact of reduced water availability in the year 2050 would be equivalent to a loss of 10,559 M$ in Spain, 6891 M$ in Morocco, and 5830 M$ in Italy.

2.3. *Socio-political aspects of water security*

Reasons to worry about the impacts of climate changes on hydrological and by extension, human systems abound. The current rate of change is unprecedented (IPCC, 2007; Stern, 2006) and hydro-climatic variations have triggered large-scale social disruptions in the past (Lucero, 2002; Davis, 2001). As a macro-driver of environmental change, climate change poses risks to security. In November 2008, a National Intelligence Council report to President-elect Obama predicted that water shortages will fuel conflict (NIC, 2008). The UN Secretary-General Ban Ki-moon (Ban, 2007), the European Commission and the High Representative to the European Council (EC, 2008) have also voiced concerns over the security implications of climate change.

However, the link between climate change and international military conflict is by no means clear: Nordås and Gleditsch (2007) find that beyond reports by think-tanks and governmental and international agencies, which in general suffer from lack of reference to empirical evidence, there is little research on the links between climate change, security and conflict. They note a lack of large-size statistical studies linking climatic, environmental and socio-economic variables with conflict or cooperation. The oft-stated statement in the media that ''21st century wars will be about water'' is thinly supported by evidence. Some studies suggest a potential for water wars (Gleick, 1993; Renner, 1996; Klare, 2001), but others are sceptical (Beaumont, 1997; Wolf, 1999). Although neighboringneighboring countries that share rivers experience low-level interstate conflict somewhat more frequently (Gleditsch et al., 2006), they also tend to cooperate more (Brochmann and Gleditsch, 2006). Cooperation consistently trumps conflict in handling shared international water resources (Yoffe et al., 2003). The literature on water scarcity and domestic conflict is even more ambiguous: some do find such a relationship (Hauge and Ellingsen, 1998) while others do not (Esty et al., 1998; Theisen, 2006). Raleigh and Urdal (2007) find that environmental and demographic variables have a moderate to low effect on the risk of civil conflict; however, local freshwater scarcity somehow increases the risk of conflict. Importantly, the use of traditional institutions in conflict management can moderate drought conflicts (Nyong et al., 2006).

Nevertheless, global environmental changes can potentially affect the foundations of social subsistence. Environmental change may reduce access to, and the quality of natural resources important to sustain livelihoods and in this way affect the security of individuals and groups; moreover, it may undermine the capacity of states to provide opportunities and services that help people sustain their livelihoods (Barnett and Adger, 2010). A concern with human (as opposed to state) implications of climate change relates security to individual and community well-being and conceptualizes climate security as ''a state whereby individuals and localities have the necessary options to respond to threats to their human, environmental and social well-being imposed by climate change and have the capacity and freedom to exercise these options'' (Adger, 2010, p.281).

Within this human security context, more in-depth empirical studies of security-oriented vulnerability research are needed (Barnett and Adger, 2007). Whereas knowledge regarding the drivers of vulnerability to climate change is increasing (Kelly and Adger, 2000), we still know little about vulnerability to socio-economic stressors acting in concert with climate change (Gallopín, 2006). A substantial body of literature examines how systems differ in their vulnerability to climate change (Adger, 2006; Ford and Smit, 2004; Eriksen et al., 2005) and how this vulnerability depends on the adaptive capacity of systems (Yohe and Tol, 2002; Smit and Wandel, 2006) and exposure to climate change (O'Brien and Leichenko, 2000; Kundzewicz, 2003). Still, this literature needs to expand to more hazards and geographical areas of high stress/exposure, high impacts and history or potential of conflict, as well as to improve integration with security research by seeking to refine the concept of security (Barnett and Adger, 2007). Climate change challenges us to re-think what we mean by security beyond traditional ideas of protection from external military threat or internal subversion of the political order, by integrating issues of justice and the relevance of the global political economy in generating insecurity (Dalby, 2009). For example, gender is one analytical category for understanding social causes of climate change vulnerability that needs to be looked at more closely, as well as the role of perceptions in mediating environmental changes and social responses to climate change (Barnet et al., 2010).

There is very little work that specifically links climate change and security threats with water resources (Goulden et al., 2008). Case studies of hydro-conflicts tend to concentrate on individual countries or river basins, with considerable emphasis on the Middle East (Lonergan and Brooks, 1994; Selby, 2003). The large-N statistical literature on water conflict and cooperation focuses primarily on transboundary water issues (Bernauer and Kuhn, 2010; Brochmann and Gleditsch, 2006; Gleditsch et al., 2006), but links between water and domestic conflict are less developed, and the literature generally suffers from data shortcomings (Theisen, 2006; Binningsbø et al., 2007). However, experience shows that the danger of violent escalation of water-related conflicts is biggest on the domestic and local (water point) level in forms of localised violent conflict between water users in rural environments or new types of violence such as 'water riots' (Ravnborg, 2004). Low-intensity conflicts between rural areas and cities, or environmentalists and water authorities are also common in the 'global North'. Domestic, inter-state water conflicts and their links to climate change have received scant attention.

