Tyndall°Centre
for Climate Change Research

Adaptive Capacity of Transboundary Basins in the Mediterranean, the Middle East and the Sahel

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January 2012

Tyndall Centre for Climate Change Research Working Paper 151

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The Tyndall Centre

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Theme: Adaptation, Water and Landuse

Tyndall Working Paper 151, January 2012

This research is part of the CLICO project on Climate Change, Hydro-Conflict, and Human Security. CLICO is carried out by 14 research institutes from Europe and the Middle East and is funded under the European Union Framework 7 Research Programme.

Climate Change, Hydro-conflicts and Human Security

SEVENTH FRAMEWORK PROGRAMME

Adaptive Capacity of Transboundary Basins in the Mediterranean, the Middle East and the Sahel

Contract number:	SSH-CT-2010-244443
Work Package:	WP5
Partner responsible:	University of East Anglia
Deliverable number:	5.3 Geo-referenced database of adaptive capacity indicators for shared river basins
Deliverable author(s):	Anita Milman, Lisa Bunclark, Declan Conway, W. Neil Adger
Planned delivery date:	December 15, 2011
Actual delivery date:	December 15, 2011
Dissemination level:	Public

Executive Summary

Climate change will have a dramatic impact on the timing and flows of water across the globe. Responses to climate change in a transboundary river basin depend not on national and sub-national capacities alone, but also on the ability of co-riparian nations to communicate, coordinate, and cooperate across their international boundary so as to prevent as well as to take advantage of any benefits that may accrue from coordinated action. Evaluating transboundary river basins in light of their transboundary adaptive capacity sheds lights on likely 'hotspots' or areas of concern, as a lack of adaptive capacity in a region at high risk of increased water hazards may lead to both international tensions and decreases in human security.

To evaluate the adaptive capacity of transboundary river basins in the Mediterranean, the Middle East, and the Sahel (i.e., the CLICO study region), we draw from research on international environmental cooperation to develop a framework of transboundary adaptive capacity. The process by which adaptation occurs differs with scale: at the transboundary level, it is interactions between co-riparians which constitute the process of adaptation. Thus our framework encapsulates the characteristics of transboundary basins that facilitate the ability of co-riparians to address potential cross-border externalities via coordinated action including: Authority, National-Level Governance, Common Perspectives, Risk Planning and Provisions, Basin Information Interchange, and Linkages. These six features are translated into twelve measurable indicators and calculated for each of the 42 basins in the study area.

We find a large variation in adaptive capacity across the study area: on a scale of 1 to 100, with 100 representing a high transboundary adaptive capacity, the mean transboundary adaptive capacity basin index score is 41, yet basins score as low as 16 (the Wadi Al Izziyah basin) and as high as 74 (the Rhone basin). Basins in Western Europe are better prepared to address the potential hazards of climate change than other basins in the study area. None-the-less, all basins in the study area would benefit from additional mechanisms for risk planning and provision.

We use a cluster analysis to develop a typology of transboundary river basins. The basins are classified into six categories: Well Prepared, Mediated Cooperation, Good Neighbour, Dependent Instability, Self-Sufficient, and Ill Prepared. We find the Douro/Duero, Guadiana, Lima, Mino, Tagus/Tejo, Rhone, and Danube river basins are Well Prepared to address potential cross-border hazards stemming from climate change whereas the Krka, Neretva, Wadi Al Izziyah, Baraka, Awash, and Juba-Shibeli river basins are Ill Prepared. Other basins tended to cluster based on the presence or absence of treaties and river basin organizations, the degree of trade linkages and the degree of water dependency. This typology points to how policy interventions are best targeted according to the characteristics of the basins. For example in some basins (i.e., Mediated Cooperation), a lack of shared norms may be a bottleneck; whereas in others the problem may be political instability of riparian countries (i.e., Dependent Instability).

To determine if adaptation policies might best focus on a particular country within a basin, rather than the basin as a whole, we analyze the intra-basin dynamics. Fourteen of the basins contain a weakest link riparian; yet 5 of those 14 scored well on the adaptive capacity index, suggesting low adaptive capacities are systemic rather than the result of any particular country.

Lastly, to examine the relationship between capacities at varying scales, basin level metrics are compared with national and treaty level metrics. Here we find indicators of transboundary adaptive capacity highlight aspects of basins not encapsulated by national level capacity metrics and thus confirm the importance of measuring capacity at the transboundary scale.

Adaptive Capacity of Transboundary Basins in the Mediterranean, the Middle East and the Sahel

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1. Introduction

Climate change will have a dramatic impact on the timing, flows, and quality of water across the globe. It has been widely suggested that these changes will increase the mutual dependencies of nation states (Biermann and Dingwerth 2004), particularly those forming part of a transboundary river basin. A transboundary river basin is one in which "any perennial tributary crosses the political boundaries of two or more nations" (Wolf 2007, pp. 245). Globally, 263 international river basins span 45.3% of the land surface of the earth (excluding Antarctica) and extend through 145 nations (Wolf, Natharius et al. 1999).[1] In a transboundary river basin, riparians must respond not only to the potential impacts of climate change within their own boundaries but also to potential stresses caused by spill over from co-ripiarian nations. This inherent interdependence underscores a need to move beyond considerations of adaptive capacity as a national or sub-national level phenomena and points to the value of improved understandings of transboundary adaptive capacity.

Of particular interest is identification of factors that enable or inhibit the ability of countries sharing river basins to be aware of and to address any potential cross-border externalities that may arise as a direct or indirect result of climate change. Evaluating the characteristics of transboundary river basins in light of their transboundary adaptive capacity sheds lights on likely 'hotspots' or areas of concern, as a lack of adaptive capacity in a region at high risk of increased water hazards may lead to both international tensions and decreases in human security. Our focus is on the a priori vulnerability of a river basin; in other words, we are concerned with the current context of transboundary relations and how those will affect the ability to address the potential impacts of climate change in each basin, irrespective of the expected magnitude of the risk.

[1] As political boundaries shift, the number of international river basins change. Though the last full inventory counted 263 (Wolf, Natharius et al. 1999), in the twelve years since this number has increased.

This research evaluates transboundary adaptive capacity of river basins in the CLICO study area: the Middle East, the Mediterranean, and the Sahel. Our analysis can then be connected with insights from CLICO Work Package 3 (domestic level conflict), CLICO Work Package 4 (policy mapping and development) and CLICO Work Package 5.2 (uncertainty in transboundary agreements) to inform greater understandings of climate change, hydro-conflict and human security in the CLICO study region.

To evaluate the transboundary adaptive capacity, we draw from research on international environmental cooperation and climate change adaptation to develop a framework of transboundary adaptive capacity. We use this framework to create a system of indicators that captures six features of transboundary basins specifically cited in the literature as closely tied to transboundary adaptive capacity including: Authority, National-Level Governance, Common Perspectives, Risk Planning and Provisions, Basin Information Interchange, and Linkages. The indicators are then calculated for each basin and used to identify areas of high and low capacity. A cluster analysis is then used to develop a typology of transboundary river basins which aids in identification of points of leverage for differing basin types. As many adaptation policies must be implemented at the national level, the intra-basin dynamics of each basin are then analyzed to determine if any one co-riparian constitutes the weakest link in a basin. Lastly, to determine connections of capacity across scale, basin level and basin-country unit level metrics are compared with metrics of national level adaptive capacity and treaty-adaptive capacity as developed by other researchers. We conclude the analysis with a discussion of our findings and how those provide insights into multi-dimensional policies which could be used for capacity building

2. Climate Change, Adaptive Capacity and Transboundary River Basins

Climate change is water change: it will affect patterns of runoff; precipitation intensity and variability; snow cover; glacier melt; water temperatures; and flooding (Bates, Kundzewicz et al. 2008). Such changes threaten the effectiveness of traditional water resources management, which relies on historic patterns of the hydrologic cycle (Milly, Betancourt et al. 2008) and when combined with other stressors (Vorosmarty, McIntyre et al. 2010) these changes are expected to lead to decreased human security in terms of water availability and access (sensu Zeitoun 2011).

In transboundary river basins climate change is of particular concern: there is the potential for disputes if the rate of change within a basin exceeds the institutional capacity to address this change (Giordano and Wolf 2003; Wolf 2009). Although disputes over water have historically fallen more to the informal verbal interchange and diplomatic disagreement side of the conflict spectrum (Wolf 1998), even if disputes are not violent they may lead to inaction, increasing vulnerability to the hazards posed by climate change. Disputes may also impact the long term stability of existing treaties and water management regimes (Goulden, Conway et al. 2009; Odom and Wolf 2011). Avoiding such problems and effectively navigating the threats imposed by climate change will require significant transboundary adaptive capacity.

Adaptive capacity refers to the “ability to mobilize scarce resources to anticipate or respond to perceived or current stresses”(Engle 2011, pp. 648) by reducing exposure, lessening the impact, or changing absorption thresholds (Smit and Wandel 2006). With respect to water and climate change, this means an ability to respond to increasing temperatures and changes in precipitation (increases, decreases, variability and extremes), including the associated impacts on hydrology and sea level rise. The measurement of adaptive capacity is fraught with difficulty due not only to fundamental contestations regarding what constitutes adaptive capacity and improvements to it (Adger and Vincent 2005; Leichenko and O'Brien 2009) but because adaptive capacity is scale dependent (Vincent 2007). Scale dependency exists because the types of activities and the processes through which those actions can be undertaken are different at the individual level, the household level, the community or local level, the city level, and so forth (Adger et al. 2005; Adger and Vincent 2005). Consequently, the factors that enable adaptation to occur, i.e., those contributing to adaptive capacity, need to be evaluated using different metrics depending on the scale of interest.

Adaptive capacity at the transboundary basin level differs from adaptive capacity in non-transboundary river basins because, due to the separation of governance created by the international boundary, responses to climate change in transboundary basins require the additional element of cross border communication (and potentially coordination) in order to prevent negative externalities or take advantage of benefits which may accrue from coordinated action. Though in any analysis of adaptive capacity, potential spill over from neighbouring units of analysis must be taken into consideration, the challenge in transboundary river basins arises from the structure of sovereign states with no superior authority. The value of evaluating adaptive capacity at the transboundary level is not only that it is the only way to encapsulate the dynamics of the international border, but also because it is particularly helpful in pointing to where interventions encouraging transboundary water programs, such as those currently funded by the World Bank and several development agencies, can be useful or where efforts might be better targeted at the national or sub-national level.

Though adaptive capacity has been studied in depth across a variety of scales (Yohe and Tol 2002; Adger and Vincent 2005; Brooks, Adger et al. 2005; Birkmann 2007; Vincent 2007) and for a number of sectors (O'Brien, Leichenko et al. 2004; Brenkert and Malone 2005; McClanahan, Cinner et al. 2008) including water resources (Milman and Short 2008; Wang and Blackmore 2009; Pandey, Babel et al. 2010) adaptive capacity at the transboundary level has been little investigated. Hamouda et al (2009) evaluated vulnerability and adaptive capacity in the Nile river basin. However their analysis is not at the basin level, rather it measures capacity at the national level for each of the riparian countries and consequently does not address the potential (or lack thereof) for the Nile riparians to effectively address environmental connections between the countries. Only De Stephano et al (2010) systematically address the response to climate change at the basin level; their definition of resilience is predicated on the status of formal institutions in the basin.

Our analysis adds to their study of resilience to climate variability by considering not just the current transboundary institutions but the characteristics of basins shown to be closely linked with the process of international regime formation. In other words, we consider adaptive capacity rather than resilience, and we look more holistically at features of basins associated with the process of cross-border communication, coordination and cooperation, as it is via those processes that responses to climate change can be planned for and implemented.

Interactions between co-riparians are mediated by the institutional regimes[2] that structure rules, norms and procedures; shape the exchange of information; and change the distribution of incentives and risks (Levy, Young et al. 1995; Young 2002; Agrawal and Perrin 2009). Comparative studies of international environmental regimes show that they indeed make a

[2] A regime is a set of "explicit or implicit principles, norms, rules, and decision making procedures around which actor expectations converge in a given issue-area" (Krasner 1983, pp. 27).

difference in addressing international environmental problems (Breitmeier et al 2011). In terms of climate and water, river basin institutions have been shown to reduce the negative impacts of transboundary flooding (Bakker 2009) and basins with effective transboundary institutions are more advanced in planning for adaptation to climate change (Kranz, Menniken et al. 2010). Thus our definition of transboundary adaptive capacity thus considers the potential in a basin for effective transboundary institutions (formal and informal), and specifically for institutions that are able to react and respond to changes or uncertainties in hydro-climatic conditions.

3. Indicators of Transboundary Adaptive Capacity

Adaptive capacity is a latent characteristic: it is the ability to respond to a future state which cannot be measured until after it has been mobilized (Engle 2011). As such, the measurement of it is the subject of much debate (Hinkel 2011). Indicators of adaptive capacity must be forward looking, and, consequently, there is no appropriate dependent variable upon which indicators of adaptive capacity can be tested. Thus adaptive capacity metrics must be developed using a deductive approach[3] through which, indicators are selected based on conceptual theory that has been substantiated by previous empirical work (Eriksen and Kelly 2007; Vincent 2007).

The system of indicators we developed to evaluate the adaptive capacity of transboundary basins in this paper has its underpinnings in research on international environmental agreements (e.g., Young 1989) conflict and cooperation over transboundary water (e.g., Wolf 1998), and climate change adaptation (e.g., Smit and Wandel 2006). Scholars of international environmental regimes have proposed regime effectiveness is a function of the character of the problem and the problem solving capacities of the regime (Miles, Underdal et al. 2002). Though this framework is useful in understanding regime effectiveness, as measured by behavioural change and functional effectiveness,[4] it is problematic to apply in an evaluation of adaptive capacity of transboundary river basins because climate change poses multiple and diverse hazards characterized by a high degree of uncertainty. In other words, climate change could potentially create multiple problems of multiple character types, each of which will require differing problem solving capacities. As we cannot evaluate individually every potential hazard and the specific problem solving capacity required to address it for each basin, we opt instead for a more generalized model comprised of factors leading to increased likelihood of cooperative[5] water management and an ability to respond to environmental changes.