Large-scale migration pressures could result as a response to hydro-climatic changes and may breed conflict by altering existing patterns of water availability and quality (Renaud et al., 2007, 2008) or by exacerbating conflict in recipient areas. Nevertheless, there is still little systematic and no concluding evidence linking hydro-climatic changes, migration and conflict (Salehyan and Gleditsch, 2006; Suhrke, 1997). Experience shows that most migration flows do not lead to conflict and this underlines the importance of social integration and citizenship policies (Salehyan, 2008). Similarly, conflict may also arise around adaptation responses such as dams or desalination plants, a source of conflict between environmentalists or displaced populations and authorities (Kallis, 2008). Additionally, conflict can occur in the context of recently proliferated 'proto-' or 'quasi-states', political entities that possess neither full legal nor full political attributes of statehood, typically borne out of partitions, inconclusive peace processes and peace-building projects (e.g. Serbia-Kosovo, Israel-Palestine, Cyprus). In these contexts, the focus of hydro-politics can be complicated by such factors as the sharing of infrastructures, opaque lines of territorial control and political authority, and a high degree of political enmity combined with inter-elite bargaining.

On a more conceptual level, a significant body of the actors-conflict research that proposes direct links between hydro-climatic change and conflict tends to adopt narrow economistic models of human action which assume utility-maximizing individuals who undertake violence when benefits of doing so exceed costs (Barnett and Adger, 2007; Cramer, 2002). Nevertheless, such models overlook the institutional premises of human action and interaction with the environment (Vatn, 2005). Systemic and historical approaches that focus on the structural outcomes of uneven resource and power distributions, and the struggles of different groups over contested entitlements, property, labour and recognition are well-suited for explaining conflicts emerging as a result of climate-induced changes (e.g. Zografos and Martínez-Alier, 2009). This political ecology research agenda shifts emphasis from psychological and economic motivations to the historical geography of conflicts, the power relations between actors, and the forms of access to and control over resources (Martínez-Alier, 2002; Peluso & Watts, 2001).

Finally, despite calls by political actors for attention to climate change and security issues, there seems to be a lack of concrete ideas concerning appropriate international and national policy responses and how these would differ from or fit in with existing ones (Meyer-Ohlendorf, 2007, 2008). There are for example various EU policies that touch issues relevant to climate changes, water resources and security (e.g. the 2007 green paper ‘adapting to climate change in Europe – options for EU action’) but none addresses them directly. There is lack of horizontal policy integration to tackle hydro-security issues. This lack of a comprehensive approach is not unrelated to the lack of rigorous scientific conceptualization or understanding of the links between climate change, water, vulnerability, security and conflict. While an inability to develop certainty (UNDP, 2006) and assess the real risks of water management (Pahl-Wostl and Jeffrey, 2007) can lead to inaction, it is important to design management systems that can address the multiple uncertainties that will always exist (Berkes, 2007; Gunderson and Light, 2006). In that sense, international water treaties are an important source of political stability and an important determinant of hydro-cooperation and resilience (Wolf, 2007; Fischhendler, 2008). However, still no quantitative analysis has been published of how risks and uncertainties have been translated into transboundary water treaty structures and language. There is a lack of a systematic study on the ways (and their effectiveness) to absorb uncertainties and resolve water conflicts that stem from uncertainties including those produced by climate change.

3. Towards an interdisciplinary research agenda

Until now, no common monitoring and/or modelling methods are available in climate change research to integratively describe interactions between natural and social processes. This is due to large differences in the way various disciplines formalize, term and describe their understanding and concepts of respective processes and interconnections. Transdisciplinary integration is required to provide a profound knowledge base to tackle current and future challenges related to climate change impacts. The clustering of projects dealing with similar topics, yet from different perspectives, is identified as a possible solution for this persistent problem in climate change research.