The transboundary adaptive capacity framework we use is composed of six features of transboundary basins specifically identified in the literature as closely tied to institutional formation, institutional effectiveness, and adaptive water governance including: Authority, National-Level Governance, Common Perspectives, Risk Planning and Provisions, Basin Information Exchange, and Linkages. These six features and their role in transboundary adaptive capacity are described in Table 1.

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3 Although Brooks et al (2005) and Yohe and Tol (2002) developed indicators of adaptive capacity at the national-level using an inductive, empirical data approach, their metrics are an ex-post measurement of characteristics of countries correlated with experiencing lower negative impacts of past climate threats. As such, they do not necessarily represent the capacity to respond to future (and unknown) stresses.

4 See Young (1994) for a discussion on metrics of effectiveness and Young (2001) on the challenges in measuring effectiveness.

5 By cooperative water management, we refer to the full spectrum of cooperation ranging from informal verbal exchanges to formal instances of joint water management as per the BAR scale described in Yoffee et al. (2003)

Table 1. Features of Transboundary Basins Linked with Adaptive Capacity

	Description	Supporting Literature
Authority	The authority by which the transboundary aspects of water in the basin are managed.	International institutions (formal and informal) facilitate cooperation by promoting concern among governments and institutionalizing expectations. Such institutions enhance the ability of riparian of countries to make and keep agreements and also serve to build national political and administrative capacity (Haggard and Simmons 1987; Levy, Keohane et al. 1993). At the national level, environmental policies have been shown to be more effective when they include a certain degree of institutionalization, e.g., via the formation of ministries, required reporting, councils etc., (Weidner, Jänicke et al. 2002). Moreover, without sufficient jurisdictional authority, water managers are unable to address the transboundary aspects of water management (Milman and Scott 2010). In transboundary river basins, memorandums of understanding, treaties and river basin organizations (RBOs) influence transboundary adaptive capacity. Although the degree of legalization of transboundary institutions (hard versus soft law) is not significantly correlated with regime effectiveness (Bohmelt and Pilster 2010), rapid change in transboundary river basins without a treaty or uncertainty mechanism often leads to disputes (Yoffe, Wolf et al. 2003). Moreover, a higher degree of legal precision, in terms of the specification of obligations and requirements of parties to an agreement, leads to more effective the international environmental regime (Bohmelt and Pilster 2010). Treaties reduce the likelihood claims will become militarized and may increase the likelihood that negotiations begin over the claims (Brochmann and Hensel 2011). RBOs also add to adaptive capacity as international environmental regimes are more effective when they include an intergovernmental organization with significant actor capacity (Miles, Underdal et al. 2002), regular bodies supporting states in their decision making (Bohmelt and Pilster 2010) or the formation of a secretariat that reviews reports and intervenes to encourage compliances (Weiss and Jacobson 1998).
National-Level Governance	The ability of co-riparian nations to devise, enact, implement and comply with transboundary policies at the national and sub-national levels.	The role of the domestic in coordination and cooperation at the international level is well recognized (Putnam 1988). In transboundary river basins, dynamics at the national level determine the framings of the issues at stake and the distribution of costs and benefits of water management policies (Furlong 2006; Sneddon and Fox 2006). Domestic institutions also mediate the ways in which international policies play out at the national level and thus a country's willingness to participate in an international agreement (Raustiala 1997). An important aspect of domestic institutions is their ability to devise, enact, implement, and comply with policies affecting the transboundary aspects of the river basin. Studies show treaty formation is more likely in river basins within which the national-level governments of co-riparians are more effective and politically stable (Dinar, Dinar et al. 2011). Once formed, the success of international environmental institutions depends on political, legal, technical, and administrative capacities at the national level (Levy, Keohane et al. 1993; Weiss and Jacobson 1998)}. Thus the adaptive capacity of a transboundary river basin requires riparian countries have sound or improving policies and institutions (Barr, Fankhauser et al. 2010); the ability to mobilize resources and institutions (Willems and Baumert 2003); and the requisite financial resources, availability of relevant information, low corruption, and human skills (Weiss and Jacobson 1998).

Common Perspectives	The 'ethos' of water that influences the approach co-riparians take towards transboundary water management.	International Law Commission of the United Nations "Convention on the law on the non-navigational uses of international water courses" specifies a variety of principles for transboundary water management. Signatories to the convention agree to abide by the principles of no appreciable harm and equitable and reasonable. They also commit to the promotion of cooperative management mechanisms; data and information exchange; and mechanisms for conflict resolution. While it is possible countries sign this agreement strategically (Fearon 1995) and regime formation in transboundary river basins is not contingent upon joint articulation of common principles (Conca 2006), an affinity between counties has been linked to more cooperative interactions over transboundary waters (Kalbhenn 2011). In addition, the general principles stated in the agreement support communication, coordination, and cooperation, thus signatories to the convention have a stated commitment to the features of adaptive capacity we are measuring.
	The networks of shared knowledge that influence decision makers, encouraging the formation of convergent policies among co-riparian countries.	Transnational networks and epistemic communities facilitate transboundary environmental regime formation (Haas 1989; Blatter and Ingram 2001; Eakin and Lemos 2006). Such networks are instrumental in developing shared understandings of a problem and aid in the formation of common objectives by defining the discourse (Raustiala 1997), and by leading on learning and the development of innovative ideas (Sendzimir, Magnuszewski et al. 2008; Huntjens, Pahl-Wostl et al. 2010). Transational networks also build and reinforce norms and expectations among countries, thus serving as a form of social capital (Ward 2006). Participation in international governmental organizations (IGOs), one type of transnational network, improve the effectiveness of environmental agreements (Ward 2006) even when the focus of the IGO is not itself the environment (Spilker 2011). In the context of transboundary rivers, though the role of joint participation in IGOs could not be statistically linked with the entire spectrum of cooperative events (Kalbhenn 2011), joint IGO membership is positively linked with treaty formation (Zawahri and Mitchell 2011; Brochman and Hensel 2011).
Risk Planning and Provisions	The provisions in transboundary institutional arrangements that allow co-riparian countries to address variability and uncertainty.	Although scientific understandings of climate change on water resources are improving, the impacts of climate change remain highly uncertain (Dessai, Hulme et al. 2009). Adapting climate change requires flexibility in management, such that riparians are able to respond to unexpected conditions and uncertainties. This is particularly the case where formal agreements exist, as treaties tend to be rigid instruments (McCaffrey 2003) that can be difficult to modify (Fischhendler 2004). Transboundary regimes are more adaptive when they include full consideration of alternative scenarios (Raadgever, Mostert et al. 2008), which are useful tools for resilience-building in social-ecological systems (Folke, Carpenter et al. 2002), and other provisions to address variability in flow, needs, and management (Drieschova, Giordano et al. 2009).
	The awareness of potential threats which then influences countries' response to climate change.	Effective adaptation responses require an awareness of the potential hazards posed by climate change, or, at minimum, an awareness of the uncertainties regarding them. In a comparison across 36 cases, Weidner et al. (2002) found that environmental policy performance depended on knowledge and the conditions under which is it produced, distributed, interpreted, and applied. Similarly, Miles (2002) found that international environmental regimes are more effective when there is a good state of knowledge about the structure of the problems and the systems. Not only is knowledge of processes and functions necessary to build resilience (Folke, Hahn et al. 2005), but awareness among the general public and all relevant agencies and stakeholders is essential in order to get policy off the ground (Willems and Baumert 2003). For example, a study of European river basins found an awareness threshold must be surpassed in order to create a policy windows through public pressure and concern can encourage adaptive actions

		(Huntjens, Pahl-Wostl et al. 2010).
Basin Information Interchange	The mechanisms for communication between co-riparian countries that reduce uncertainties and improve planning.	The willingness of countries to engage in or coordinate activites with their co-riparians depends both on their perceptions of the expected outcome, in terms of the costs and benefits, of specific transboundary policies and on their expectations of the actions or inactions of their co-riparians (Iida 1993; Rathbun 2007). In the context of great uncertainty (such as climate change), countries may develop disparate perspectives on potential hazards (Milman and Ray 2011), and thus interpret the need for action differently. Data sharing provides essential information for co-riparians to plan for potential cross border hazards and expected changes in water flows and quality. Moreover, regular communication and notifications provide co-riparians with a clearer picture of changes in other parts of the basin. Such information exchange not only aids in planning and analysis, it also serves to build trust and mutual understanding (Timmerman and Langaas 2005; Raadgever, Mostert et al. 2008; Gerlak, Lautze et al. 2011). In fact, countries with higher levels of communication, as measured by diplomatic relations, are more likely to sign formal agreements (Dinar, Dinar et al. 2011).
Linkages	The economic and water co-dependencies of co-riparian countries that contribute to the formation of convergent policies among co-riparian countries.	The more integrated co-riparians are, the more likely it is they will work together to address transboundary water problems (Bernauer 2002). Cooperation is more likely when there is greater integration because there are more incentives for cooperation and possibilities for enforcement of agreements (Just and Netanyahu 1998). Two metrics of interconnection that have been shown to influence cooperation over transboundary water include economic and water inter-dependence. Increased trade dependence has been statistically linked with treaty formation in transboundary river basins (Espey and Towfique 2004; Tir and Ackerman 2009)., though trade openness may be a more important factor when both treaties and informal events are considered (Kalbenn 2011). Trade has a higher effect on multi-lateral then on bi-lateral agreements (Zawahri and Mitchell 2011) as too much trade at a bi-lateral basin may lead to tensions (Dinar, Dinar et al. 2011). Dependence on the river also increases treaty formation (Zawahri and Mitchell 2011) and the greater the importance of the river, the more likely countries are to cooperate (Brochmann and Hensel 2011).

The six features of transboundary basins identified as linked to transboundary adaptive capacity were operationalized as measureable quantities. In order to ensure consistently across the 42 river basins in the study area, metrics were designed to use data from publically available global datasets and peer-reviewed publications with substantial cross-sectional data. Twenty metrics were selected as potential indicators and calculated for each basin. These metrics were then analyzed and both highly correlated metrics and metrics with little variation across basins were excluded,[6] resulting in a final set of twelve indicators. As with all indicators, these should be interpreted with care. Indicators are by nature, simplifications of complex processes. Though we believe the indicators we have devised reflect best practice in that they are parsimonious, easy to interpret, responsive to change, and consistent (Gallopin 1996; Briassoulis 2001; McCool

[6] The three potential metrics (Failed States Index, Corruption Perception Index, and Human Development Index) were excluded because they were highly correlated with other indicators (correlation coefficient greater than 0.8). Two potential metrics (average basin at risk value and water intensity of the economy) were excluded due to extremely low variation across the study basins. Lastly, three other potential metrics (interstate war or military crisis in the basin during the past 10 years; intra-state war or civil unrest within a riparian country within the past 10 years; and nationalism) were excluded as Political Stability and Government Effectiveness were selected instead to represent this feature of the basin. Although not included in the system of indicators, data on these last three metrics was used to inform interpretation of the indicator results.

2004), biases arising from constraints due to the availability of data and assumptions embedded in the selection or choice of metrics, standardization, weighting, and aggregation may obscure factors influencing adaptive capacity (Eriksen and Kelly 2007; Barnett, Lambert et al. 2008).

A summary of the metrics used for each indicator is included in Table 2. Information on the data sources and calculation methods is included in Appendix B. All twelve indicators developed are on a scale of 0 to 100, with 100 representing high capacity, to allow for equal weighting in the cluster analysis. One outcome of this scaling is that changes in certain indicators calculated on a discontinuous scale (e.g., Authority or Shared Water Norms) will have a greater impact on the aggregate transboundary adaptive capacity index than others.

One critique of existing indicators of vulnerability (which can be inferred to also apply to adaptive capacity) is that they would be more policy-relevant if they captured the processes that shape vulnerability (Eriksen and Kelly 2007). The system of indicators we have developed addresses this critique: the indicators represent the factors which make co-riparians likely to communicate, coordinate, and cooperate in the planning and implementation of adaptation measures and thus capture the process of adaptation rather than the current state of preparedness or resilience within the basin.

Table 2. Indicators of Transboundary Adaptive Capacity

	Indicator	Metric
Authority	Formal Agreements	Formal agreement & geographic scope
	River Basin Organizations (RBOs)*	River basin organization & geographic scope
National-Level Governance	National Level Political Capacity (Political Stability)*	Political Stability Index
	Transparency, Accountability & Resources (National Governance)*	Government Effectiveness Index
Common Perspectives	Shared Water Norms	Signatory UN Convention on Non-navigational Uses of International Watercourses
	Transnational Networks/ Epistemic Communities (IGOs)*	Shared membership inter-governmental organizations
Risk Planning and Provision	Mechanisms for Managing Uncertainty (Uncertainty)*	Specific elements of existing treaties and agreements
	Risk Preparedness	Global Assessment Report on Disaster Risk Reduction: Hyogo Framework for Action Reporting
Basin Information Interchange	Mechanisms for Data Sharing (Data Sharing)*	Specific elements of treaties and existing agreements
	Liaisons Between Countries (Diplomatic Exchange)*	Diplomatic exchange
Linkages	Economic and Trade Interdependence (Trade Dependency)*	Regional trade (between co-riparians) as a percent of basin total trade
	Reliance on Water from the Basin (Water Dependency)*	Ratio of external to total renewable water

*Text in brackets represents shorthand name used in subsequent tables, where space does not permit use of full indicator name.

4. Basin Evaluation

This research aims to evaluate the adaptive capacity of transboundary river basins in the Mediterranean, Middle East and Sahel (hereafter, MMES)[7] as they are among those expected to be most affected by changes in water availability. The MMES region is highly exposed to floods and droughts (Kallis 2008) and many of the basins in the region currently experience or will experience severe water stress by 2050 (Alcamo, Martina et al. 2007). Precipitation is projected to decrease across much of the Mediterranean and the Middle East and, though projections for the Sahel are more uncertain, they include increased variability (Christensen, Hewitson et al. 2007). Moreover, the river basins in our study span a variety of levels of development, wealth, economic and political structures. A list of the forty-two basins and the riparian nations within them is included in Appendix A.

4.1. Overall Adaptive Capacity of Transboundary River Basins

To identify high and low capacity basins, we developed an aggregate transboundary adaptive capacity index (hereafter, aggregate index) calculated as the average across the twelve indicators for each basin. Results are presented in Figure 1 and the distribution of the index across river basins is shown in Figure 2. This method for aggregating to a single score for each basin implicitly assumes compensation[8] between indicators, an assumption which has not been confirmed by empirical analysis (Füssel 2009).[9] Thus we use the aggregate index only for identifying broad trends in high and low adaptive capacities. The twelve indicators provide more appropriate information for designing policy interventions, such as in the cluster and weakest link analyses described in the following sections.

There is a large variation in adaptive capacity across the study area: the mean aggregate index score is 41, yet basins score as low as 16 (the Wadi Al Izziyah basin) and as high as 74 (the Rhone basin). As might be expected, basins located in the Horn of Africa tend to have lower transboundary adaptive capacities and basins located in Mediterranean Europe tend to have higher transboundary adaptive capacities. None-the-less, it is interesting to note that the Niger and Volta basins in Africa have greater capacities than several basins in Europe.

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[7] For a full list of the basins and countries in the study area, refer to Appendix A.

[8] Compensation is the process by which a shortfall in one domain is made up for by another domain. In this context, we refer to the assumption that a low capacity in one determinant of adaptive capacity can be mitigated for by higher capacities in another determinant.

[9] As climate change poses a number of different hazards, it may be that compensation between these features is practicable in some basins and for some potential risks and not in others. This is because the the types of problem solving skills needed for an environmental regime to be effective depend on the character of the problem (Miles et al. 2002).

Figure 1. Aggregate Adaptive Capacity Index for Transboundary River Basins in the Mediterranean, Middle East and Sahel[10]

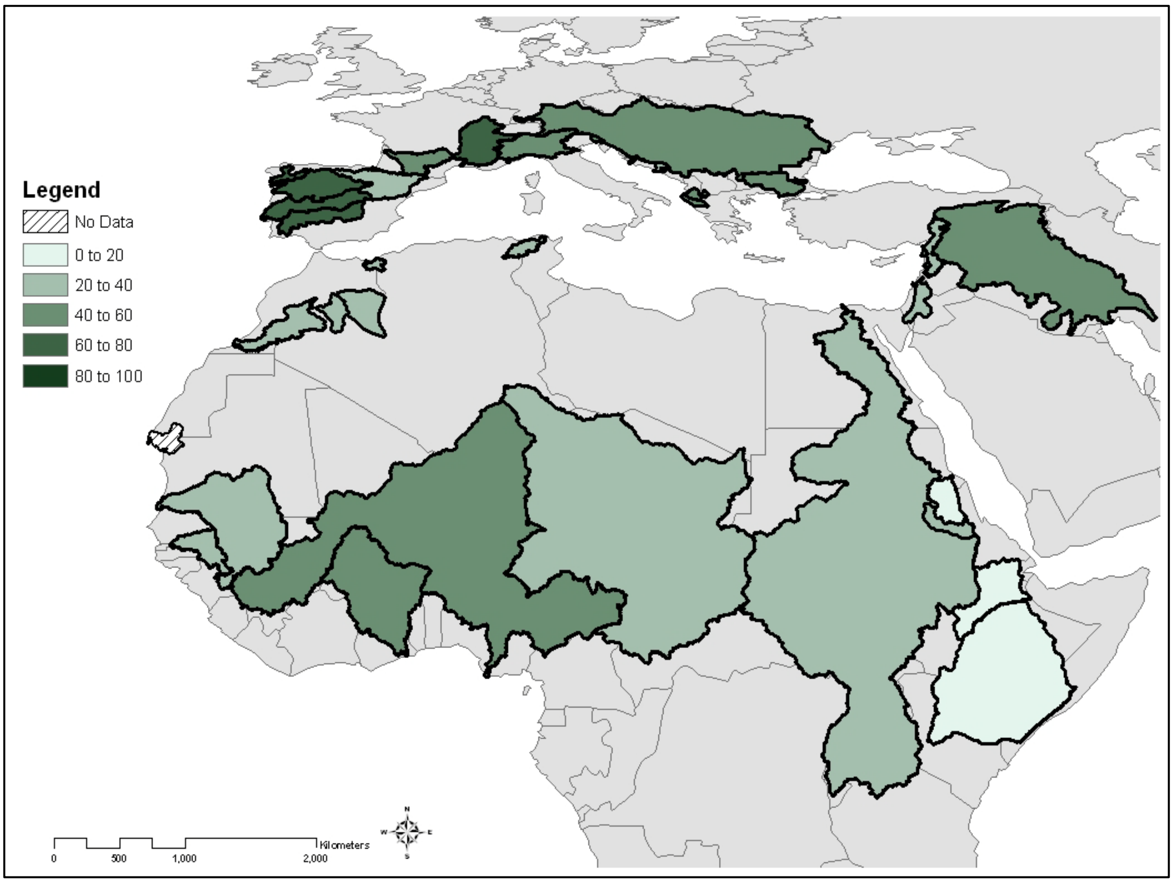
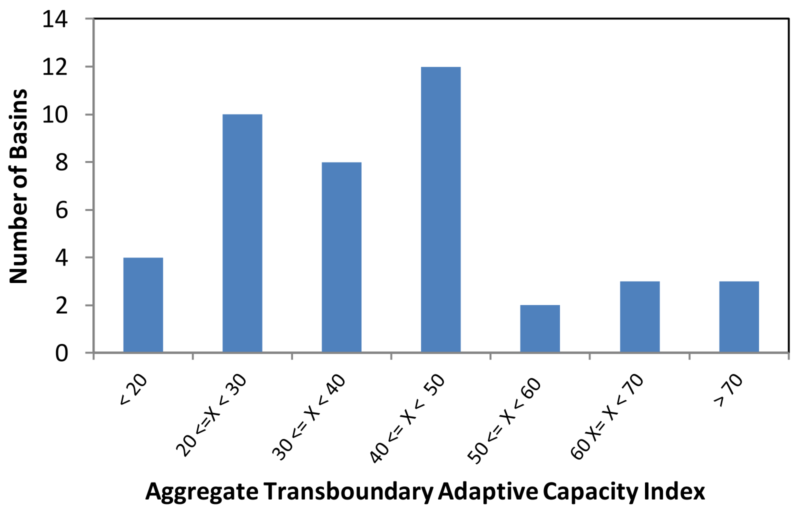


Figure 2. Distribution of Aggregate Transboundary Adaptive Capacity Index Scores



4.2. Typology of Transboundary Basins

Once indicators were calculated for all 42 basins, a cluster analysis was performed to develop an adaptive capacity typology of transboundary basins. The purpose of this analysis was to identify patterns of similarity and difference across basins which could serve as a framework for

[10] GIS shapefiles courtesy of the Transboundary Freshwater Dispute Database at Oregon State University.

classifying basins based on leverage points.[11] A hierarchical cluster analysis was performed in SPSS and cluster combinations developed using multiple distance metrics were compared.[12] The final clusters were developed manually based on groupings of basins which remained together across each distance metric considered and based on inspection.[13]

Basins tended to cluster based on four main characteristics: the presence or absence of Formal Agreements and River Basin Organizations (hereafter RBOs), the degree of Economic and Trade Interdependence (hereafter Trade Dependency) and the degree of Reliance on Water from the Basin Water Dependency (hereafter Water Dependency). Mechanisms for Addressing Uncertainty and for Data Sharing also influence the basin groupings; however this is to be expected as if a basin has noformal agreement or RBO, by definition it will not have a formal mechanism for managing uncertainty or for data sharing. Basins also tended to cluster geographically in small groupings; this is because basins with the same set of co-riparians tend to have similar features. Geographical clustering of basins is expected, as the behaviour of co-riparians in a specifi c basin influences both their behaviour in other basins shared by those same riparians (Kalbhenn 2011). The basins were classified into six categories: Well Prepared, Good Neighbour, Mediated Cooperation, Dependent Instability, Self-Sufficient, and Ill Prepared. The basins grouped into each category are listed in Table 3 and their average indicator scores presented in Table 4. The geographic distribution of the clusters is illustrated in Figure 3.

Table 3. List of Basins by Category

Cluster Name	Basins[14]
Well Prepared	Douro/Duero, Guadiana, Lima, Mino, Tagus/Tejo, Rhone, Danube[15]
Good Neighbour	Roia, Ebro, Garonne, Bidasoa, Maritsa, Rezvaya
Mediated Cooperation	Lake Prespa, Volta, Niger, Gambia, Nile, Senegal
Dependent Instability	Nahr El Kebir, Asi/Orontes, An Nahr Al Kabir, Jordan, Tigris-Euphrates/Shatt al Arab, Lake Chad, Gash
Self-Sufficient	Daoura, Dra, Guir, Oued Bon Naima, Tafna, Velaka, Medjerda
Ill Prepared	Krka, Neretva, Wadi Al Izziyah, Baraka, Awash, Juba-Shibeli

[11] For a discussion on points of leverage see Meadows (1999)
[12] Distance metrics used in the cluster analysis included: within-groups, between-groups, nearest, furthest, median, centriod, and ward methods. See Tan et al. (2006) for an explanation of data clustering methods.
[13] Manual supervision of the clustering process was necessary due to the scaling of the indicators. Although all twelve indicators range between 0 and 100, not all indicators are continuous variables. For example, though the Political Stability metric can be any real number within the range, the value of the Shared Water Norms indicator is a discontinuous variable whose potential values are determined by the number of countries in the basin. Moreover, it would be impossible to score 100 on either trade or water dependencies.
[14] Three basins are classified as outliers as they do not fit into any of the above categories: Vijose (Albania/Greece); Po (France/Italy/Switz); Isonzo (Italy/Slovania)
[15] Although the Danube scores lower than the other basins in this cluster, it also has significantly more riparians.

Figure 3: Basins by Clusters

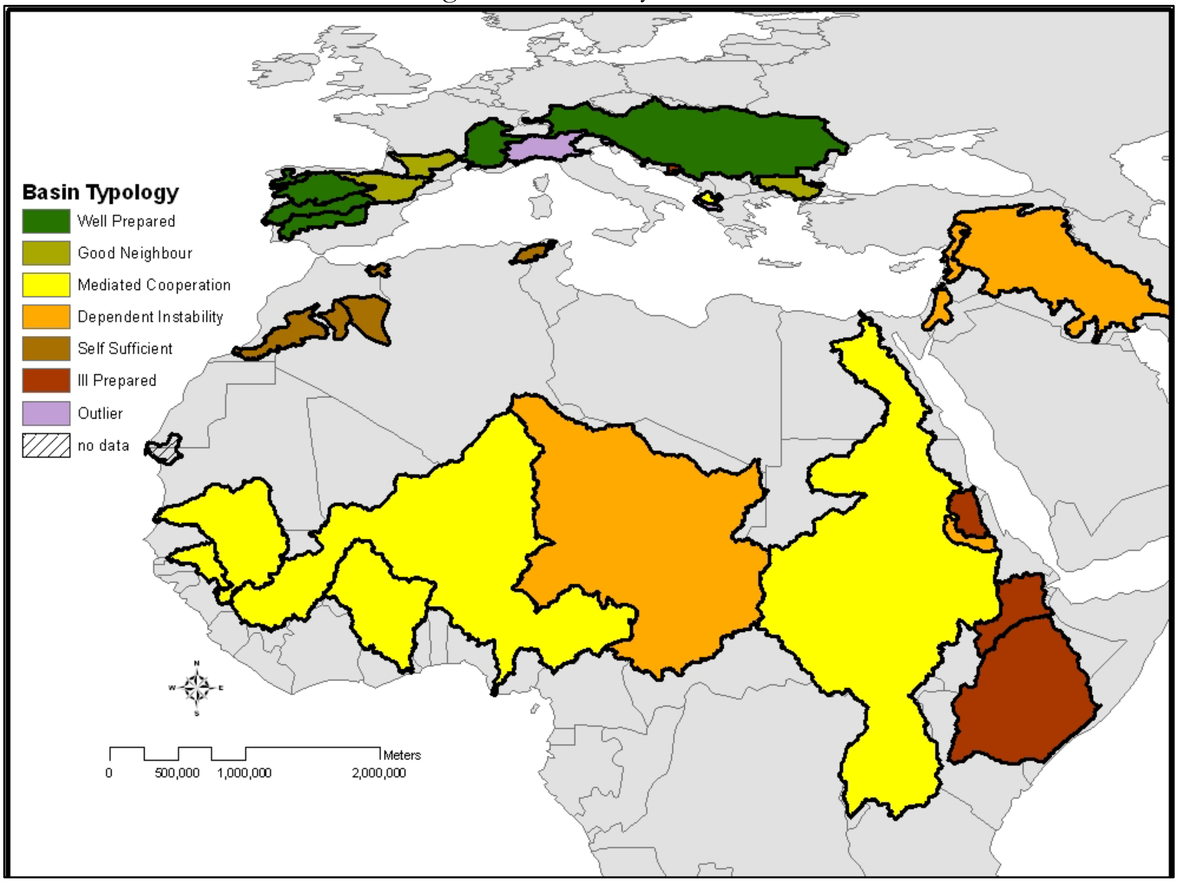


Table 4. Average of Indicator Scores, per Basin Category

	Authority		National-Level Governance		Common Perspectives		Risk Planning & Provisions		Basin Information Interchange		Linkages		
Category	Formal Agreement	RBO	Political Stability	Government Effectiveness	IGOs	Shared Water Norms	Uncertainty	Risk Preparedness	Data Sharing	Diplomat Exchange	Trade Dependency	Water Dependency	Aggregate Index
Well Prepared	100	97	56	70	82	80	53	58	86	94	14	18	67
Good Neighbour	90	11	53	67	56	53	15	58	29	100	7	4	45
Mediated Cooperation	96	93	33	35	36	16	12	38	58	55	5	23	42
Dependent Instability	79	23	25	38	35	47	14	52	32	44	4	22	35
Self Sufficient	0	0	35	45	68	7	0	93	0	100	1	2	29
Ill Prepared	0	0	24	36	34	8	0	25	0	75	6	27	20

Well Prepared: These basins score highly across all twelve indicators and are well positioned to address the transboundary risks of climate change. All riparians in the basin are signatory to at least one formal agreement and participate in an RBO. The governments of the riparians are highly effective and stable, scoring highly on the National-Level Governance indicators. A majority of countries in each basin have signed the UN Convention on the Non-Navigational

Use of International Water Courses and there is a high degree of participation in inter-governmental organizations. In terms of Risk Planning and Provisions, the basin includes at least one mechanism for addressing uncertainty and at least once riparian has completed the Hyogo Framework for Action disaster risk reporting, which is the metric used for the Risk Preparedness indicator. Full diplomatic relations exist in the basin and provisions exist for data sharing. The basins are also characterized by high trade and water dependencies. Geographically, they are primarily Europe based.