3.1. *The CLIWASEC cluster*

The European commission actively prepares Europe and neighboring regions for climate induced ecological and socio-economic challenges that lie ahead and has placed related priority research topics in the Seventh Framework Program for Research and Technological Development (FP7). In order to better assess the consequences and uncertainties regarding climate impacts upon human-environment systems, a coordinated topic has been established between Theme 6 (‘environment (incl. climate change)’) and Theme 8 (‘social sciences and the humanities’) of the programmatic setup of FP7. Three recently launched projects form the research cluster CLIWASEC (CLimate change Impacts on Water and SECurity, www.cliwasec.eu) for multi-disciplinary scientific synergy and improved policy outreach. The cluster comprises a critical mass of scientists from 44 partners (29 institutions from the EU, 5 institutions from S&T countries and 10 international institutions) to build relationships with relevant policy representatives and stakeholders at EU level and Mediterranean and neighboringneighboring countries covered by the projects. It tackles most relevant research questions with regard to climate change impacts on water resources as a threat to security in an integrated way:

- WASSERMed – Water Availability and Security in Southern Europe and the Mediterranean (funded under FP7-ENV), co-ordinated by CMCC, Italy (www.wassermed.eu)
- CLICO – Climate Change, Hydro-Conflicts and Human Security (funded under FP7-SSH), co-ordinated by UAB-ICTA, Spain (www.clico.org)
- CLIMB – Climate Induced Changes on the Hydrology of Mediterranean Basins (funded under FP7-ENV), co-ordinated by LMU, Germany (www.climb-fp7.eu)

Details on the projects can be found in Roson et al. (2010).

3.2. *Potential and challenges of cluster research*

Cooperation between partner projects from different backgrounds creates scientific synergies: it allows researchers to identify and utilize complementary monitoring and modellingmethods, harmonize and share data, discuss dissemination strategies or elaborate and propose adaptation alternatives. To optimize benefits from the variety of cluster partners’ competences, joint research must be devoted towards a better understanding and description of interfaces in such complex systems. Two main challenges lie ahead: (i) bridging scales and (ii) quantifying and reducing uncertainty. Integrating different methods from natural and social sciences can contribute to better conceptualize each project’s research

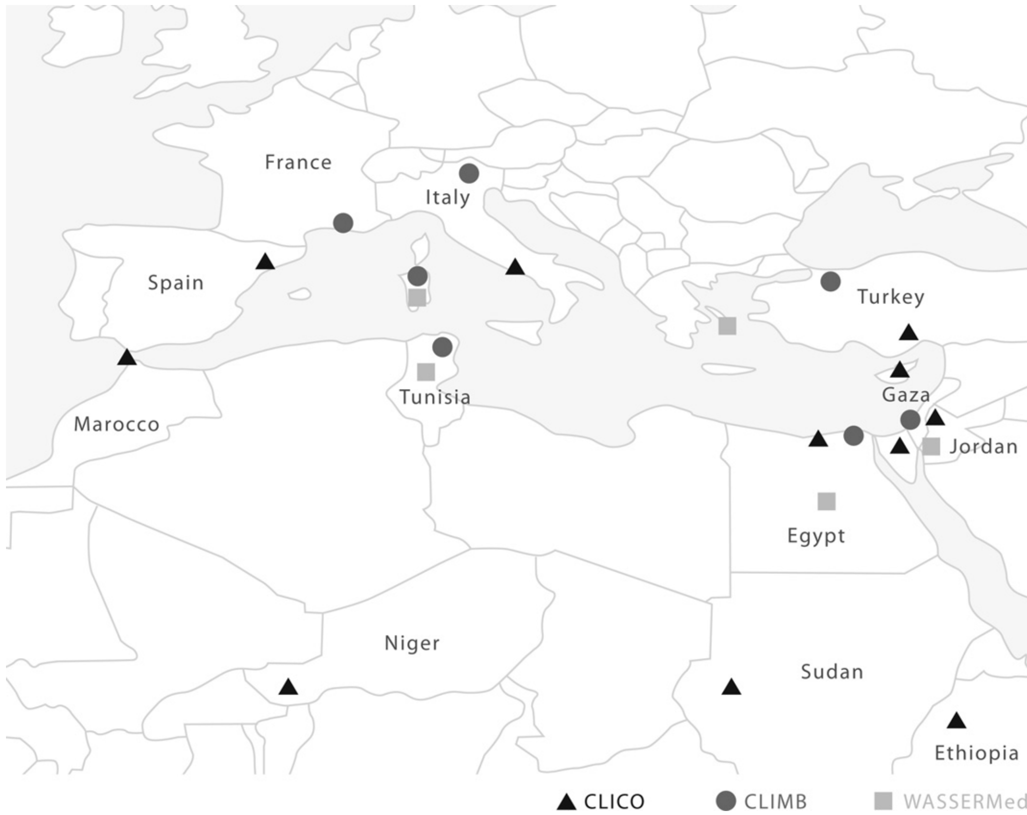

Fig. 1 – The distribution of study sites in the CLIWASEC cluster projects.

findings and propose solutions for water resource management under climate change, especially when a variety of different situations can be covered in complementary case studies (Fig. 1).