Good Neighbour: These basins score highly on eight of the twelve indicators; moreover, their low water dependence may explain the lack of joint management organizations and lower levels of formal uncertainty management and data sharing. All riparians in the basin are signatory to at least one formal agreement, yet participation in RBOs is limited. The national governments of the riparian countries are highly effective and stable. The percentage of riparians signing the UN Convention on the Non-Navigational Use of International Water Courses is mixed across the basins as is participation in IGOs. In terms of Risk Planning and Provisions, although mechanisms for addressing uncertainty are quite limited, riparians are participating in Hyogo Framework for Action disaster risk reporting. Full diplomatic relations exist in the basin and, for many of the basins, provisions exist for data sharing. Trade dependencies are high, yet water dependencies are quite low. Geographically these basins fall in the Southern Europe Mediterranean region.

Mediated Cooperation: These basins have high levels of Authority and Basin Information Interchange despite lower scores on other indicators. This cooperation may be the result of both high inter-dependences and international involvement, as the Economic Commission for Africa, the World Bank, and other donor communities have extensively promoted cooperation in these basins since the mid 1960's (GTZ 2008). Most of the riparians in the basin are signatory to at least one formal agreement[16] and participate in an RBO. The national governments of the riparians score low on Political Stability and Government Effectiveness, achieving scores of between 20 and 50. In fact, in most basins at least one country has experienced intra-state war or civil unrest within the last ten years. Less than half of the riparians have signed the UN Convention on the Non-Navigational Use of International Water Courses and participation in IGOs is low. With respect to Basin Information Interchange, between 45-70% of potential diplomatic relations exist. Few provisions for Managing Uncertainty and less than 40% of riparians basin have completed the Hyogo Framework for Action disaster risk reporting. In terms of Linkages, the basins are also characterized by high trade and water dependencies. Geographically these basins include the largest of the African river basins included in the study and Lake Prespa.

Dependent Instability: These basins have high water dependencies and some formal agreements addressing their shared waters, yet only achieve medium scores most indicators. At least one formal agreement exists for each a basin, though not all riparians participate. A few RBOs exist, however none include all riparians. The national governments of the riparian countries score medium low on Political Stability and Government Effectiveness, and, within all of these basins at least one country has experienced intra-state war or civil unrest during the past ten years. The percentage of riparians signing the UN Convention of the Non-Navigational Use of International Watercourses is mixed across the basins and participation in IGOs is medium-low.

[16] As a reminder, treaties that only include a portion of the riparians in the basin are included. Thus although the Nile does not include a basin-wide treaty, there exist a number of formal agreements between the various groups of the countries.

Some basins include mechanisms for management of uncertainty and participation in the Hyogo Framework for Action disaster risk reporting is mixed. Data sharing exists to a limited extent across most of the basins, yet there is less than full diplomatic exchange in each of the basins. With respect to Linkages, most of the basins have high trade and water dependence. Geographically, these basins are located in the Middle East and the Sahel.

Self-Sufficient: These basins have few provisions for addressing their shared waters, yet riparians show some capacities for preparedness at the national level. The basins are not covered by formal agreements or RBOs. The national governments of the riparian countries score medium-low on Political Stability and medium on Government Effectiveness. None of the riparians are signatory to the UN Convention on the Non-Navigational Use of International Watercourses; however, participation in IGOs is high. As there are no formal agreements in the basin, there are no formal mechanisms for addressing uncertainty; none-the-less, all countries in the basins are in the process of completing or have completed Hyogo Framework for Action disaster risk reporting and score highly in the Risk Preparedness indicator. In terms of Basin Information Interchange, there are no formal mechanisms for data sharing but full diplomatic relations are in place. Trade and water dependencies are quite low. Geographically speaking most of these basins include Algeria, though one crosses Bulgaria and Turkey.

Ill Prepared: These basins score poorly on most indicators and thus appear to be poorly positioned to address the risks posed by climate change. These basins are characterized by a lack of formal agreements and RBOs and medium to low political stability and government effectiveness. With the exception of Lebanon in the Wadi basin, none of the riparian countries have signed the UN Convention on the Non-Navigational Use of International Water Courses and participation in IGOs is low. No formal mechanisms for managing uncertainty exist and participation in Hyogo Framework for Action disaster risk reporting is limited. Similarly, there are no provisions for data sharing; however diplomatic relations vary across the basins, as some basins have full diplomatic relations and others have none. Trade dependency varies by basin, yet water dependency is high across all basins. In terms of geography, these basins are spread across the Mediterranean (Bosnia-Croatia), the Middle East (Israel-Lebanon), and the Horn of Africa.

An interesting outcome of the cluster analysis is that it points to divergence between indicators within a basin. To explain: two indicators are used to represent different aspects of each of the six features of transboundary basins being evaluated. For some basins those two indicators point to differing degrees of capacity. For example, Risk Preparedness and Provisions is represented by two indicators: Hyogo Framework for Action disaster risk preporting and mechanisms for addressing uncertainty. These two indicators are uncorrelated. Reporting for the Hyogo Framework for Action is high for the Well Prepared, Good Neighbour, Dependent Stability, and Self-Sufficient clusters but not for the Mediated Cooperation or Ill Prepared clusters. This suggests that for these basins national level capacities may be high but the transboundary level has been overlooked. Similarly, the two indicators used to represent Basin Information Interchange are uncorrelated for the Mediated Cooperation and Dependent Instability basins. In these basins, there are mechanisms for data sharing despite a lack of full diplomatic relations, suggesting it is possible to communicate and maintain communication on water-related issues despite other political differences. In fact, this has been the case between Israel and Palestine, who manage communicate regarding their shared waters despite military disputes. The last point of divergence is that, for the Good Neighbour and the Self-Sufficient clusters, participation in joint IGOs does not correlate with signatories to the UN Convention on the Non-Navigational Use of International Watercourses. For the Good Neighbour cluster, this may be a bias in the data due to Andorra's low participation in IGOs, given Andorra is a co-riparian in two of the six basins in this category. For the Self-Sufficient cluster this may be due to the fact that shared surface waters contribute minimally to the water supply of each country, and there is little impetus to sign the UN Convention.

4.3. Weakest Link: Intra-Basin Variation

As transboundary adaptive capacity is a function of the basin characteristics including the joint capacities of riparian countries, the next step in our analysis was to determine if adaptive capacity of a basin is particularly limited due to one of its co-riparians. In considering the provision of transboundary adaptive capacity, the contributions of individual riparians could coalesce in one of three ways: i) they could be additive, such that capacity is equivalent to the sum of the contributions from each riparian and a surplus in a characteristics on the part of one riparian could compensate for a weakness in another; ii) they could follow what is called the 'best shot approach' such that capacity depends on at least one riparian having specific characteristics; or iii) there could be a 'weakest link' effect where capacity is limited by the lowest common denominator (Yohe and Tol 2002; Holzinger 2001; Hirshleifer 1985; Hirschleifer 1983).

To date, no empirical studies have investigated which of these three amalgamation mechanisms best characterize the provision of adaptive capacity in transboundary river basins. An empirical test of the weakest link hypothesis for adaptive capacity at the national level, found qualified support for the weakest link hypothesis when tested by using some metrics of vulnerability and not for others (Tol and Yohe 2007). That study found in adapting to natural disasters, it is difficult but not impossible for capacities in education and income to make up for one another. However, if life expectancy is used as the metric of vulnerability (rather than population affected by disasters), it is unclear is some capacities can compensate for others. These findings suggest the weakest link hypothesis may hold true for adaptive capacity to some stressors and situations and not for others. None-the-less, the "weakest link" approach is the most stringent of the potential amalgamation mechanisms and thereby provides a lowest bound for transboundary adaptive capacity; thus we use it in our analysis.

Our interest is in identifying whether or not a particular co-riparian limits transboundary adaptive capacity, rather than in identifying which of the twelve factors contributing to adaptive capacity is the weakest link. To determine if a riparian constitutes the weakest link in a basin, we compared indicator scores calculated at the basin-country level[17] within a basin. Figure 4a shows the basin-country level aggregate index scores within each basin; Figure 4b details the basin-country aggregate index scores for the Tigris basin with radar plots of the component scores for each of the six features of transboundary basins linked with adaptive capacity for each co-riparian, which were used to calculate the aggregate index. A riparian is considered the weakest link if it the basin-country level aggregate index for that riparian is lower than that of each of its co-riparians by at least ten points. As per these criteria, fourteen basins in the study region contain weakest links; these basins along with their weakest links are presented in Table 5

[17] For each basin, the basin-country level represents the indicator score as calculated for individual riparians rather than at the basin level. Appendix D contains the indicator values as calculated for each basin-country unit.

Table 5. Weakest Links in Basins

Basin Name	Weakest Link Riparian	Lowest Indicator Scores	Category	Aggregate Index
An Nahr Al Kabir	Lebanon	Political Stability, Risk Preparedness, Water Dependency	Dependent Instability	46
Douro/Duero	Spain	Political Stability, Risk Preparedness, Trade Dependency, Water Dependency	Well-Prepared	72
Ebro	Andorra	Formal Agreements, IGOs, Shared Water Norms, Data Sharing	Good Neighbor	40
Garonne	Andorra	Formal Agreements, RBO, IGOs, Shared Water Norms, Uncertainty Mechanisms, Data Sharing	Good Neighbor	48
Gash	Ethiopia	Formal Agreements, Water Dependency	Dependent Instability	17
Guadiana	Spain	Political Stability, Risk Preparedness, Trade Dependency, Water Dependency	Well-Prepared	70
Krka	Bosnia	Political Stability, Government Effectiveness, IGOs, Risk Preparedness, Water Dependency	Ill-Prepared	19
Lima	Spain	Political Stability, Risk Preparedness, Trade Dependency, Water Dependency	Well-Prepared	70
Mino	Spain	Political Stability, Risk Preparedness, Trade Dependency, Water Dependency	Well-Prepared	72
Nahr El Kebir	Turkey	Shared Water Norms, Diplomatic Relations, Water Dependency	Dependent Instability	38
Neretva	Bosnia	Political Stability, Government Effectiveness, IGOs, Risk Preparedness, Water Dependency	Ill-Prepared	19
Roia	Italy	Government Effectiveness, Shared Water Norms, IGOs, Risk Preparedness	Good Neighbor	38
Senegal	Guinea	Data Sharing, Water Dependency	Mediated Coop	33
Tagus/Tejo	Spain	Political Stability, Risk Preparedness, Trade Dependency, Water Dependency	Well-Prepared	64

The riparians considered the weakest link tend to score lower than their co-riparians on Water Dependency [18] (11 of the 14 basins); Risk Preparedness (9 of the 14 basins); and Political Stability (8 of the 14 basins). Water Dependency will of course vary within a basin, particularly if the river has an upstream/downstream configuration.[19] However, differences in Political Stability within a basin can greatly undermine the ability of riparians to communicate and coordinate to prevent spillover. Moreover, if one riparian has a much lower degree of Risk Preparedness and Provisions, the others may not be able to plan accordingly.

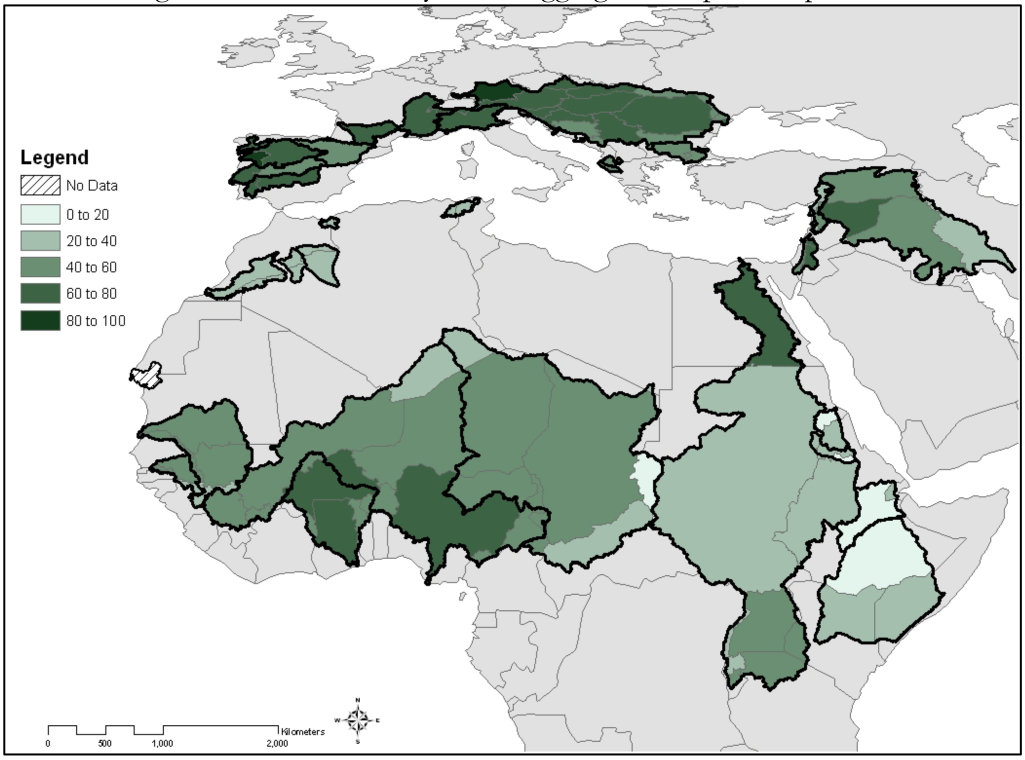
The presence of a weakest link does not necessarily imply a basin has low adaptive capacity; a weakest link existed within all basin clusters except the self-sufficient category and occurred most often in Well Prepared basins (5 of the 14 weakest links, all Spain). The presence of a weakest

[18] A lower score on Water Dependency indicates that other sources of water are available to that country (it may frequently also be the upstream riparian. This indicator simply points out that water dependence is not likely an incentive for these riparians.

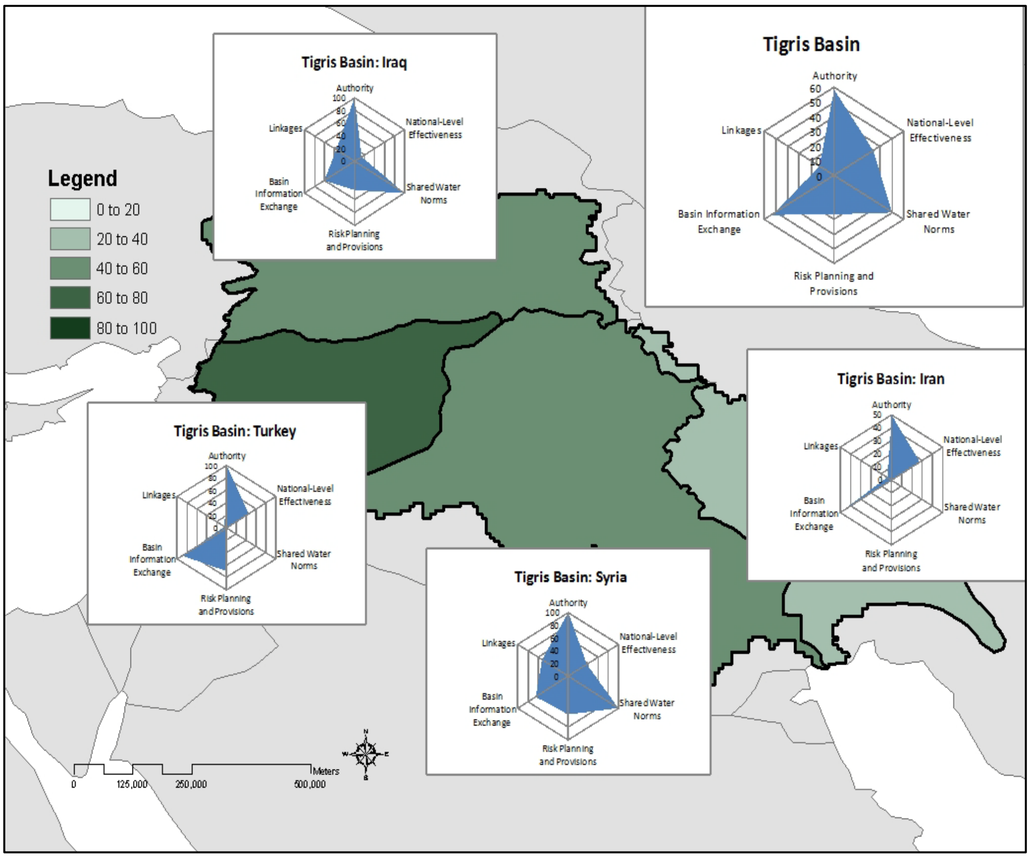
[19] Riparians cooperate for a variety of reasons, see for example Zeitoun and Warner's (2007) the theory of hydrohegemony. A number of studies have investigated the impact of the geographical configuration of a river on cooperation (Song and Whittington 2004; Yoffe, Fiske et al. 2004; Gleditsch, Furlong et al. 2006; Brochmann and Hensel 2011; Dinar, Dinar et al. 2011; Zawahri and Mitchell 2011); those studies have had mixed conclusions.

link even in a high-capacity basin does not suggest co-riparians are compensating, as even though Spain contributes less to transboundary adaptive capacity lower than its co-riparians, it still scores quite highly overall.

Figure 4. Basin-Country Level Aggregate Adaptive Capacities



a) Basin-Country Level Aggregate Adaptive Capacities for All Basins in the Study



b) Tigris Basin-Country Level Aggregate Adaptive Capacities and Average Scores for Each of the Six Transboundary Adaptive Capacity Features.

4.4. Comparison Adaptation at Varying Scales

Our system of indicators represents the characteristics of a basin that facilitate the process of communication, coordination, and cooperation across the international boundary - which we see as the defining feature of transboundary adaptive capacity. Yet adaptive capacity at the national scale and the resilience of formal basin institutions are other features of a basin which could be used as indicators transboundary adaptive capacity. Consequently, we wanted to see how our indicators compare with those metrics. If our metric of transboundary adaptive capacity compares similarly with valuations of the basins as determined by studies of national level adaptive capacity, a focus on improving national level capacities would likely improve transboundary adaptive capacity. If the transboundary and national level metrics do not coincide, this argues for policies that incorporate specific consideration of transboundary interactions. Similarly, if the metrics of transboundary adaptive capacity overlap considerably with an assessment of the resilience of formal basin institutions, this suggests existing institutions are good proxy for transboundary adaptive capacity. Conversely, if the metrics do not coincide, the resilience of existing institution may not well represent the ability of basins to address future cross border spill over.

For the first analysis, we compared our aggregate transboundary adaptive capacity index with national level indicators developed by Brooks et al. (2005). They calculated a vulnerability score for each of 204 countries using eleven proxies for vulnerability including: 1) population with access to sanitation; 2) literacy rate, 15-24 year olds; 3) maternal mortality; 4) literacy rate, over 15 years; 5) calorie intake; 6) voice and accountability; 7) civil liberties; 8) political rights; 9) government effectiveness; 10) literacy ratio (female to male); and 11) life expectancy at birth. Of these metrics, only one – government effectiveness – overlaps with our indicators. Country vulnerability scores ranged 10 to 50, with a higher score representing greater vulnerability.

In order to compare the metrics developed by Brooks et al. (2005) with our indicators of transboundary adaptive capacity we had to undertake three transformations. The first was to ensure equivalent units of analysis. Thus we converted their vulnerability indicator, which was calculated using the country as the unit of analysis to the basin level using the same method of limited-substitutability averaging that we used when aggregating several of our indicators to the basin level (see Appendix B for more information on this method). The second transformation involved converting their indicator of vulnerability to an indicator of adaptive capacity by reversing its scale. Lastly, as the metrics use different scales, we normalized both our metrics and theirs to a similar five unit scale by dividing the scale into groups covering an equal range and assigning the categories of low, medium-low, medium, medium-high, and high capacities.

As a whole, the metric of national-level adaptive capacities matched or predicted higher capacities than our aggregate tranboundary adaptive capacity index: metrics of national level adaptive capacity exceeded our index for 20 of the basins; matched metrics for 18 of the basins; and were lower for four of the basins.[20] These results suggest national level metrics of adaptive capacity do not encapsulate specific basin features which influence transboundary interaction. In fact, the metric of national-level adaptive capacity were higher than our transboundar index for all basins in both the Self-Sufficient and Good Neighbour clusters, confirming that key differences do indeed stem from consideration of characteristics related to transboundary authority and cross border communication.

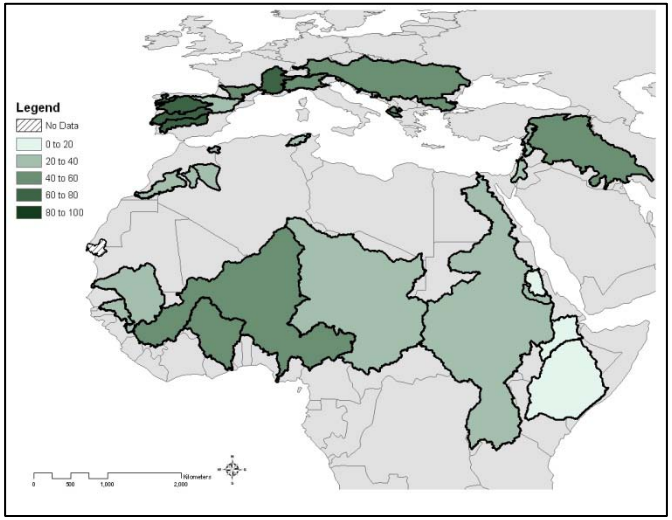
We also compared our analysis of transboundary adaptive capacity the measure of the resilience of existing transboundary institutions developed by De Stephano et al. (2010). Their metric institutional resilience considers the presence of water treaties, allocation mechanisms, variability management mechanisms, conflict resolution mechanisms, and RBOs. Except for conflict resolution mechanisms, each of these features of a basin is incorporated into the indicators of transboundary adaptive capacity index we have developed. Thus a comparison between the resilience metrics developed by De Stephano et al. (2010) with our indicators also serves to determine if a more parsimonious metric can capture the same features of transboundary basins.

In order to compare the metrics developed by De Stephano et al. (2010) with our indicators of transboundary adaptive capacity we had to undertake two transformations. The first was to ensure equivalent units of analysis. Thus we converted their indicator, which was calculated using the basin-country unit as the unit of analysis to the basin level using the same method of limited-substitutability averaging that we used when aggregating several of our indicators to the basin level (see Appendix B for more information on this method). Next, as the metrics use different scales, we normalized both our metrics and theirs to the same five unit scale by dividing the scale into groups covering an equal range and assigning the categories of low, medium-low, medium, medium-high, and high capacities.

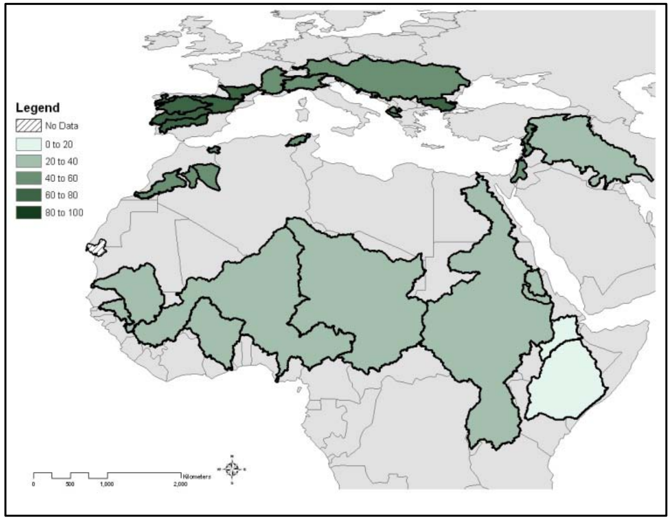
[20] The national-level adaptive capacities are based on data from 1998 whereas the transboundary metrics are calculated for 2010, thus some of these differences may stem from changes in the basin over time rather than differences resulting from the focus of the analysis. However, there is no substantive reason to believe that capacities overall have declined so dramatically.

Similar to the national level metrics, we find that our index of transboundary adaptive capacity results in lower evaluations than metric of institutional resilience. Metrics of institutional resilience exceeded our aggregate transboundary adaptive capacity index for 16 of the basins; matched for 13 of the basins; and were lower for 16 of the basins. However, unlike with the metrics of national level adaptive capacity by Brooks et al. (2005), there is not clear trend across basin types.

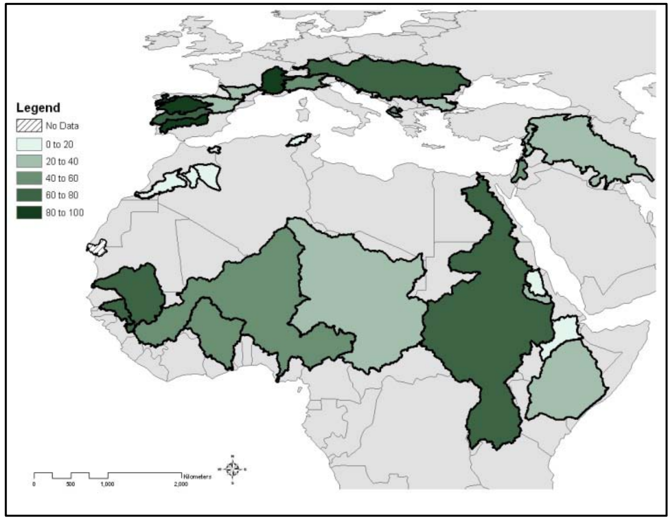
Figure 5. Comparison Transboundary, National & Treaty Level Adaptive Capacities



a) AggregateTransboundary Adaptive Capacity Index



b) Basin Adaptive Capacity Calculated By Aggregating National Level Metrics from Brooks et al. (2005)



c) Basin Adaptive Capacity Calculated Using Treaty Resilience Metrics from De Stephano et al. (2010)

5. Discussion

Transboundary adaptive capacity varies substantially across the MMES region. Unsurprisingly, river basins in Western Europe are better prepared for climate change than basins traversing less developed countries. Yet our analysis suggests the region as a whole suffers systematically from a paucity of mechanisms for addressing uncertainty. Moreover, outside of the European basins, political instability and lower levels of governance pose a challenge for transboundary adaptive capacity.

During 2011, a massive transformation has traversed the MMES region; the "Arab Spring" has touched upon at least 16 of the 42 river basins in the study and the new state of South Sudan was formed. The impact of these shifts are already being experienced in the Nile Basin, as Ethiopia and Egypt have moved forward on discussions on dam building, though no new formal agreements have been reached. The implications of these socio-political changes will reverberate for years to come and cannot be predicted or well captured using data from 2010.

In terms of policy, our cluster analysis highlights how certain types of basins would benefit more from targeted interventions. Policies aimed at improving data sharing would benefit Good Neighbour, Dependent Instability, and Ill Prepared basins, but might not add to Mediated Cooperation Basins. In Mediated Cooperation basins, although there are currently high levels of formal agreements and data sharing, co-riparians do not hold shared water norms, which might be a point of contention. The Nile again provides a useful example of this conundrum: despite participation in treaties and formal basin organizations, there remains much disagreement between Egypt and Ethiopia regarding who has the right to undertake what actions. Thus in Mediated Cooperation basins, additional policies aimed at sharing data or joint management may be ineffective if underlying normative factors are not first addressed.

Beyond pointing to variation across basin types, our research also highlights that adaptive capacity at higher scales requires a different gestalt than simply the sum of its component parts. A comparison of our metrics of transboundary adaptive capacity with metrics of national level adaptive capacity shows that the characteristics of basins which facilitate communication and coordination across the political boundary include elements not well encapsulated by metrics of adaptive capacity at the country level.