3.2.1. *Bridging scales*

Besides the different perspectives on climate induced changes as a threat to water security, the CLIWASEC projects are considering different scales, as processes with a pronounced spatial character (e.g. precipitation, evapotranspiration) interact with linear processes (e.g. river runoff) as well as with processes without any direct connection to one specific spatial scale (e.g. economic, political or social decision making, where impacts are spatially disaggregated to various scales). Depending on selected process and scale, these processes can be described: (i) explicitly (microscale – field to small-sized catchments in the range of up to several 100 km^2), (ii) mechanistically (mesoscale – in the order of medium sized river catchments in the range of up to several 1000 km^2) or (iii) effectively (macroscale – in the order of regions, possibly ranging up to over 100,000 km^2). The transition from microscale to macroscale and back is always complex if the described processes are not linear and the case studies being investigated are heterogeneous, such as the ones proposed by the CLIWASEC projects. While maintaining project research focus, one great opportunity for project collaboration comprises improved descriptions of scale interfaces. The spatially explicit results of distributed scale-crossing (environmental) models, such as the ones used in CLIMB (micro- to mesoscale) and WASSERMed (meso- to macroscale), can support and feed a yet largely unused interface to socio-economic sciences, which transfer the high-resolution signal of climate induced hydrological change into relevant socio-economic information at the appropriate scale. Decisions and courses of action which are consequently derived, such as any change in management practices, can in return be spatially disaggregated using the same interface to provide an additional external force for the hydrological/environmental models operating at the small scale. In this way, research groups can follow their sectoral expertise and joint efforts can focus on the definition of interfaces and their functionality to bridge scales.

3.2.2. *Quantifying and reducing uncertainty*

The current potential to develop appropriate regional adaptation measures towards climate change impacts suffers heavily from large uncertainties. These spread along a long chain of components, starting from the definition of emission scenarios to global and regional climate modelling to impact models and a subsequent variety of management options. The critical mass of research capacity obtained through clustering the projects will allow for quantifying uncertainties in climate change impact analysis for the Mediterranean and neighboring regions to a yet unprecedented level, as most of the inherent contributors to uncertainty are being addressed. Again, a specified definition of interfaces, linked to an exchange of data, methods and model results, is the key prerequisite. Most projects dealing with climate change impact analysis are usually making vast use of available Global and Regional Climate Model data (GCM and RCM, respectively) without ever exchanging the methods and reasons for making their climate data selections. The audits that lead to select the best regional performers as compared to observed values during the climatic reference period can be openly discussed and exchanged and thus contribute substantially to the reduction of uncertainty. Conjointly evaluated procedures for downscaling RCM data will deliver the driving inputs for subsequent (hydrological) impact models, transferring a future climate signal into hydrological quantities at the catchment or landscape scale.

However, very limited quantitative knowledge is as yet available about the role of hydrological model complexity for climate change impact assessment, where predictive power becomes more and more important and raises the demand for process-based and spatially explicit model types (Ludwig et al., 2009). Hydrological model ensembles serve to analyse existing models and help to identify the appropriate level of model complexity, and thus to determine the data specifications required to provide robust results in a climate change context.

The joint research forces provided by clustering expands the possibilities for data mining and exchange. Data uncertainty can be reduced by creating a potent and multi-scale data repository that serves to parameterize integrated impact models and comprehensively describe the regions' vulnerability, associated risks and adaptive capacity. Further, the lack of awareness or understanding of the complex climate-resource-society dynamics often leads to take inappropriate or no measures at all. An inventory of international, national and regional policies dealing with responses to climate change, water resources management, responses to hazards and disasters, and security in the region, is essential for proposing a suitable policy framework to integrate security, climate change adaptation and water management issues and specific recommendations for policy streamlining at the UN, EU, national and regional levels.

3.3. Contribution to the 5th assessment report of the IPCC

The revised table of cross-cutting contents for the 5th AR, as announced in the outline compilation (www.ipcc.ch), is in several ways conducive to the research goals tackled by the cluster and its regional focus on the Mediterranean and neighboring countries, possibly being the most important cross-regional hotspot.

We expect that the intensified consideration of climate change and variability on regional scales in all Working Groups is providing a wider platform to pronounce the clusters' perspective on impact and adaptation research for the region. In addressing the physical science basis, the auditing and downscaling approaches for climate model data, including frequency and intensity analysis of meteorological extremes, is highly pertinent. The ensemble of (coupled) hydrological and hydro-geological models applied to the case studies in the region, the first of its kind, will foster the physical understanding of climate change impacts on the diminishing availability of water resources and associated changes in the hydrological cycle, runoff regimes and extremes.

The cluster's strong focus on the quantification and reduction of uncertainties is of particular relevance for all aspects of Working Group II (impact, adaptation and vulnerability), as it will add substantially to the availability of regionally harmonized data, and for the framing issues outlined in Working Group III, where an assessment of risk and uncertainty of climate change response policies as well as tools for respective analysis are specifically requested. In the latter, a full chapter will be devoted to the social, economic and ethical aspects of climate change.

4. Conclusion

A review on the current state of the art on climate change research for the Mediterranean region shows large scientific consensus that climate change is impacting the area in a manifold and distinct fashion. Recently observed trends and projections from climate model ensembles indicate a strong susceptibility to change in hydrological regimes, an increasing general shortage of water resources and consequent threats to water availability and management. Our comprehensive summary highlights threats resulting from decreasing groundwater resources, strongly increasing drought risk or flash floods, advancing sea-level rise, and their impact on key strategic sectors of regional economies with consequent macroeconomic and social implications. It shows that the magnitude of change contains a strong capacity to aggravate tensions that may lead into conflict among different socio-economic actors. However, it must be clearly stated that current uncertainties in climate projections and subsequent (hydrological) model chains, a yet incomplete understanding of the impact of a climate change signal on (micro- and macro-) economic mechanisms, and the lack of an elaborate and integrated human security conceptual framework are imposing strong limitations on water-related decision-making under conditions of climate change. This is particularly true due to the general lack of regional data and the yet unresolved mismatch of spatial and temporal scales of operation from different scientific perspectives.

The clustering of projects can help push forward current understanding of the interactions of climate change impacts on ecological, economic and social components of human-environment systems. This is essential for advancing towards optimized regional solutions for water resources management under climate change.

Acknowledgements

The authors would like to thank the European Commission for funding WASSERMed (GA: 244255), CLICO (GA: 244443) and CLIMB (GA: 244151) projects in the 7th Research Framework Program. Collaboration and contributions from all project partners is gratefully acknowledged.

REFERENCES

Adger, W.N., 2006. Vulnerability Global Env. Change 16 (3) 268–281.