In terms of interaction across the scales, the fact that of the 42 basins analyzed only 14 contain a weak link riparian indicates usually no one riparian alone is the cause of lower transboundary adaptive capacity, rather lower adaptive capacity is systemic to the basin. This finding supports our assumption of limited compensation across riparians: although riparian A may have a high level of government effectiveness, it cannot make up for a lack of effectiveness on the part of riparian B.[21] This is an important point in the context of transboundary adaptive capacity: the general presumption is that in order for transboundary adaptive capacity to be high, it must be high across the entire basin. Were our definition of transboundary adaptive capacity solely based on financial, technical, or human resources available, a higher degree of substitutability might be expected as a wealthier riparian could pay for adaptation activities on the part of its less well-off co-riparian. However, when transboundary adaptive capacity is defined as the ability to communicate, coordinate and cooperate across the basin, substitution is less feasible. The

[21] See Appendix B – in aggregating the indicators that are use country-level data as inputs, we assumed limited substitution.

question that then arises is must all riparian's contribute to communication, coordination and cooperation? This is in part a question of geography.

The potential for externalities as well as the significance or importance of those externalities varies from basin to basin. In some instances, although a river is transboundary by definition, the portion or significance of a river to some riparians may be such that few if any externalities would become a substantial threat. This might be the case where water dependencies and likely hydrologic connections are quite small, such as is the case for the Self Sufficient basins or even several of the Good Neighbour basins. Or it may be the case when the upstream riparian has minimal influence for a variety or reasons. For example, although the Ebro river spans parts of Spain, France, and Andorra, it is primarily characterized as a Spanish river (personal communication, two Ebro river basin water researchers, August 2011).

The need to consider how risks (perceived or actual) influence transboundary adaptive capacity suggests it may be useful to combine our contextual adaptive capacity indicators with an analysis of potential hazards. An extension of this research would thus be to incorporate into our indicators an analysis projected changes in the basin so as to develop a prognostic of outcome risk.[22] In particular, it would be useful to identify overlap between basins with low levels of transboundary adaptive capacity that are projected to experience high degrees of change in water availability (flooding or drought) as well as with other sources of change (population, economic).

Lastly, though our indicators are designed to be "contextual" there are limits to the depth of context indicators can convey. This is a problem of all analyses that attempts to describe complex socio-political situations quantitatively. The need to synthesize characteristics into measurable units that can be calculated using easily available data means that certain features cannot be captured and others are dramatically simplified. The result is some of the defining characteristics of a basin are rendered invisible. For example, the Nile scores relatively well in the aggregate transboundary adaptive capacity index, yet communication, coordination and cooperation on the Nile are quite spotty. In fact, the basin often is posed on the brink of violence, with Ethiopian and Egyptian ministers threatening war[23] and Sudan freezing its participation in the Nile Basin Initiative.[24]

In particular, the indicators we have developed do not shed light on specific factors within a basin which may open or close policy windows. Our use of generalized indicators and our reliance on global datasets means we lack information issues such as when a key political figure has vested interest in that portion of the basin falling within that country (be it due to power relationships, economic rents, etc) or transboundary interactions might be used discursively within a country, so as to achieve political gains.

Nonetheless, there is a growing interest in the development of standardized datasets that can be used to identify regions that are particularly vulnerable to the impacts of climate change. The demand for indicators of adaptive capacity stems from a need to objectively and consistently identify priority areas for investment of global climate adaptation funds (Barr, Fankhauser et al. 2010; Klein and Möhner 2011). Our analysis begins this process for transboundary river basins.

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[22] For a definition of and discussion on outcome risk see (Sarewitz, Pielke et al. 2003)
[23] See Malone, B. (2010). Ethiopian PM warns Egypt off Nile War. Reuters, http://uk.reuters.com/assets/print?aid=UKTRE6AM5V820101123
[24] See "Sudan Freezing Its Membership in the Nile Basin Initiative" 27 June 2010, http://www.sudantribune.com/Sudan-freezing-its-membership-in,35508

In adopting a process based approach, we highlight the importance of understanding how adaptation occurs at the transboundary level. This approach provides more information than simply the identification of less prepared basins; it leads to more nuanced understanding of types of interventions that would be more effective in improving cross-border communication, coordination, and cooperation.

6. Acknowledgements

We thank Aaron Wolf and Jennifer Veilleux with the Oregon State Transboundary Freshwater Dispute Database for the GIS files used in this analysis; Itay Fischhendler with the Hebrew University of Jerusalem for data on uncertainty mechanisms and data sharing; Lucia De Stephano with the Universidad Complutense de Madrid for data on treaty resilience; and W. Neil Adger with the University of East Anglia for data on national level vulnerabilities. We also thank Marisa Goulden and the CLICO internal reviewer who provided valuable feedback and suggestions. This research is part of the CLICO project on Climate Change, Hydro-Conflict, and Human Security. CLICO is carried out by 14 research institutes from Europe and the Middle East and is funded under the European Union Framework 7 Research Programme.

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8. Appendix A: List of Basins and Riparian Countries in the Study Region

River Basin	BCODE	Riparian Countries	CCODE	BCCODE
An Nahr Al Kabir	ANAK	Lebanon	LBN	ANAK_LBN
		Syrian Arab Republic	SYR	ANAK_SYR
Asi/Orontes	ASIX	Lebanon	LBN	ASIX_LBN
		Syrian Arab Republic	SYR	ASIX_SYR
		Turkey	TUR	ASIX_TUR
Awash	AWSH	Djibouti	DJI	AWSH_DJI
		Ethiopia	ETH	AWSH_ETH
		Somalia	SOM	AWSH_SOM
Baraka	BRKA	Eritrea	ERI	BRKA_ERI
		Sudan	SDN	BRKA_SDN
Bidasoa	BDSO	France	FRA	BDSO_FRA
		Spain	ESP	BDSO_ESP
Danube	DANU	Albania	ALB	DANU_ALB
		Austria	AUT	DANU_AUT
		Bosnia and Herzegovina	BIH	DANU_BIH
		Bulgaria	BGR	DANU_BGR
		Croatia	HRV	DANU_HRV
		Czech Republic	CZE	DANU_CZE
		Germany	DEU	DANU_DEU
		Hungary	HUN	DANU_HUN
		Italy	ITA	DANU_ITA
		Montenegro	MNE	DANU_MON
		Poland	POL	DANU_POL
		Republic of Moldova	MDA	DANU_MDA
		Romania	ROU	DANU_ROM
		Serbia	SRB	DANU_SRB
		Slovakia	SVK	DANU_SVK
		Slovenia	SVN	DANU_SVN
		Switzerland	CHE	DANU_CHE
		Ukraine	UKR	DANU_UKR
Daoura	DAUR	Algeria	DZA	DAUR_DZA
		Morocco	MAR	DAUR_MAR
Douro/Duero	DURO	Portugal	PRT	DURO_PRT
		Spain	ESP	DURO_ESP
Dra	DRAX	Algeria	DZA	DRAX_DZA
		Morocco	MAR	DRAX_MAR
Ebro	EBRO	Andorra	AND	EBRO_AND

River Basin	BCODE	Riparian Countries	CCODE	BCCODE
		France	FRA	EBRO_FRA
		Spain	ESP	EBRO_ESP
Gambia	GAMB	Gambia	GMB	GAMB_GMB
		Guinea	GIN	GAMB_GIN
		Senegal	SEN	GAMB_SEN
Garonne	GRON	Andorra	AND	GRON_AND
		France	FRA	GRON_FRA
		Spain	ESP	GRON_ESP
Gash	GASH	Eritrea	ERI	GASH_ERI
		Ethiopia	ETH	GASH_ETH
		Sudan	SDN	GASH_SDN
Guadiana	GUDN	Portugal	PRT	GUDN_PRT
		Spain	ESP	GUDN_ESP
Guir	GUIR	Algeria	DZA	GUIR_DZA
		Morocco	MAR	GUIR_MAR
Isonzo	ISNZ	Italy	ITA	ISNZ_ITA
		Slovenia	SVN	ISNZ_SVN
Jordan	JORD	Egypt	EGY	JORD_EGY
		Israel	ISR	JORD_ISR
		Jordan	JOR	JORD_JOR
		Lebanon	LBN	JORD_LBN
		Syrian Arab Republic	SYR	JORD_SYR
Juba-Shibeli	JUBA	Ethiopia	ETH	JUBA_ETH
		Kenya	KEN	JUBA_KEN
		Somalia	SOM	JUBA_SOM
Krka	KRKA	Bosnia and Herzegovina	BIH	KRKA_BIH
		Croatia	HRV	KRKA_HRV
Lake Chad	LKCH	Algeria	DZA	LKCH_DZA
		Cameroon	CMR	LKCH_CMR
		Central African Republic	CAF	LKCH_CAF
		Chad	TCD	LKCH_TCD
		Libyan Arab Jamahiriya	LBY	LKCH_LBY
		Niger	NER	LKCH_NER
		Nigeria	NGA	LKCH_NGA
		Sudan	SDN	LKCH_SDN
Lake Prespa	LKPP	Albania	ALB	LKPP_ALB
		Greece	GRC	LKPP_GRC

River Basin	BCODE	Riparian Countries	CCODE	BCCODE
		The former Yugoslav Republic of Macedonia	MKD	LKPP_MKD
Lima	LIMA	Portugal	PRT	LIMA_PRT
		Spain	ESP	LIMA_ESP
Maritsa	MRSA	Bulgaria	BGR	MRSA_BGR
		Greece	GRC	MRSA_GRC
		Turkey	TUR	MRSA_TUR
Medjerda	MDJD	Algeria	DZA	MDJD_DZA
		Tunisia	TUN	MDJD_TUN
Mino	MINO	Portugal	PRT	MINO_PRT
		Spain	ESP	MINO_ESP
Nahr El Kebir	NHRK	Syrian Arab Republic	SYR	NHRK_SYR
		Turkey	TUR	NHRK_TUR
Neretva	NRTV	Bosnia and Herzegovina	BIH	NRTV_BIH
		Croatia	HRV	NRTV_HRV
Niger	NGER	Algeria	DZA	NGER_DZA
		Benin	BEN	NGER_BEN
		Burkina Faso	BFA	NGER_BFA
		Cameroon	CMR	NGER_CMR
		Chad	TCD	NGER_TCD
		Cote d'Ivoire	CIV	NGER_CIV
		Guinea	GIN	NGER_GIN
		Mali	MLI	NGER_MLI
		Niger	NER	NGER_NER
		Nigeria	NGA	NGER_NGA
Nile	NILE	Burundi	BDI	NILE_BDI
		Central African Republic	CAF	NILE_CAF
		Democratic Republic of Congo	ZAR	NILE_ZAR
		Egypt	EGY	NILE_EGY
		Eritrea	ERI	NILE_ERI
		Ethiopia	ETH	NILE_ETH
		Kenya	KEN	NILE_KEN
		Rwanda	RWA	NILE_RWA
		Sudan	SDN	NILE_SDN
		Uganda	UGA	NILE_UGA
		United Republic of Tanzania	TZA	NILE_TZA
Oued Bon Naima	ODBN	Algeria	DZA	ODBN_DZA
		Morocco	MAR	ODBN_MAR
Po	POXX	France	FRA	POXX_FRA

River Basin	BCODE	Riparian Countries	CCODE	BCCODE
		Italy	ITA	POXX_ITA
		Switzerland	CHE	POXX_CHE
Rezvaya	REZV	Bulgaria	BGR	REZV_BGR
	REZV	Turkey	TUR	REZV_TUR
Rhone	RHON	France	FRA	RHON_FRA
		Switzerland	CHE	RHON_CHE
Roia	ROIA	France	FRA	ROIA_FRA
		Italy	ITA	ROIA_ITA
Senegal	SENG	Guinea	GIN	SENG_GIN
		Mali	MLI	SENG_MLI
		Mauritania	MRT	SENG_MRT
		Senegal	SEN	SENG_SEN
Tafna	TAFN	Algeria	DZA	TAFN_DZA
		Morocco	MAR	TAFN_MAR
Tagus/Tejo	TAGU	Portugal	PRT	TAGU_PRT
		Spain	ESP	TAGU_ESP
Tigris-Euphrates/Shatt al Arab	TIGR	Iran (Islamic Republic of)	IRN	TIGR_IRN
		Iraq	IRQ	TIGR_IRQ
		Jordan	JOR	TIGR_JOR
		Saudi Arabia	SAU	TIGR_SAU
		Syrian Arab Republic	SYR	TIGR_SYR
		Turkey	TUR	TIGR_TUR
Velaka	VLKA	Bulgaria	BGR	VLKA_BGR
		Turkey	TUR	VLKA_TUR
Vijose	VJSE	Albania	ALB	VJSE_ALB
		Greece	GRC	VJSE_GRC
Volta	VOLT	Benin	BEN	VOLT_BEN
		Burkina Faso	BFA	VOLT_BFA
		Cote d'Ivoire	CIV	VOLT_CIV
		Ghana	GHA	VOLT_GHA
		Mali	MLI	VOLT_MLI
		Togo	TGO	VOLT_TGO
Wadi Al Izziyah	WADI	Israel	ISR	WADI_ISR
		Lebanon	LBN	WADI_LBN

The GIS files used in this analysis were provided by the Transboundary Fresh Water Dispute Database at Oregon State University (See http://www.transboundarywaters.orst.edu/database/) In this database, codes are used for identifying the basins and riparians. The BCode identifies the river basin; the CCode identifies countries, and the BCCode identifies the portion of a country falling in a specific basin/the portion of a basin falling in a specific country.

9. Appendix B: Table of Indicator Metrics, Data Sources, and Aggregation Methods

	Metric	Calculation	Data Source (Database/reference, URL, Date accessed)	Initial Unit of Analysis	Aggregation method	Comments
Authority	Formal agreement & geographic scope	The percentage of riparians in the basin that are signatory to any agreement.	International Freshwater Treaties Database, Transboundary Freshwater Dispute Database (TFDD). http://ocid.nacse.org/tfdd/treaties.php 23/06/2011 ----- Drieschova, A., Fischhendler, I., & Giordano, M. (2011). The role of uncertainties in the design of international water treaties: an historical perspective. Climatic Change, 105(3-4), 387-408. ----- de Stefano et al, 2010. Mapping the resilience of international river basins to future climate change-induced water variability, Appendix 2. World Bank, Washington DC. http://water.worldbank.org/water/node/83945 22/07/2011	Basin	a	Only treaties and agreements that are specific to the river basin are included. Broad conventions are not included (e.g. The African convention on the conservation of nature and natural resources). Treaties that only a portion of the basin or a sub-basins *are* included.
	River basin organization & geographic scope	The percentage of riparians in the basin that are members of any river basin organization.	Transboundary Freshwater Dispute Database (TFDD), River Basin Organization Database http://www.transboundarywaters.orst.edu/research/RBO/ 29/06/2011 ----- de Stefano et al, 2010. Mapping the resilience of international river basins to future climate change-induced water variability, Appendix 3. World Bank, Washington DC. http://water.worldbank.org/water/node/83945 22/07/2011	Basin	a	Organizations that cover only sub-basins are included.