Alcamo, J., Döll, P., Henrichs, T., Kaspar, F., Lehner, B., Rösch, T., Siebert, S., 2003. Development and testing of the WaterGAP 2 global model of water use and availability. Hydrol. Sci. J. 48, 317–338.
Allan, J.A., 1993. Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. In: ODA, Priorities for water resources allocation and management, ODA, London, pp. 13–26.
Ban, K.M., 2007. A climate culprit in Darfur. Washington Post, 16 June 2007.
Barnet, J., Matthew, R.A., O'Brien, K.L., 2010. Charting the next generation of global environmental change and human security research. In: Matthew, R., McDonald, B., Barnett, J., O'Brien, K. (Eds.), Global Environmental Change and Human Security. MIT Press, Cambridge, MA.
Barnett, J., Adger, N., 2007. Climate change, human security and violent conflict. Polit. Geogr. 26 (6), 639–655.
Barnett, J., Adger, N., 2010. Environmental change, human security, and violent conflict. In: Matthew, R., McDonald, B., Barnett, J., O'Brien, K. (Eds.), Global Environmental Change and Human Security. MIT Press, Cambridge, MA.
Bates, B.C., Kundzewicz Z.W., Wu S., Palutikof J.P. (Eds.), 2008: Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, pp. 210.
Beaumont, P., 1997. Water and armed conflict in the Middle East: a fantasy or reality? In: Gleditsch, N.P. (Ed.), Conflict and the Environment. Kluwer Academic, pp. 355–374.
Berkes, F., 2007. Understanding uncertainty and reducing vulnerability: lessons from resilience thinking. Nat. Hazard. 41 (2), 283–295.
Bernauer, T., Kuhn, P., 2010. Is there an environmental version of the kantian peace? insights from water pollution in Europe. Eur. J. of Intern. Rel. 16 (1), 77–102.
Berrittella, M., Rehdanz, K., Roson, R., Tol, R.S.J., 2008. The economic impact of water taxes: a computable general equilibrium analysis with an international data set. Water Policy 10 (3), 259–271.
Binningsbø, H.M., de Soysa, I., Gleditsch, N.P., 2007. Green giant or straw man? environmental pressure and civil conflict, 1961–99. Popul. Environ. 28 (6), 337–355.
Blenkinsop, S., Fowler, H.J., 2007. Changes in drought characteristics for Europe projected by the PRUDENCE regional climate models. Int. J. Climatol. 27 (12), 1595–1610.
Brochmann, M., Gleditsch, N.P., 2006. Shared rivers and international cooperation. Workshop on Polarization and Conflict Nicosia, Cyprus, 26–29 April.
Cramer, C., 2002. Homo economicus goes to war: methodological individualism, rational choice and the political economy of war. World Dev. 30, 1845–1864.
Dalby, S., 2009. Security and Environmental Change. Policy Press, Cambridge.
Davis M., 2001. Late Victorian Holocausts: El Niño Famines and the Making of the Third World' London, Verso. p. 464.
Diffenbaugh, N.S., Pal, J.S., Giorgi, F., Xuejie, Gao, 2007. Heat stress intensification in the Mediterranean climate change hotspot. Geophys. Res. Lett. 34, 11706.
Döll, P., 2002. Impact of climate change and variability on irrigation requirements: a global perspective. Climatic Change 54, 269–293.
Donevska, K., Dodeva, S., 2002. The Impact of Climate and Rain Data on Irrigation Requirements in Semi Arid Areas, Int. Conf. on Drought Mitigation and Prevention of Land Desertification. Bled, Slovenia.
El-Raey, M., Dewidar, K.R., El-Hattab, M., 1999. Adaptation to the impacts of sea level rise in Egypt. Mitigation Adapt. Strategies Global Change 4, 343–361.
Eriksen, S.H., Brown, K., Kelly, P.M., 2005. The dynamics of vulnerability: locating coping strategies in Kenya and Tanzania. Geogr. J. 171, 287–305.
Estrela, M.J., Penarrocha, D., Millan, M., 2000. Multi-annual drought episodes in the Mediterranean (Valencia region) from 1950–1996. A spatio-temporal analysis. Int. J. Climatol. 20 (13), 1599–1618.
Esty, D.C., Goldstone, J.A., Gurr, T.R., Surko, P.T., Unger, A.N., 1998. State Failure Task Force Report: Phase II Findings, McLean, VA: Science Applications International, for State Failure Task Force.
European Commission, 2008. Climate change and international security. Council Doc. 7249/08 of 03.03.2008.
European Environment Agency, 2004. Impacts of Europe's changing climate–An indicator based assessment. TR No. 2/2004, European Environment Agency, 2005. Climate change and river flooding in Europe. EEA Briefing 01/2005.
Fischhendler, I., 2008. Ambiguity in transboundary environmental dispute resolution: the Israeli-Jordanian water agreement. J. Peace Res. 45 (1), 79–97.
Ford, J.D., Smit, B., 2004. A framework for assessing the vulnerability of communities in the Canadian arctic to risks associated with climate change. Arctic 57 (4), 389–400.
Gallego, M.C., Garcıa, J.A., Vaquero, J.M., Mateos, V.L., 2006. Changes in frequency and intensity of daily precipitation over the Iberian Peninsula. J. Geophys. Res. 111, 280 doi:0.1029/2006JD007.
Gallopín, G.C., 2006. Linkages between vulnerability, resilience, and adaptive capacity. Glob. Environ. Change 16, 293–303.
Giorgi, F., 2006. Climate change hot-spots. Geophys. Res. Lett. 33 L08707, doi:10.1029/2006GL 025734.
Gleditsch, N.P., Furlong, K., Hegre, H., Lacina, B., Owen, T., 2006. Conflicts over shared rivers: resource scarcity or fuzzy boundaries? Polit. Geogr. 25 (4), 361–382.
Gleick, P.H., 1993. Water and conflict: fresh water resources and international security. Int. Secur. 18 (1), 79–112.
Goulden, M., Conway, D., Persechino, A., 2008. Adaptation to Climate Change in International River Basins in Africa: a Review. In: Tyndall Centre Working Paper 127, December 2008.
Gunderson, L., Light, S.S., 2006. Adaptive management and adaptive governance in the Everglades ecosystem. Policy Sci. 39 (4), 323–334.
Hauge, W., Ellingsen, T., 1998. Beyond environmental scarcity: causal pathways to conflict. J. Peace Res. 35 (3), 299–317.
Hertig, E., Jacobeit, J., 2008. Downscaling future climate change: temperature scenarios for the Mediterranean area. Global Planetary Change 63 (2–3), 127–131.
Hisdal, H., Stahl, K., Tallaksen, L., Demuth, S., 2001. Have stream flow droughts in Europe become more severe or frequent? Int. J. Climatol. 21, 317–333.
Hoekstra, A.Y., 2003. Virtual Water: an Introduction. in: A.Y. Hoekstra (ed.). Virtual water trade. Value of Water Research Report Series No. 12, IHE Delft.
IPCC, 2007. Climate Change 2007: Synthesis report. Contribution of Working Groups I–III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.
Kallis, G., 2008. Droughts. Annu. Rev. Environ. Resour. 33, 85–118.
Kelly, P.M., Adger, W.N., 2000. Theory and Practice in Assessing Vulnerability to Climate Change and Facilitating Adaptation. Climate Change 47 (4), 325–352.
Klare, M.T., 2001. The new geography of conflict. Foreign Aff. 80 (3), 49–61.
Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Doll, P., Jimenez, B., Miller, K., Oki, T., Sen, Z., Shiklomanov, 2008. The implications of projected climate change for freshwater resources and their management. Hydrol. Sci. J. 53 (1).

Kundzewicz, Z.W., 2003. Extreme precipitation and floods in the changing world. Water Resour. Syst.-Hydrol. Risk, Manage.Dev. 281, 32–39.

Lana, X., Burgueno, A., Martínez, M.D., Serra, C., 2009. A review of statistical analyses on monthly and daily rainfall in Catalonia. Tethys – J. Mediterranean Meteorol. Climatol. 6 (1).

Lehner, B., Döll, P., Alcamo, J., Henrichs, T., Kaspar, F., 2006. Estimating the impact of global change on flood and drought risks in Europe: a continental, integrated analysis. Climatic Change 75 (3), 273–299.

Lionello, P., Malanotte-Rizzoli, P., Boscolo, R., 2006. Mediterranean Climate Variability. Elsevier Science, p. 438.

Lonergan, S.C., Brooks, D., 1994. Watershed: The Role of Fresh Water in the Israeli-Palestinian Conflict. International Development Research Center, Ottawa.

Lucero, L.J., 2002. The collapse of the Classic Maya: A case for the role of water control. Am. Anthropol. 104, 814–826.

Ludwig, R., Turcotte, R., Vescovi, L., 2009. The role of hydrologic model complexity and uncertainty in climate change impact assessment. Adv. Geosci. 7, 1–9.

Marcos, M., Tsimplis, M.N., Shaw, A.G.P., 2009. Sea level extremes in southern Europe. J. Geophys. Res. 114 C01007, doi:10.1029/2008JC004912.

Martínez-Alier, J., 2002. The Environmentalism of the Poor: A Study of Ecological Conflicts and Valuation. Edward Elgar, Cheltenham.

Meyer-Ohlendorf, N., 2007. Reconceptualisation of Security Strategies and Political Processes. Note based on a presentation given at the Bonn International Centre for Conversion (BICC), 27 September 2007.

Meyer-Ohlendorf, N., 2008. Environmental and resource policies in the context of the UN: A chance for cooperation?' Note based on a presentation given at the UNO-Symposium: The Conflict on Resources: A threat for the international security?. Haus Rissen Hamburg, 9 October 2008.

Milly, P.C.D, Dunne, K.A., Vecchia, A.V., 2005. Global pattern of trends in streamflow and water availability in a changing climate. Nature 438, 347–350 doi:10.1038/nature04312.

National Geographic, 2010. Water–our thirsty world, Special Issue (US Edition), April 2010, National Geographic Society, Washington D.C.

NIC (National Intelligence Council), 2008. Global Trends 2025, Washington DC: National Intelligence Council and Office of the Director of National Intelligence.

Nordås, R., Gleditsch, N.P., 2007. Climate change and conflict. Polit. Geogr. 26, 627–638.

Norrant, C., Douguédroit, A., 2006. Monthly and daily precipitation trends in the Mediterranean. Theor. Appl. Climatol. 83, 89–106.

Nyong, A., Fiki, C., McLeman, R., 2006. Drought-related conflicts, management and resolution in the West African Sahel: considerations for climate change research. Die Erde 137 (3), 223–248.

O'Brien, K.L., Leichenko, R.M., 2000. Double exposure: assessing the impacts of climate change within the context of economic globalization. Global Environ. Change-Hum. Policy Dimensions 10 (3), 221–232.

OECD, 2009. Managing Water for All. An OECD Perspective on Pricing and Financing. Organisation for Economic Cooperation and Development, Paris.

Pahl-Wostl, C., Jeffrey, P., 2007. Adaptive water management: how to cope with uncertaint. NeWater 4, 1–7.

Peluso, N.L., Watts, M., 2001. Violent Environments. Cornell University Press, Ithaca, NY.

Räisänen, J., Hansson, U., Ullerstig, A., Doscher, R., Graham, L.P., Jones, C., Meier, H.E.M., Samuelsson, P., Willen, U., 2004. European climate in the late twenty-first century: regional simulations with two driving global models and two forcing scenarios. Climate Dyn. 22 (1), 13–31.

Raleigh, C., Urdal, H., 2007. Climate change, environmental degradation and armed conflict. Polit. Geogr. 26 (6), 674–694.

Ravnborg, H.M. (Ed.), 2004. Water and conflict: conflict prevention and mitigation in water resources management. Danish Institute for International Studies, Copenhagen.