National-Level Governance	Political Stability Index	The World Bank indicators for each riparian were normalized to a scale from 1 to 100 and aggregated.	The World Bank, Worldwide Governance Indicators http://info.worldbank.org/governance/wgi/sc_country.asp 16/06/2011	Country	d	
	Government Effectiveness Index	The World Bank indicators for each riparian were normalized to a scale from 1 to 100 and aggregated	The World Bank, Worldwide Governance Indicators http://info.worldbank.org/governance/wgi/sc_country.asp 16/06/2011	Country	d	
Common Perspectives	Signatory UN convention on non-navigational use of water	The percentage of riparians that are signatory to the convention.	United Nations (UN), UN Treaty Collection http://treaties.un.org/Pages/ViewDetails.aspx?src=UNTSONLINE&tabid=2&mtdsg_no=XXVII-12&chapter=27&lang=en#Participants 06/06/2011	Country	c	
	Shared membership of inter-governmental organizations	The number of inter-governmental organizations in which *all* riparians participate.	Pevehouse, Jon C., Timothy Nordstrom, and Kevin Warnke. 2004. "The COW-2 International Organizations Dataset Version 2.0," *Conflict Management and Peace Science* 21(2):101-119. http://www.correlatesofwar.org/COW2%20Data/IGOs/IGOv2.3.htm 23/06/2011	Basin	b	This indicator is biased towards European basins due to the high number of European organisations. A coding of 0-3 in the original dataset was taken as membership for the analysis.
Risk Planning and ProvisionS	Specific elements of existing treaties and agreements regarding uncertainty management	For each of the following characteristics if they were included in an agreement that included a sub-set of riparians, five points were added and if they were included in an agreement that included all riparians, ten points were added: a. Formal agreement includes provisions to address flow variability b. Formal agreement includes provisions that allow for variability in management (flood or dry season controls) c. Formal agreement includes provisions that address variability in hydropower or water needs d. Formal agreement includes provisions for at least one situation in which a different development can occur and alternative modes of action are	Drieschova, A., Fischhendler, I., & Giordano, M. (2011). The role of uncertainties in the design of international water treaties: an historical perspective. Climatic Change, 105(3-4), 387-408. Data provided by CLICO Partner Hebrew University of Jerusalem. 22/06/2011 ----- de Stefano et al, 2010. Mapping the resilience of international river basins to future climate change-induced water variability, Appendix 4. World Bank, Washington DC. http://water.worldbank.org/water/node/83945 22/07/2011	Basin	a	

		stipulated e. Formal agreement develops or mentions available mechanisms for predicting particular aspects about the future, such as for example the occurrence of floods.				
	Hyogo Framework for Action Progress Reporting	The percentage of riparians that have completed the Hyogo Framework for Action Progress Reports. Half a riparian is counted if the report is in process but not complete.	Global Assessment Report on Disaster Risk Reduction 2011, Hyogo Framework for Action (HFA) Progress Reports http://www.preventionweb.net/english/hyogo/gar/2011/en/hfa/reports.html 21/06/11	Country	c	
Basin Information Interchange	Specific elements of existing treaties and agreements regarding data sharing	For each of the following characteristics if they were included in an agreement that included a sub-set of riparians, twenty-five points were added and if they were included in an agreement that included all riparians, fifty points were added: information exchange; consultations.	Transboundary Freshwater Dispute Database (TFDD), International Freshwater Treaties Database (TFDD, http://ocid.nacse.org/tfdd/treaties.php 23/06/2011 ----- Drieschova, A., Fischhendler, I., & Giordano, M. (2011). The role of uncertainties in the design of international water treaties: an historical perspective. Climatic Change, 105(3-4), 387-408. Not accessed online ----- de Stefano et al, 2010. Mapping the resilience of international river basins to future climate change-induced water variability, Appendix 4. World Bank, Washington DC. http://water.worldbank.org/water/node/83945 22/07/2011	Basin	a	
	Diplomatic exchange	The percentage of diplomatic exchanges between riparians compared to maximum possible relations.	Bayer, R. 2006.Diplomatic Exchange Data set, V.2006.1. http://www.correlatesofwar.org/COW2%20Data/Diplomatic/Diplomatic.html 14/06/11	Country	b	Diplomatic relations were considered to be in place if COW DR variable equal to: 2, 3 or 9. All other values represent no diplomatic relations. If data is missing on any one riparian, the calculation was conducted by subtracting that riparian from both the potential and the total number of relations. This applies to the Senegal basin (Mauritania) and the Danube

						basin (Montenegro and Serbia).
Linkages	Regional trade	Ratio of $ of trade occurring among riparians to trade occurring between riparians and the rest of the world.	Economic and Social Data Service (ESDS), International Monetary Fund (IMF) Direction of Trade Statistics (DOTS) http://www.esds.ac.uk/International/access/dataset_overview.asp#desc_IMFDOTS 09/06/11	Country	a	The average trade level from 2008, 2009 and 2010 is used to allow for the occurrence of events in any one year that may have caused an anomaly in the trade balance. If data is missing on any one riparian, the calculation was conducting using solely the data from the other co-riparians. This applies to the Ebro and Garonne basins (Andorra) and the Gash and Nile basins (Eritria). No calculation was performed for the Baraka (Eritria, Sudan) or Wadi Al Izziyah (Israel, Lebanon) basins because data was missing from all riparians.
	Dependency on external renewable water resources.	Aggregation of the ratio of external renewable water resources to total renewable water resources for each riparian.	Food and Agricultural Organization of the United Nations (FAO), Country Datasheets http://www.fao.org/nr/water/aquastat/main/index.stm 01/08/2011	Country	d	If data is missing on any one riparian, the calculation was conducted using solely the data from the other co-riparians. This applies to the Ebro, Garonne basins (Andorra) and the Danube basin (Montenegro and Serbia).

Aggregation method	Description	Metrics applicable
a. Data intrinsically basin-wide	No aggregation required, as metrics are intrinsically at the basin scale.	• Formal agreement & geographic scope • River basin organization & geographic scope • Regional trade • Mechanisms for managing uncertainty • Mechanisms for data sharing
b. Data used to describe relationships between countries in the basin	No aggregation required, as metrics are intrinsically at the basin scale.	• Shared membership of inter-governmental organizations • Diplomatic Exchange
c. Portion of basin with specific characteristics	No aggregation required, as metrics are intrinsically at the basin scale.	• Signatory of UN Convention for non-navigational use of water • Hyogo Framework for Action Progress Reporting
d. Limited-Substitutability Averaging	These metrics are intrinsically at the country scale and had to be aggregated to the basin scale. However, as there is not perfect substitutability across country lines (e.g., country A cannot necessarily transfer its characteristics to country B), rather than average we use an aggregation mechanism that assumes limited substitutability. The aggregation method selected is similar to that used in the development of the Human Poverty Index (see Anand and Sen 1997). Basin Score = 100 - $\sqrt[\propto]{\underline{[\sum_{i=1}^{n}(P_i)^{\propto}]n}}$ where: P_i = the transformed metric at the country level n = number of riparians in the basin and alpha = the elasticity of substitution As there have been no empirical studies indicating an appropriate elasticity of substitution, we used alpha = 3 which translates to an elasticity of substitution of 0.5. The method places greater importance on higher scores, thus to place greater emphasis on countries with poorer characteristics, we first transformed the country level metrics by subtraction of the scores from 100 such that higher scores represent lower capacities. The basis metric is then re-transformed to that higher scores represent higher capacities.	• Political Stability • Government Effectiveness • Dependency on external renewable water resources

Aggregation to Six Indices for Radar Diagram Reporting

Indicators	Metric	Calculation
Authority	Formal agreement & river basin organization & geographic scope	Sum of percentage of riparians in the basin signatory to any formal agreement and percentage of riparians in the basin participating in a river basin organization divided by two. Equivalent to ratio of actual to potential portion of basin participating in formal agreements and river basin organizations.
National-Level Governance	Political Stability and Government Effectiveness Indices	Average of the aggregated basin scores for Political Stability and Government Effectiveness.
Common Perspectives	Signatory UN convention on non-navigational use of water	The percentage of riparians that are signatory to the convention. Participation in Intergovernmental Organizations was omitted in presentation on the radar diagrams due to lack of a metric with mathematical significance that would combine information on signatories to the UN convention and the number of IGOs in which riparians share membership.
Risk Planning and Provisions	Specific elements of existing treaties and agreements regarding uncertainty management and Hyogo Framework for Action Progress Reporting	Average of the percentage of riparians that meet each of the criteria as shown below: a. Formal agreement includes provisions to address flow variability b. Formal agreement includes provisions that allow for variability in management (flood or dry season controls) c. Formal agreement includes provisions that address variability in hydropower or water needs d. Formal agreement includes provisions for at least one situation in which a different development can occur and alternative modes of action are stipulated e. Formal agreement develops or mentions available mechanisms for predicting particular aspects about the future, such as for example the occurrence of floods. f. Hyogo Framework for Action reporting is in progress g. Hyogo Framework for Action reporting is complete
Basin Information Interchange	Specific elements of existing treaties and agreements regarding data sharing & diplomatic exchange	Average of the percentage of riparians signatory to an agreement that includes provisions for data exchange, the percentage of riparians signatory to an agreement that includes provisions for consultations, and the ratio of existing to maximum possible number of diplomatic relations between riparians.
Linkages	Regional trade & dependency on external renewable water resources.	Average of the intra-regional trade share and water dependency ratios for the basin.

10. Appendix C: Indicator Values for Each Basin

Basin	Formal Agreements	RBO	Political Stability	Government Effectiveness	Shared Water Norms	IGOs	Uncertainty	Risk Preparedness	Data Sharing	Diplomatic exchange	Trade Dependency	Water Dependency	Aggregate Index
An Nahr Al Kabir	100	0	27	37	57	100	40	50	50	0	8	21	41
Asi/Orontes	100	0	29	42	33	67	0	67	25	50	3	13	36
Awash	0	0	9	22	27	0	0	17	0	100	5	12	16
Baraka	0	0	12	28	34	0	0	0	0	50	no data[25]	63	17
Bidasoa	100	0	53	73	98	100	0	50	50	100	10	3	53
Danube	100	78	56	54	21	11	50	53	50	58	38	28	50
Daoura	0	0	33	43	70	0	0	100	0	100	1	2	29
Douro/Duero	100	100	54	71	94	100	60	50	100	100	11	17	71
Dra	0	0	33	43	70	0	0	100	0	100	1	2	29
Ebro	67	0	58	75	18	67	0	50	25	100	10	3	39
Gambia	100	100	33	33	50	0	0	33	50	50	3	23	40
Garonne	67	67	58	75	18	67	20	50	25	100	10	3	47
Gash	67	0	13	28	34	0	20	0	0	50	2	28	20
Guadiana	100	100	54	71	94	100	40	50	100	100	11	17	70
Guir	0	0	33	43	70	0	0	100	0	100	1	2	29
Isonzo	100	0	64	66	63	0	60	50	0	100	2	19	44
Jordan	67	50	26	43	29	50	20	58	25	20	5	34	36
Juba-Shibeli	0	0	4	24	32	0	0	33	0	100	1	23	18
Krka	0	0	48	47	39	0	0	50	0	100	10	24	26
Lake Chad	50	63	19	28	28	13	0	38	25	63	1	19	29

[25] Missing data at the basin-country unit is noted in Appendix D. Where data from one riparian data was missing, adjustments for the basin indicator calculations where made as described in Appendix B. There was insufficient data for the Baraka and Wadi Al Izziyah basins to calculate a trade dependency indicator

Basin	Formal Agreements	RBO	Political Stability	Government Effectiveness	Shared Water Norms	IGOs	Uncertainty	Risk Preparedness	Data Sharing	Diplomatic exchange	Trade Dependency	Water Dependency	Aggregate Index
Lake Prespa	100	67	48	51	38	33	20	33	75	67	3	23	46
Lima	100	100	54	71	94	100	40	50	100	100	11	17	70
Maritsa	100	0	45	57	51	33	30	50	75	100	4	7	46
Medjerda	0	0	37	46	73	50	0	75	0	100	1	6	32
Mino	100	100	54	71	94	100	60	50	100	100	11	17	71
Nahr El Kebir	100	0	34	46	38	50	0	100	50	50	1	21	41
Neretva	0	0	48	47	39	0	0	50	0	100	10	24	26
Niger	100	90	24	30	30	30	20	35	50	54	5	18	40
Nile	73	100	21	31	23	0	30	41	50	52	5	23	37
Oued Bon Naima	0	0	33	43	70	0	0	100	0	100	1	2	29
Po	100	67	64	71	78	33	40	83	25	100	13	11	57
Rezvaya	100	0	43	55	52	0	40	75	0	100	2	1	39
Rhone	100	100	66	82	85	50	80	100	100	100	4	14	73
Roia	100	0	61	67	101	50	0	75	0	100	9	5	47
Senegal	100	100	30	33	53	0	0	38	25	44	5	28	38
Tafna	0	0	33	43	70	0	0	100	0	100	1	2	29
Tagus/Tejo	100	100	54	71	94	100	40	50	50	100	11	17	66
Tigris-Euphrates/Shatt al Arab	67	50	27	41	26	50	20	50	50	77	8	17	40
Velaka	0	0	43	55	52	0	0	75	0	100	2	1	27
Vijose	100	0	49	53	47	50	0	25	100	100	1	28	46
Volta	100	100	42	34	24	33	0	50	100	63	9	23	48
Wadi Al Izziyah	0	0	20	48	35	50	0	0	0	0	no data	19	16

11. Appendix D: Indicator Values for Each Basin Country Unit

Basin	Country	Formal Agreements	RBO	Political Stability	Government Effectiveness	Shared Water Norms	IGOs	Uncertainty	Risk Preparedness	Data Sharing	Diplomatic exchange	Trade Dependency	Water Dependency	Aggregate Index
An Nahr Al Kabir	Lebanon	100	0	20	37	100	54	40	0	50	0	12	1	34
	Syrian Arab Republic	100	0	36	38	100	57	40	100	50	0	6	72	50
Asi/Orontes	Lebanon	100	0	20	37	100	54	0	0	0	50	16	1	31
	Syrian Arab Republic	100	0	36	38	100	57	0	100	50	50	12	72	51
	Turkey	100	0	32	57	0	77	0	100	50	50	1	1	39
Awash	Djibouti	0	0	60	32	0	47	0	0	0	100	12	0	21
	Ethiopia	0	0	15	42	0	49	0	0	0	100	0	0	17
	Somalia	0	0	-16	4	0	44	0	50	0	100	21	59	22
Baraka	Eritrea	0	0	34	22	0	35	0	0	0	100	No data	56	22
	Sudan	0	0	-3	24	0	70	0	0	0	0	0	77	14
Bidasoa	France	100	0	61	79	100	125	0	100	50	100	7	5	61
	Spain	100	0	46	69	100	105	0	0	50	100	15	0	49
Danube	Albania	100	0	49	46	0	53	40	50	50	59	57	35	45
	Austria	100	100	73	83	0	88	60	0	100	88	67	29	66
	Bosnia and Herzegovina	100	100	39	37	0	40	80	0	100	71	83	5	55
	Bulgaria	100	100	59	53	0	72	40	50	50	76	45	1	54
	Croatia	100	100	62	63	0	63	80	100	100	82	61	64	73
	Czech Republic	100	100	68	70	0	68	60	100	100	76	61	0	67
	Germany	100	100	67	80	100	109	80	100	100	88	27	31	82
	Hungary	100	100	62	65	100	75	40	0	100	88	58	94	73
	Italy	100	0	61	60	0	107	40	50	50	88	30	5	49

Basin	Country	Formal Agreements	RBO	Political Stability	Government Effectiveness	Shared Water Norms	IGOs	Uncertainty	Risk Preparedness	Data Sharing	Diplomatic exchange	Trade Dependency	Water Dependency	Aggregate Index
	Montenegro	100	100	61	49	0	54	80	50	100	0	60	No data	60
	Poland	100	0	68	63	0	83	40	100	50	71	50	13	53
	Republic of Moldova	100	100	40	39	0	50	80	0	100	35	52	91	57
	Romania	100	100	58	47	0	72	100	100	100	76	55	80	74
	Serbia	100	100	40	47	0	54	60	50	100	No data	65	No data	62
	Slovakia	100	100	68	68	0	68	60	50	100	71	64	75	69
	Slovenia	100	100	67	73	0	65	80	50	100	76	67	41	68
	Switzerland	100	0	74	88	0	91	0	100	50	88	42	24	55
	Ukraine	100	100	45	35	0	57	100	0	100	71	23	62	58
Daoura	Algeria	0	0	26	38	0	81	0	100	0	100	1	4	29
	Morocco	0	0	41	48	0	80	0	100	0	100	1	0	31
Douro/Duero	Portugal	100	100	66	74	100	99	60	100	100	100	28	45	81
	Spain	100	100	46	69	100	105	60	0	100	100	7	0	66
Dra	Algeria	0	0	26	38	0	81	0	100	0	100	1	4	29
	Morocco	0	0	41	48	0	80	0	100	0	100	1	0	31
Ebro	Andorra	0	0	77	81	0	20	0	50	0	100	No data	No data	33
	France	100	0	61	79	100	125	0	100	50	100	7	5	61
	Spain	100	0	46	69	100	105	0	0	50	100	15	0	49
Gambia	Gambia	100	100	55	37	0	62	0	0	50	50	9	63	44
	Guinea	100	100	12	24	0	72	0	0	50	50	2	0	34
	Senegal	100	100	47	42	0	84	0	100	50	50	2	34	51
Garonne	Andorra	0	0	77	81	0	20	0	50	0	100	No data	No data	33
	France	100	100	61	79	100	125	40	100	50	100	7	5	72
	Spain	100	100	46	69	100	105	40	0	50	100	15	0	60

Basin	Country	Formal Agreements	RBO	Political Stability	Government Effectiveness	Shared Water Norms	IGOs	Uncertainty	Risk Preparedness	Data Sharing	Diplomatic exchange	Trade Dependency	Water Dependency	Aggregate Index
Gash	Eritrea	100	0	34	22	0	35	0	0	0	50	No data	56	27
	Ethiopia	0	0	15	42	0	49	40	0	0	50	3	0	17
	Sudan	100	0	-3	24	0	70	40	0	0	50	1	77	30
Guadiana	Portugal	100	100	66	74	100	99	40	100	100	100	28	45	79
	Spain	100	100	46	69	100	105	40	0	100	100	7	0	64
Guir	Algeria	0	0	26	38	0	81	0	100	0	100	1	4	29
	Morocco	0	0	41	48	0	80	0	100	0	100	1	0	31
Isonzo	Italy	100	0	61	60	0	107	60	50	0	100	1	5	45
	Slovenia	100	0	67	73	0	65	60	50	0	100	14	41	48
Jordan	Egypt	0	0	37	44	0	86	0	100	0	80	4	97	37
	Israel	100	100	21	72	0	57	40	0	50	40	0	58	45
	Jordan	100	100	45	56	100	64	40	50	50	80	9	27	60
	Lebanon	100	0	20	37	100	54	40	0	50	40	17	1	38
	Syrian Arab Republic	100	100	36	38	100	57	40	100	50	40	11	72	62
Juba-Shibeli	Ethiopia	0	0	15	42	0	49	0	0	0	100	0	0	17
	Kenya	0	0	24	37	0	71	0	50	0	100	1	33	26
	Somalia	0	0	-16	4	0	44	0	50	0	100	6	59	21
Krka	Bosnia and Herzegovina	0	0	39	37	0	40	0	0	0	100	19	5	20
	Croatia	0	0	62	63	0	63	0	100	0	100	7	64	38
Lake Chad	Algeria	0	0	26	38	0	81	0	100	0	71	0	4	27
Lake Chad	Cameroon	100	100	42	34	0	84	0	0	50	71	8	4	41
Lake Chad	Central African Republic	0	100	9	22	0	63	0	50	0	43	8	2	25
Lake Chad	Chad	100	100	15	20	0	64	0	0	50	71	4	65	41
	Libyan Arab Jamahiriya	0	0	62	28	0	59	0	50	0	71	0	0	23

Basin	Country	Formal Agreements	RBO	Political Stability	Government Effectiveness	Shared Water Norms	IGOs	Uncertainty	Risk Preparedness	Data Sharing	Diplomatic exchange	Trade Dependency	Water Dependency	Aggregate Index
	Niger	100	100	27	35	0	67	0	0	50	57	17	90	45
	Nigeria	100	100	11	25	100	80	0	100	50	57	1	23	54
	Sudan	0	0	-3[26]	24	0	70	0	0	0	57	0	77	19
Lake Prespa	Albania	100	100	49	46	0	53	40	50	100	100	15	35	57
	Greece	100	0	49	62	100	91	40	0	100	50	2	22	51
	The former Yugoslav Republic of Macedonia	100	100	46	47	0	43	40	50	50	50	10	16	46
Lima	Portugal	100	100	66	74	100	99	40	100	100	100	28	45	79
	Spain	100	100	46	69	100	105	40	0	100	100	7	0	64
Maritsa	Bulgaria	100	0	59	53	0	72	40	50	100	100	14	1	49
	Greece	100	0	49	62	100	91	20	0	50	100	6	22	50
	Turkey	100	0	32	57	0	77	40	100	100	100	2	1	51
Medjerda	Algeria	0	0	26	38	0	81	0	100	0	100	1	4	29
	Tunisia	0	0	55	58	100	82	0	50	0	100	3	9	38
Mino	Portugal	100	100	66	74	100	99	60	100	100	100	28	45	81
	Spain	100	100	46	69	100	105	60	0	100	100	7	0	66
Nahr El Kebir	Syrian Arab Republic	100	0	36	38	100	57	0	100	50	100	5	72	55
	Turkey	100	0	32	57	0	77	0	100	50	0	1	1	35
Neretva	Bosnia and Herzegovina	0	0	39	37	0	40	0	0	0	100	19	5	20
	Croatia	0	0	62	63	0	63	0	100	0	100	7	64	38
Niger	Algeria	100	0	26	38	0	81	0	100	0	89	0	4	36

[26] The indicator used for Political Stability at the country level is a rescaling of the World Bank governance indicators (See Appendix B for a reference to that data). The Political Stability indicators have the characteristics of a normal random variable, with a mean of zero and a unit standard deviation. This means the indicators ranging approximately from -2.5 to 2.5. We transformed this data to a scale of 0 to 100 by setting -2.5 equal to zero and 2.5 equal to 100. This means the few outlying countries with a World Bank Political Stability score lower than 0 (Sudan and Somalia) will be negative on our scale.

Basin	Country	Formal Agreements	RBO	Political Stability	Government Effectiveness	Shared Water Norms	IGOs	Uncertainty	Risk Preparedness	Data Sharing	Diplomatic exchange	Trade Dependency	Water Dependency	Aggregate Index
	Benin	100	100	59	40	0	77	40	0	100	22	4	61	50
	Burkina Faso	100	100	48	37	100	75	40	100	100	56	21	0	65
	Cameroon	100	100	42	34	0	84	40	0	100	33	10	4	46
	Chad	100	100	15	20	0	64	40	0	100	22	4	65	44
	Cote d'Ivoire	100	100	19	26	100	80	40	0	100	89	21	5	57
	Guinea	100	100	12	24	0	72	40	0	100	44	2	0	41
	Mali	100	100	45	35	0	76	40	0	100	56	11	40	50
	Niger	100	100	27	35	0	67	40	0	100	44	23	90	52
	Nigeria	100	100	11	25	100	80	40	100	100	89	3	23	64
Nile	Burundi	100	100	22	28	0	47	0	100	50	30	20	20	43
	Central African Republic	0	100	9	22	0	63	0	50	0	30	3	2	23
	Democratic Republic of Congo	0	100	7	16	0	58	0	0	0	30	7	30	21
	Egypt	100	100	37	44	0	86	40	100	100	90	1	97	66
	Eritrea	0	100	34	22	0	35	0	0	0	40	No data	56	26
	Ethiopia	100	100	15	42	0	49	20	0	50	70	3	0	37
	Kenya	100	100	24	37	0	71	20	50	100	90	11	33	53
	Rwanda	100	100	43	46	0	50	0	0	50	30	43	0	39
	Sudan	100	100	-3	24	0	70	40	0	0	40	6	77	38
	Uganda	100	100	29	37	0	59	20	50	100	60	25	41	52
	United Republic of Tanzania	100	100	52	42	0	64	20	100	100	60	8	13	55
Oued Bon Naima	Algeria	0	0	26	38	0	81	0	100	0	100	1	4	29
	Morocco	0	0	41	48	0	80	0	100	0	100	1	0	31
Po	France	100	0	61	79	100	125	0	100	0	100	11	5	57
	Italy	100	100	61	60	0	107	80	50	50	100	14	5	61

Basin	Country	Formal Agreements	RBO	Political Stability	Government Effectiveness	Shared Water Norms	IGOs	Uncertainty	Risk Preparedness	Data Sharing	Diplomatic exchange	Trade Dependency	Water Dependency	Aggregate Index
	Switzerland	100	100	74	88	0	91	80	100	50	100	18	24	69
Rezvaya	Bulgaria	100	0	59	53	0	72	40	50	0	100	6	1	40
	Turkey	100	0	32	57	0	77	40	100	0	100	1	1	42
Rhone	France	100	100	61	79	100	125	80	100	100	100	3	5	79
	Switzerland	100	100	74	88	0	91	80	100	100	100	9	24	72
Roia	France	100	0	61	79	100	125	0	100	0	100	8	5	57
	Italy	100	0	61	60	0	107	0	50	0	100	10	5	41
Senegal	Guinea	100	100	12	24	0	72	0	0	0	67	1	0	31
	Mali	100	100	45	35	0	76	0	0	50	100	13	40	47
	Mauritania	100	100	27	32	0	80	0	50	50	No data	1	96	49
	Senegal	100	100	47	42	0	84	0	100	50	67	7	34	53
Tafna	Algeria	0	0	26	38	0	81	0	100	0	100	1	4	29
	Morocco	0	0	41	48	0	80	0	100	0	100	1	0	31
Tagus/Tejo	Portugal	100	100	66	74	100	99	40	100	50	100	28	45	75
	Spain	100	100	46	69	100	105	40	0	50	100	7	0	60
Tigris-Euphrates/ Shatt al Arab	Iran (Islamic Republic of)	100	0	20	35	0	59	0	0	0	100	6	2	27
	Iraq	100	100	3	25	100	52	40	50	100	20	19	53	55
	Jordan	0	0	45	56	100	64	0	50	0	100	27	27	39
	Saudi Arabia	0	0	43	48	0	61	0	0	0	80	4	0	20
	Syrian Arab Republic	100	100	36	38	100	57	20	100	50	80	32	72	65
	Turkey	100	100	32	57	0	77	40	100	100	80	8	1	58
Velaka	Bulgaria	0	0	59	53	0	72	0	50	0	100	6	1	29
	Turkey	0	0	32	57	0	77	0	100	0	100	1	1	31
Vijose	Albania	100	0	49	46	0	53	0	50	100	100	13	35	45

Basin	Country	Formal Agreements	RBO	Political Stability	Government Effectiveness	Shared Water Norms	IGOs	Uncertainty	Risk Preparedness	Data Sharing	Diplomatic exchange	Trade Dependency	Water Dependency	Aggregate Index
	Greece	100	0	49	62	100	91	0	0	100	100	1	22	52
Volta	Benin	100	100	59	40	0	77	0	0	100	40	5	61	49
	Burkina Faso	100	100	48	37	100	75	0	100	100	80	27	0	64
	Cote d'Ivoire	100	100	19	26	100	80	0	0	100	80	8	5	52
	Ghana	100	100	53	51	0	69	0	100	100	100	6	43	60
	Mali	100	100	45	35	0	76	0	0	100	60	11	40	47
	Togo	100	100	46	23	0	75	0	100	100	20	18	22	50
Wadi Al Izziyah	Israel	0	0	21	72	0	57	0	0	0	0	No data	58	19
	Lebanon	0	0	20	37	100	54	0	0	0	0	No data	1	19

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