Renaud, F., Bogardi, J.J., Dun, O., Warner, K., 2007. Control, adapt or flee: How to face environmental migration. InterSecTions no. 5, UNU-IEHS Bonn.

Renaud, F., Dun, O., Warner, K., Bogardi, J.J., 2008. Deciphering the Importance of Environmental Factors in Human Migration. Paper presented at the EFMSV conference in Bonn, 9–11 October 2008.

Renner, M., 1996. Fighting for survival. Environmental decline, social conflict, the new age of insecurity. Norton, for Worldwatch Institute, New York and London.

Roson, R. and M. Sartori, 2010. Water Scarcity and Virtual Water Trade in the Mediterranean. IEFE Working Paper No. 38.

Roson, R., Kallis, G., Zografos, C., Ludwig, R., 2010. Climate change impacts on water and security: orientations of the research foreseen over 2010–2013. In: Quevauviller, P., et al. (Eds.), Water Framework Directive: action programmes and adaptation to climate change. RSC Publishing.

Salehyan, I., Gleditsch, K.S., 2006. Refugees and the spread of civil war. Int. Organization 60 (2), 335–366.

Salehyan, I., 2008. From Climate Change to Conflict?: No Consensus Yet. Journal of Peace Research. 45 (3), 315–326.

Schröter, D., Cramer, W., et al., 2005. Ecosystem service supply and vulnerability to global change in Europe. Science 310 (5752), 1333–1337.

Selby, J., 2003. Water, power and politics in the Middle East: The other Israeli-Palestinian conflict. I.B. Tauris, London, p. 281.

Sherif, M.M., Singh, V.P., 1999. Effect of climate change on sea water intrusion in coastal aquifers. Hydrol. Process. 13, 1277–1287.

Smit, B., Wandel, J., 2006. Adaptation, adaptive capacity and vulnerability. Global Environ. Change 16 (3), 282–292.

Stahl, K., Hisdal, H., Tallaksen, L.M., van Lanen, H.A.J., Hannaford, J. and Sauquet, E., 2008. Trends in low flows and streamflow droughts across Europe. UNESCO Report, Paris.

Stern, N., 2006. The economics of climate change. Stern review. HM Treasury, London.

Suhrke, A., 1997. Environmental degradation, migration, the potential for violent conflict. In: Gleditsch, N.P., et, al. (Eds.), Conflict and the Environment. Kluwer Academic, pp. 255–272.

Theisen, O.M., 2006. Other pathways to conflict? Environmental scarcities and domestic conflict. 47th Annual Convention of the International Studies Association San Diego, CA, 22–25 March.

Tsimplis, M.N., Marcos, M., Somot, S., 2008. 21st century Mediterranean sea level rise: steric and atmospheric pressure contributions from a regional model. Global Planetary Change 63 (2–3), 105–111.

UNDP, 2006. Human Development Report. Beyond Scarcity: Power, Poverty, and the Global Water Crisis. Palgrave Macmillan, Basingstoke.

UNEP–Plan Bleu, 2006. Facing water stress and shortage in the Mediterranean, Blue Plan Notes no. 4.

van der Linden P., and J.F.B. Mitchell (eds.), 2009. ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, pp. 160.

Vatn, A., 2005. Institutions and the Environment. Edward Elgar, Cheltenham.

Vörösmarty, C.J., Green, P., Salisbury, J., Lammers, R.B., 2000. Global water resources: vulnerability from climate change and population growth. Science 289, 284–288.

Weiß, M., Flörke, M., Menzel, L., Alcamo, J., 2007. Model-based scenarios of Mediterranean droughts. Adv. Geosci. 12, 145–151.
Wolf, A.T., 1999. ''Water wars'' and water reality: conflict and cooperation along international waterways. In: Lonergan, S. (Ed.), Environmental Change, Adaptation, Human Security. Kluwer Academic, pp. 251–265.
Wolf, A., 2007. Shared waters: conflict and cooperation. Ann. Rev. Environ. Res. 32, 241–269.
Yang, H., Zehnder, A., 2007. ''Virtual water'': an unfolding concept in integrated water resources management. Water Res. Res. 43.
Yoffe, S., Wolf, A., Giordano, M., 2003. Conflict and cooperation over international freshwater resources: indicators of basins at risk. J. Am. Water Res. Assess. 39 (5), 1109–1126.
Yohe, G., Tol, R.S.J., 2002. Indicators for social and economic coping capacity – moving toward a working definition of adaptive capacity. Global Environ. Change 12 (1), 25–40.
Zografos, C., Martínez-Alier, J., 2009. The politics of landscape value: a case study of wind farm conflict from rural Catalonia. Environ. Plann. A 41, 1726–1744.